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## **Genetic Algorithms Applications to Power System Security Schemes**

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*Award date:*  
2009

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# **Genetic Algorithms Applications to Power System Security Schemes**

**Mahmud Hadi El-werfelli**

**Submitted for the degree of Doctor of Philosophy**

**University of Bath**

**August 2009**

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## Summary

This thesis details the approaches which aim to automatically optimize power system security schemes. In this research, power system security scheme includes two main plans. The first plan, which is called *the defence plan scheme*, is about preventing cascading blackouts while the second plan, which is called *the restoration plan*, is about rebuilding the power system in case of failure of the first plan. Practically, the defence plan includes under-frequency load shedding and under-frequency islanding schemes. These two schemes are always considered the last stage of the defensive actions against any severe incident. It is recognized that it is not easy for any power system's operational planner to obtain the minimum amount of load shedding or the best power system islanding formation. In the case of defence plan failure, which is always possible, a full or partial system collapse may occur. In this situation, the power system operator is urgently required to promptly restore the system. This is not an easy task, since the operator must not violate many power system security constraints.

In this research, genetic algorithms and expert systems are employed, as optimization methods, to identify the best amount of load shedding and island formation for the defence plan and the shortest path to rebuild the power system for the restoration plan. In the process of designing the power system security scheme, the majority of the electromechanical power system security constraints are considered.

It is well known that power system optimization problems often have a huge solution space. In this regard, many successful techniques have been used to reduce the size of the solution spaces associated with the optimization of the power system security schemes in this work.

The Libyan power system is used as an industrial case study to validate the practicality of the research approaches.

The results clearly show that the new methods that have been researched in this PhD work have shown great success. Using the Libyan power system, the optimized defence plan has been compared to the current defence plan. The results of this comparison have shown that the optimized defence plan outperforms the current one. Regarding the optimized restoration plan, the results present the fact that the Libyan power system can be restored in reasonable time.



## Acknowledgments

I wish to express my sincere and deepest gratitude and appreciation to my supervisor, *Dr. Rod Dunn* for his invaluable guidance, support and encouragement throughout the preparation of this thesis.

I would also like to thank graduate students and staff in the Centre of Sustainable Power Distribution at the University of Bath for creating an atmosphere of friendship, mutual understanding and cooperation. Special thanks are due to *Dr. Pegman Iravani, Dr. Girish Pudaruth, Hamza Alsafeh and Hazem Alzobi* for their helpful discussions and suggestions.

I would like to gratefully acknowledge the continued financial support for the completion of the research from both *Libyan Cultural Affairs* and the *General Electricity Company of Libya*. Particular thanks go to the General Electricity Company of Libya for providing me with the necessary technical and operational data in operating the Libyan power system and contributing to the discussion of this research.

I am grateful to *my parents* for the infinite love, support, and encouragement through all my dreams, study, and life. Also lots of thanks to *my parents in-law and all my relatives and friends* who have supported me with their love, kindness, and happiness.

The last but not the least, I offer my heartfelt thanks to my extraordinary, beautiful, and magnificent wife *Amal* and my children *Jood* and *Hamed* for their Love, understanding, never-ending patience, and constant encouragement. Thank you very much for the great time and memories we share.

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## List of Abbreviations

Artificial Intelligence.....	AI
Expert System.....	ES
Genetic Algorithm.....	GA
Power System Simulator Engine .....	PSSENG
Mathematical Optimization.....	MO
Optimized Defence Plan.....	ODP
Optimized Restoration Plan .....	ORP
Stability class.....	SC
Time Decay ratio.....	TDR
Severity Index.....	SI
Restoration Time .....	RT
Generation Management Tool.....	GMT
Load Management Tool.....	LMT
Load Increment Tool.....	LIC
Path Management Tool.....	PMT
Physical Constraints Investigator.....	PCI
Current Defence Plan .....	CDP
Time Required for Loading .....	TRL

# 1 Introduction

## 1.1 Problem Scene

During recent decades, different major power system blackouts have been experienced in many parts of the world, for instance, the US-Canadian blackout of 14 August 2003[1], the Libyan blackout of 8 November 2003 [2] and the Italian blackout of 28 September 2003 [3,4]. It seems that modern power systems are more exposed to blackouts due to complexity and the fact that they operate near their boundaries of security. The cause of blackout is usually related to a lack of investment in the power system industry, power system deregulation and the related lack of maturing of regulatory rules or human errors.

*A major blackout* occurs when a large area, or a complete area of a power system, collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units. These failures or faults are called *contingencies*. A partial blackout may start with a severe contingency which can cause a large variation in power flow and busbar voltage which, in turn, can cause the outage of generation units or transmission lines. This certainly causes an imbalance in the demand for and generation of power. This process can be the beginning of a major blackout when it spreads uncontrollably throughout the power system. For economic reasons, most power systems operate at the minimum level required for security. This increases the likelihood of a conversion from a local to a major blackout occurring. All of these factors make it necessary to have a generic security scheme to help protecting against major incident [5].

In order to maintain power system security, the active and reactive power balance constraints must not be violated. These types of constraints are

called *equality constraints*. On the other hand, there is another type called *inequality constraints*. Inequality constraints include voltages, power angles, frequencies and thermal limits, etc.

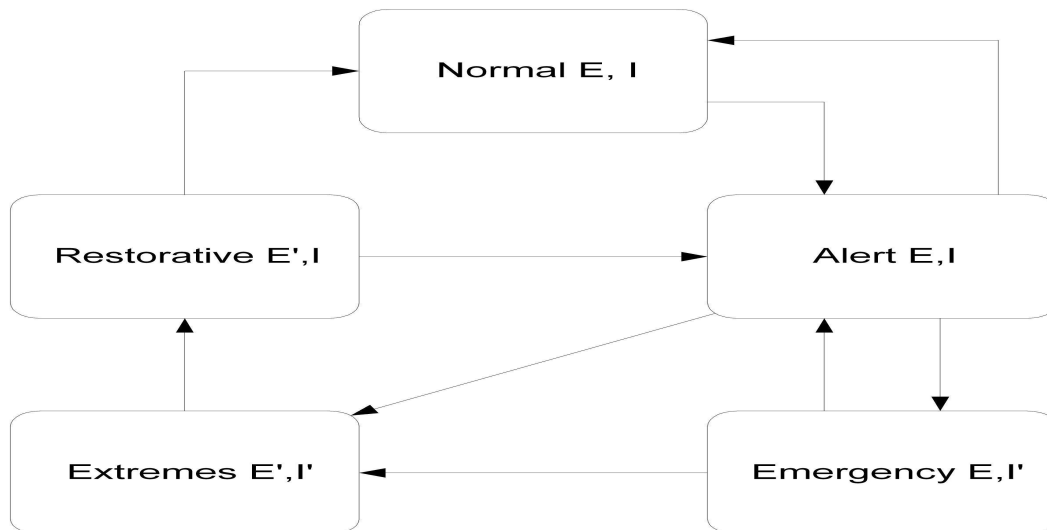


Figure 1-1 Power system operating states

Figure 1-1 shows the operating conditions that can be classified as five different states: *normal*, *alert*, *emergency*, *extreme*, and *restorative* [6, 7] where E is the equality constraint, I is the inequality constraint and ` is an interruption. In the normal operating state, all system variables are within the normal range and no equipment is being overloaded. The system can withstand a contingency without its security being threatened, and both equality and inequality constraints are satisfied. In the alert operating state, the system's security level is reduced, but the equality and inequality constraints are still satisfied. Even though the system is still operated within allowable limits, a contingency might lead to an emergency state, or, in the case of a severe disturbance to an extreme state. In the emergency state, the inequality constraints are violated with the system operating at an incorrect frequency with abnormal voltages, or with some portion of the equipment overloaded. After the system has entered an

emergency state as a consequence of a severe disturbance, it may be led back to an alert state by applying emergency control actions.

These emergency controls are normally grouped in security schemes which are known by electrical engineers as *Power System defence Plans*. If the defence plan is not applied successfully, the system may enter an extreme state where both inequality and equality constraints are violated. On extreme state, cascading outages might lead to partial or complete shut-downs of the system, which is sometimes called *Cascading Blackout*.

The system condition where control actions are being taken to reconnect the facilities, to restore system load, and to eventually bring the system back to its normal state, is called the restorative state. In this state the inequality constraints are satisfied and the equality constraints are violated. In this state, there are groups of control actions that are taken to restore the system back to the normal state. These control actions are practically known as *Power System Restoration Plans*.

Due to the worldwide deregulation of the power industry, and the almost revolutionary changes in the industrial structure, power systems are operated closer to their limits of security. Furthermore, in recent years, they have grown considerably in size and complexity. This is coincidental with an increasing number of major blackouts.

Disturbances that can cause such power blackouts are natural disasters, line overloads, system instabilities, etc. Furthermore, temporary faults such as lightning, even if cleared immediately, can initiate a "domino effect" that might lead to a partial or complete outage, involving network separation into several subsystems, and load shedding.

Although power outages differ in cause and scale, virtually every utility has experienced blackouts and gone through restoration procedures. As a

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consequence, there is an increasing interest in the area of defence and restoration plan studies.

## 1.2 Drawbacks of Current Schemes

### 1.2.1 Drawbacks of Defence Plan Studies

Defence plans are a set of various emergency power system controls. The goal of a defence plan is to retrieve a new equilibrium operation point following a severe contingency. In general, the emergency controls used to prevent the system from moving from the alert state to extreme state (or in practical terminology it is used to prevent cascading blackouts) are generator tripping, rapid closing and opening of turbine valves in prescribed manners (*fast-valving*), load shedding, excitation controls and system islanding [7]. However, generator tripping, load shedding and system islanding are the most effective control actions. This is due to the fact that they can be actuated in a very short time scale. As such, these are considered as the main emergency control actions in this research.

Practically, defence plans are used to limit the geographical extent, duration and effects of the disturbances. Their important role is to minimize the number of interrupted customers and to preserve as many stable areas as possible. This also can help to shorten the restoration process period.

Owing to the complexity of modern power systems, the design of defence plans can be very difficult. Most power system utilities use human experience and observation as the main keys in designing the necessary measures. Although using the experience of engineers can be of assistance in the design of a good defence plan, minimizing the number of interrupted costumers can not be guaranteed [8, 9].

The problem of determining the optimum settings for the emergency controls, that enables defence plans to disconnect the minimum number of customers, is a complex nonlinear problem which is very difficult to solve using an ordinary numerical optimization method such as mixed integer linear programming.

Practically, load shedding schemes are applied in many frequency thresholds; mainly five thresholds. This is done to allow the amount of load shedding to vary with the severity of the incident. These frequency thresholds are described in section 6.2.4.1.

There are many studies involving applications of artificial intelligence (AI) in the problem of determining the minimum amount of load shedding that can secure the network following a severe fault. However, all of these studies deal with this problem, as it is developed for one contingency and one frequency threshold. They ignore the fact that the type and the location of the fault can not be predicted and the fault should be dealt with in four or five frequency thresholds. Also, the variation in operation points is not taken into considerations. So, in general, the developed load shedding scheme is only suitable for the fault for which it was designed [10-15].

## 1.2.2 Drawbacks of Restoration Plan Studies

Power systems are getting more complicated and more exposed to severe blackouts. This heightens the necessity for designing restoration plans with high robustness. As a matter of fact, it is mandatory to restore the power system quickly and safely after a disturbance. The problem of restoration after a blackout is a complex-decision making and control problem of a power system operator. In general, power system restoration problems can be described as multi-objective, multi-stage, combinatorial,

non-linear, and constrained optimization problems. Most operators lack any practical experience in restoring the bulk power system [16].

In addition to this, the operator has to deal with many abnormal voltages, line flows, stability issues, and resource constraints [17-21]. Commonly, this complexity prevents the development of generic rules or methods of determining restorative control actions. However, many utilities have concluded that restoring a power system without clear guidance can lead to unacceptable delays [22-29].

Considering their individual situation and experience, several utilities have developed one or more generic rules based procedures to restore the system as soon as possible. One of the main drawbacks that these kinds of rules may face is the fact that it is most likely the status of the system following a major disturbance could be different from the conditions used to develop these rules. This leads to more pressure on the operator to rapidly modify the generic rules to suit the developing situation. It is worth noting that the second leading reason of restoration problems is the expiring of restoration rules [18].

In the development of automated restoration plans, expert systems (ES) have been extensively and successfully used [16, 30-32]. Commonly, expert systems rely on operator knowledge and experience to automate restoration plans. The use of ES has shown great potential. However, the experience and the knowledge used might be different from operator to operator or from utility to utility. Moreover, ESs are not optimal searching technique. Therefore, the obtained solutions are not adaptable to new situations and are not guaranteed to be the best.

The AI and mathematical programming approaches (MPA) as unaccompanied searching techniques are quite rare in the field of power system restoration. This is due to the huge solution space associated with



this kind of problem, which can increase the computation time to an unacceptable limit. In order to be able to apply AI and MPA to the restoration problem, some researchers have divided the problem into two sequential stages to bring down the complexity of the problem [33-35]. The first stage is about determining an optimal configuration as a restoration target, while the second stage is about bringing the faulted power system towards the obtained target system, whilst maintaining an acceptable level of power system security. The applications of AI and MPA focus only on the first stage. These methods are limited to the first part, concentrating on the topology and the structure of the skeleton or target network, without considering most of the system constraints such as abnormal voltage, line flow, stability, generator ramping rate and resource constraints, etc.

Based on the above line of reasoning, the major challenges of reviewed studies are:

1. The design of a defence plan is very complicated and time consuming.
2. So far, human experience is used to design real world defence plans. However, the optimality of the defence plan can not be guaranteed.
3. There is a considerable lack of application of the AI in the field of generic defence planning.
4. Defence plans are normally considered to be only one control action, such as load shedding or system islanding. Referring to the literature review conducted in this research, there is no study considering both of these in one scheme.

5. The design of restoration plans is very complicated and time consuming.
6. Generally, power system utilities use generic rules to restore power systems. The conditions may vary from one blackout to another. This fact makes the generic restoration rules suitable in some cases, but not in all cases. Because of this, they might be a cause for collapsing the system again.
7. Even though ESs have major drawbacks due to their inability to search for optimized solutions, they currently dominate the field of restoration plan design.
8. Power system restoration design is characterized by huge solution spaces which require a combination of good expert knowledge and strong searching capability to discover a good solution.

### 1.3 Motivations

Based on the aforementioned challenges, it is clear that considerable improvement to current schemes can be achieved. Regarding defence plans, a reliable, comprehensive and feasible defence plan can be obtained by applying powerful optimization tools. This helps to design an optimized defence plan (ODP) that sheds a minimum amount of load. An optimized restoration plan (ORP) with minimum restoration time can also be obtained. This can be done by using sophisticated optimization tools to discover and reduce the solution space associated with restoration problems. These are the main motivating factors behind this research.

### 1.4 Objectives

The main objective of this work is to design a reliable and optimized security scheme with the minimum amount of control actions. This scheme

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is divided into two outlines. The first one, the defence plan, is proposed to act in short time scales following any incident. The second part, the restoration plan, is proposed to act if the first part failed to protect the system.

Regarding the first part of optimized security scheme, the objectives are:

- Design an ODP using two methods of preventing blackouts, including load shedding and low frequency system islanding.
- Use a suitable AI algorithm as an optimization tool to design the ODP.
- Applying the ODP to the Libyan power system.

Regarding the second part of the optimized scheme, the objectives are:

- Design an ORP considering realistic power system constraints.
- Using a combination of AI and ES as optimization tools to obtain the ORP.
- Converting the experience of the Libyan power system's operators into a set of rules to be used as ES.
- Applying the ORP to the Libyan power system.

## 1.5 Contributions

This research is mainly to design a methodology to determine an optimized security scheme. This scheme aims to prevent cascading blackouts from spreading and, in the case of partial or total system collapse, to restore the system as soon as possible.

The research work introduces novel achievements:

- A novel application of Genetic Algorithms (GA) to design a defence plan.
- A novel combination of load shedding schemes and low frequency islanding in the design of the defence plan.
- The introduction of a novel combination of GA and ES in the design of an ORP.
- The practical design of an optimized security scheme to the Libyan power system.
- A practical comparison between the ODP and the current defence plan (CDP).

## 1.6 PhD Thesis Structure

A comprehensive overview of system security and the related problem are presented in *chapter 2*. In the same chapter a detailed discussion of the features and the design of the defence and restoration plan are presented. *Chapter 3* states the definition and the meaning of optimization with respect to this research. A discussion of some optimization techniques, suitable or partially suitable for the research problem, is also presented. An overview of the GA and ES is also presented in this chapter. This is followed by a review of the potential power system simulators that can be used in this study.

*Chapter 4* presents the application and the implementation of the GAs and the ES to design the optimized security scheme.

Results and discussions of the application of the optimized security plan to the Libyan power system are presented in *Chapter 5*. A comparative case between the ODP and the CDP used in the Libyan power system is

presented in this chapter. Moreover, this chapter includes a comparison between the restoration part of the optimized security and a pure ES to show the feasibility of the algorithm.

*Chapter 6* exhibits a conclusion of the work done in this research. This is followed by possible further works that can be an extension to the designed algorithms.

## 2 Power System Security

### 2.1 Introduction

This chapter is intended to deliver a deep insight into the power system security problem from an engineering point of view. A definition of blackouts and the means by which to prevent them are illustrated. This is followed by introducing the meaning of secure operation and the phenomena affecting it such as system stability and thermal limits. Following this, the need and the way of designing defence plans are detailed. Finally, many issues and aspects related to power system restoration are explained.

### 2.2 What is power system security?

Power system security is the capability to maintain the flow of electricity from the generators to consumers. Disturbances can be small or big, localized or widespread, but ultimately the design of the power system must achieve an adequate level of security. As necessity is the mother of invention, so the need to maintain a reliable and safe power system is the main driving force for the design of power system. To obtain a system that sustains power flow during inevitable disturbances, it is necessary to meticulously design the system even though this may be expensive. Ultimately the design should meet an appropriate level of security [36].

A major failure occurs when a large area of a power system collapses. The main cause of a major blackout is a recurrent succession of failures that disconnects a transmission line or power producing units. A partial problem may start as a major fault that causes a large variation in power flow and voltage which in turn, can cause the damage of generation units

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or transmission lines. This certainly causes an imbalance in the demand, supply and generation of power.

The whole process can be the beginning of cascading when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for it to be stable. This increases the chance of turning from a local to a wider failure [5].

Figure 2-1 shows the inter-relationship between the events and the system as blackout unfolds. As seen in the figure 2-1 major collapse starts with equipment failure. Old equipment, mishandling or environmental factors are the major causes. Well-built power system networks are designed so as to withstand any fault. However, it depends on the severity of the unexpected event because one failure might take the system near the borders of the stability while another would not affect the integrity of the system [37]. Commonly, this kind of situations may cause the power system network to fall in cascading manner and can be divided into two main parts. The Swedish blackout of 23 September 2003 is a good example of a situation where the system may have a severe contingency that could bring it into the boundary of stability followed by another contingency that causes total shutting down of the system [38]. This type of problem, called N-1-1 contingency, is rare, but can possibly be observed in the Swedish case. The other type of failure occurs when the system has a severe contingency (N-1 contingency) that makes some lines overloaded due to power redistribution. This can easily make the process of cascading recurrent. The Italian blackout of the 28 September 2003 and US-Canadian blackout of 14 August 2003 are of similar types [39]. We rarely come across the instances where the power system network cannot withstand a given N-1 contingency, for example, the Bangladesh blackout. This type of hidden problem is associated with a shortage of investment in the power industry [5].

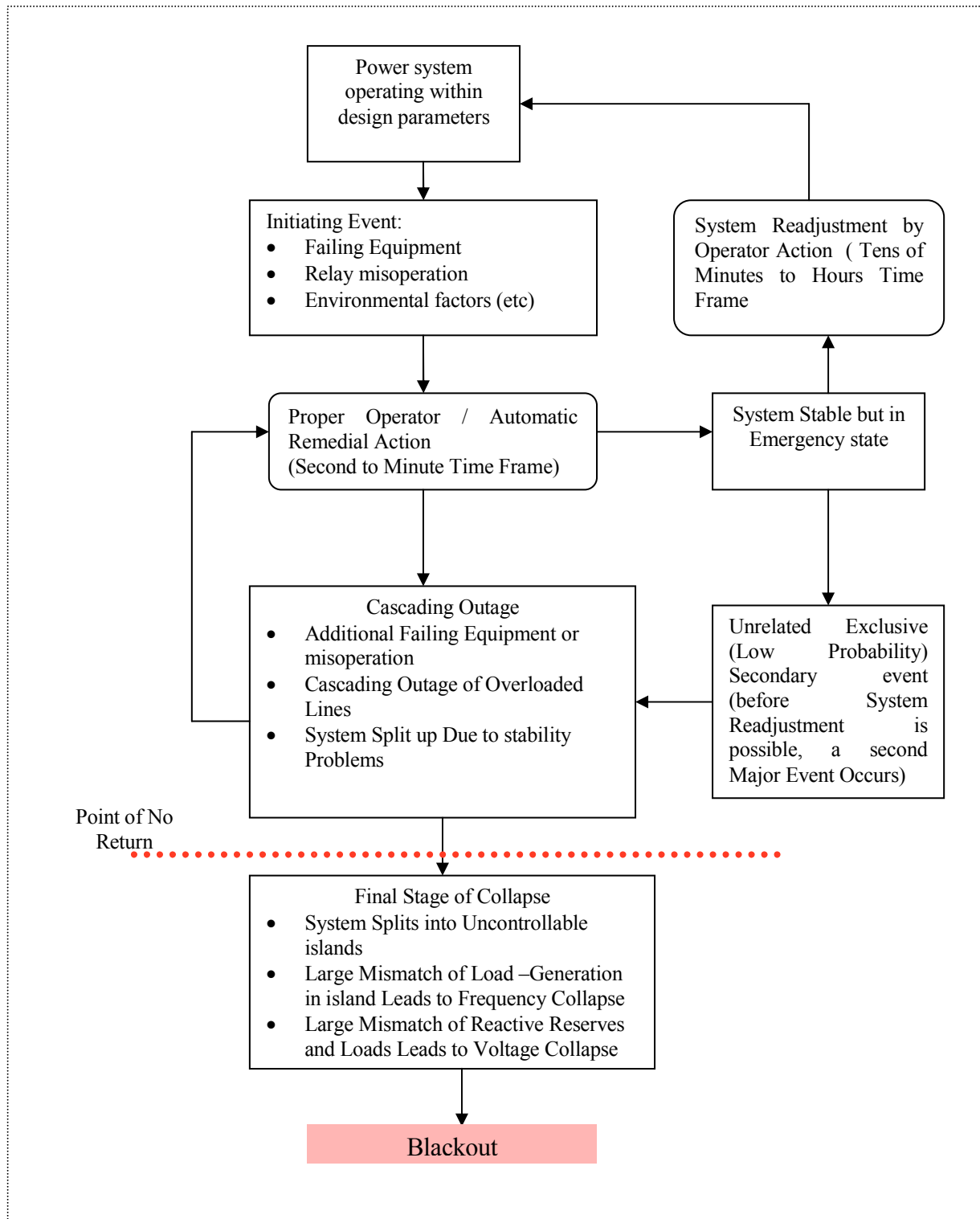


Figure 2-1 Blackout structure



Without an efficient operator or automatic control systems, all of the above-mentioned situations may lead to one of the following problems if preventative measures are not taken.

- Transient angular instability
- Small-signal instability
- Voltage instability

## 2.3 Means of Preventing Cascading Blackouts

### 2.3.1 Overview

In fact, it is not possible to completely prevent accidental failures such as human error and environmental factors. However, there are many methods to improve power system performance, so as to reduce the occurrence of blackouts. Regular maintenance, Emergency control coordination, flexible AC transmission lines, online dynamic security assessment and real-time system monitoring are the few activities which can make a difference. Following a fault, emergency control coordination is the only method that operates instantaneously, quickly enough to prevent the blackouts [7].

### 2.3.2 Emergency Controls

The transient stability must be enhanced immediately following the moment of clearing the fault, as a preventive measure. There are many methods to improve the transient stability following a major disturbance. However, all of these methods try to achieve the results of minimizing the kinetic energy absorbed by the generators, by minimizing the fault severity, by increasing the restoring synchronizing forces, by reduction of accelerating torque through the control of prime mover mechanical power,

and reduction of accelerating torque, by applying artificial loads. All of these results can be achieved by the following method.

**High speed fault clearing:** Longer fault duration leads to more kinetic energy that could be absorbed by the generators, which may lead to system instability. Therefore, a fast clearance of the fault can certainly help to improve the stability following a severe contingency. This can be achieved by using a very fast relay [40].

**Reduction of transmission system reactance:** The series inductive reactance is an important method to enhance the transient stability of the system, since the reduction of it increases the post fault synchronizing power transfer [41].

**Regulated shunt compensation:** The power flow in the power system can be controlled by using shunt compensation and it can increase the maximum power transfer capability of long transmission lines. This helps in improving the transient stability of the system [42].

**Dynamic Braking:** Rotor acceleration can be reduced by applying an artificial load during a transient disturbance. It occurs by increasing the electrical output of the generator [43].

**Reactor Switching:** The generator internal voltage can be increased by connecting shunt reactors to the generators which is beneficial to the transient stability following an accident. This can be further stabilized by switching off the reactor [44].

**Fast-valving:** The process of fast valving involves the control of the acceleration power (which drives the generator shaft) following the recognition of a severe transmission system fault which results in a reduction by rapid closing and opening of steam valves in a prescribed manner [45].

**Generator tripping:** Since the rejection of generation at certain locations in the system can reduce power to be transferred in critical transmission lines, it can play a very important role in transient stability enhancement [46].

**High-speed excitation system:** A rapid but temporary increase of generator excitation causes increases in the generator internal voltage. This, in turn, results in an increase in the generator's capacity to provide more reactive power, which can enhance the transient stability following a fault [47].

**Load shedding:** Following a severe fault, some generation units or transmission lines could be uncontrollably tripped. The disconnection of generation units directly affects the load-generation balance of a power system, while the disconnection of feeders affects this balance indirectly.

In case of the interruption of the load-generation balance, the system frequency is severely affected. If the load is higher than the generation, the frequency declines. The frequency decline directly leads to a system collapse. Therefore it is more than important to maintain this balance. To do this, a certain amount of loads has to be shed. This happens using a load shedding scheme. This scheme is a sort of table of loads that assigns certain loads to be tripped to certain frequency thresholds. So if the frequency reaches the first frequency threshold, a certain amount of load is tripped. If the frequency is not recovered, the frequency reaches the second threshold, so another amount of load is tripped and so on and so forth, until the frequency is recovered. Load shedding schemes normally have four or five frequency thresholds depending on the power system utility [48].

**Low frequency system isolation (Controlled Islanding):** This method is usually adopted as a final option to prevent major disturbances in one part

of a power system from spreading into other parts of the system, causing a severe system breakdown. So it is about tripping a transmission line to isolate an affected part of the network. This solution is built on the theory that losing a part of the power system is much better than losing the whole power system. So it is normally applied after the last stage of the load shedding scheme. If the load shedding scheme could not recover the frequency decline, the frequency reaches the system islanding threshold, which trips the part of the system where the frequency is affected [49].

This islanding method is often associated with balancing load shedding to maintain the balance between demands and generated power in every island in the system.

## 2.4 Secure Operation

### 2.4.1 Quality of Supply

A reliable supply with decent quality is desirable for power consumers. The quality of an electrical supply can be measured in terms of its operating tolerance on both voltages, frequency. Loads such as synchronous motors and computer equipment can be extremely sensitive and are affected by frequency fluctuations and voltage difference. So it is essential that the frequency and the voltage of the power supply be maintained within designed limits [50].

### 2.4.2 Thermal Limitations

Each element of a power system is designed to carry a certain amount of electrical power and not to exceed the power transfer limits. If somehow these components are loaded above these limits, these components are overheated and thermally fail. This imposes thermal limitations on the configuration of power systems which may mean there are extra constraints at which have to abide by [51].

### 2.4.3 Power System Stability

The ability of the power system to reach a state of equilibrium after being subjected to a disturbance is called *stability*. Power system stability is similar to the stability of any dynamic system with the same fundamental relationships. The stability of the system depends on the initial conditions of the system and the type of the disturbance that affects it. Disturbances may be either small or large. Often small interruptions, in the form of load changes, occur. System failures such as a tripping off of a transmission line or generator are considered large disturbances. Power system stability can be divided to the following types:-

#### 2.4.3.1 Small Signal Stability

Oscillatory stability can be stated as a form of dynamic stability that exists when a power system is unstable. It is also known as *small signal stability*. Such instability is generally characterized by small oscillations, usually between a small number of generators, which gradually increase in magnitude over a period of time until the critical angle of one of the oscillating machines eventually exceeds and loses harmony with the rest of the system. This loss of synchronism is called pole-slipping. During pole-slipping, very large current and voltages may be produced in the slipping machine causing a substantial amount of damage.

In one of two cases small signal instability can arise. Firstly, and perhaps the most concerning, is that for a long period of time the operating point of the power system can be moved to a point which is fundamentally unstable. Then it only requires a very small disturbance to excite the instability. It may be very difficult to find out which part of the system is causing the effect under such a condition. The second case may be initiated when the system undergoes a fault, such as a loss of a transmission line or a generator. Such a sudden change causes a rapid shift in the operating point, and it is possible that this post fault operating point

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may exhibit fundamental instability. The second case might fall under the category of a transient instability [52].

### 2.4.3.2 Transient Stability

The transient stability of a power system can be defined as the ability of the system to remain stable during and following a major disturbance, such as a transmission line fault or generator trip. Such an interruption can lead to rapid changes in the internal system states.

The main features of transient instability fall into one of two classes. These are *first swing* and *subsequent swing* instability. First swing instability is featured by a fault sufficiently heavy and close to a single generator to cause the generator to pole-slip within the first cycle of arising rotor angle oscillations. Subsequent swing instability is characterized by the first machine pole-slipping towards the end of the first oscillation cycle after the application of the fault.

Subsequent swing instability can mainly arise for two distinct reasons. The first occurs when the post fault operating point is fundamentally unstable (right hand poles). In this case the system does not settle to steady state following the fault, as the small signal instability is immediately excited by the transient during the fault period. This is similar to small signal instability, but is usually considered to be a transient problem as it is exhibited following a system fault. The second instance of subsequent swing instability arises when, following the application of a fault, the disturbance modes across the system interact a particular generator in such a way as to induce a sufficiently large rotor swing for the machine's critical angle to be exceeded; even though the disturbance at other machines in the system may be small; and the post-fault system otherwise stable [53].

### 2.4.3.3 Frequency and Voltage Stability

Voltage and frequency instability, or collapse, is characterized by a rapid and system-wide fall in either voltage or frequency.

If there is a sudden shortage of generation in a system, either due to an increase in load or the failure of a generator, the system frequency falls. The cause of such instability is relatively simple. As significant damage can occur to synchronous generators operating away from the nominal system frequency, most machines have protection circuits which automatically disconnect them if the system frequency is incorrect. It is thus possible that the fall in system frequency from one unit's failure can cause another generator's protection circuits to trip, which further lowers the system frequency. It is easy to see that a very rapid cascading effect of generator tripping can occur, causing an almost complete blackout of the power system [54].

By sufficiently providing spinning reserve, this condition can usually be practically avoided. Therefore, the activation of *load shedding* relays may be avoided. These relays automatically detect low system frequency and disconnect load to reduce the generation demand imbalance.

The phenomenon of voltage instability in electric power systems is characterized by a progressive decline of voltage, which can occur because of the inability of the power system to meet increasing demand for reactive power. The process of voltage instability is generally triggered by some form of disturbance or change in operating conditions that create increased demand for reactive power in excess of what the system is capable of supplying. The dynamic characteristics of loads, location of reactive compensation devices and other control actions such as those provided by load tap changing transformers, automatic voltage regulating equipment, speed governing mechanism on generators are important factors which affect voltage stability.

In general, voltage collapse is caused by load variations or contingencies. The basic configuration used to explain voltage collapse is shown below in figure 2-2, illustrating voltage collapse due to load variations.

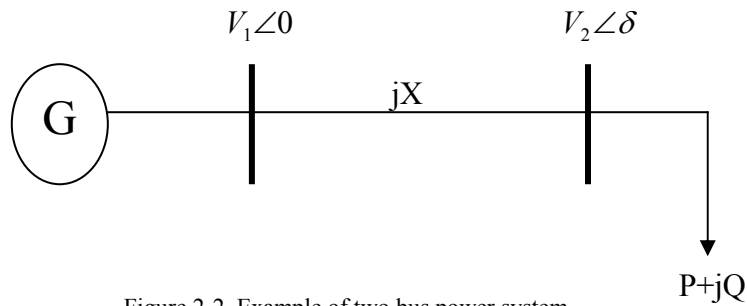


Figure 2-2 Example of two bus power system

Where  $V_2$  is receiving end load voltage,  $X$  is reactance of the line,  $V_1$  is sending end voltage and  $\delta$  is load angle.

In figure 2-2, a synchronous generator is connected to a load through a lossless transmission line. The load is described by its real and reactive powers  $P$ ,  $Q$  and the load voltage  $V_2$ . The governing algebraic relations are

$$P = \frac{|V_1||V_2|}{X} \sin(\delta) \quad (2-1)$$

$$Q = -\frac{|V_2|^2}{X} + \frac{|V_1||V_2|}{X} \cos(\delta) \quad (2-2)$$



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Under steady-state conditions, equations (2-1) and (2-2) represent the voltage-power relation at the load end of the circuit.

Figure 2-3 shows the plot of load voltage versus real power for several power factors and different sending-end voltages. The graph of these equations is a parabola. In the region corresponding to the top half of the curves, the load voltage decreases as the receiving-end power increases. The edge points of these curves represent the maximum power that can theoretically be delivered to the load. If the load demand were to increase beyond the maximum transfer level, the amount of actual load which can be supplied as well as the receiving-end voltage will decrease. These curves indicate that there are two possible values of voltage for each loading. The system cannot be operated in the lower portion of the curve even though a mathematical solution exists. Consider an operating point in the lower portion of the curve, if an additional quantity of load is added under this condition, this added load will draw additional current from the system. The resulting drop in voltage in this operating state would be more than offset increase in current so that the net effect is a drop in delivered power. If the load attempts to restore the demanded power by some means, such as by increasing the current, the voltage will decrease even further and faster. The process will eventually lead to voltage collapse or avalanche, possibly leading to loss of synchronism of generating units and a major blackout.

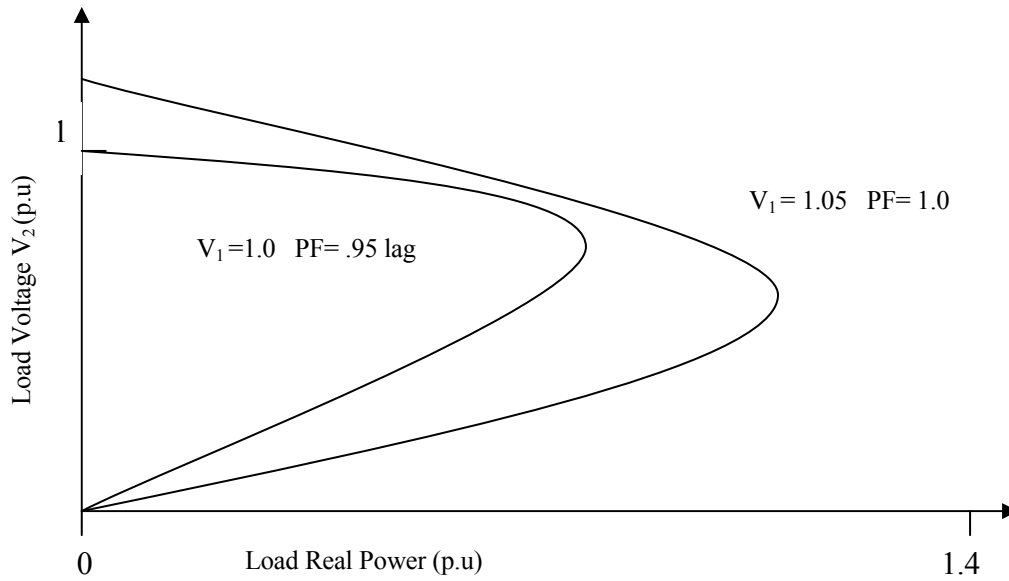


Figure 2-3 Voltage- real power curve

Generally, the security margin is estimated with respect to credible contingencies with a reasonable probability of occurrence, and then appropriate preventive actions are taken by re-adjusting the most effective controls to provide a sufficient margin when needed. Corrective control actions, on the other hand, are usually used for improvement of security, acceptable only in the presence of severe disturbances. Under voltage load shedding may be needed if the operating conditions violate some constraints and no control action is available. According to the classification of power system states (as mentioned in section 1.1), under voltage load shedding would be allowed under the emergency and extreme emergency states, when many system variables are out of their normal ranges and hence the system is driven toward collapse [53,54,55].

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## 2.5 Defence Plans

### 2.5.1 Why Defence Plans are Needed

During planning and operation of power system, the main goals of power system security are to minimize the number of disturbed customers and lessen the likely incidents. Through implementation of proper plans and operation rules, these goals can be achieved. However, power systems can not be fully protected against all incidents. This is due to the fact that major incidents are the results of unanticipated complications associated with control or protection failures.

Practically, special defensive measures called defence plans are used. By limiting the geographical extent, duration and effects of the disturbances, defence plans play an important role in minimizing the number of interrupted consumers. The complexity of modern power systems makes the design of defence plans a very difficult task. Human experiences are the main keys in designing the necessary measures. The experience of engineers can be of much use in designing a good defence plan. However, the optimality of these kinds of defence plans can not be guaranteed.

### 2.5.2 The Main Features of the Defence Plans

There are two lines of defence against incidents which are not covered under planning studies. Firstly, a line consists of a certain number of measures that can be implemented by the operators in the control centres whenever an incident occurs. These actions are linked to slow dynamic phenomena that are compatible with a human response time. The main aim of these operators' emergency actions is to re-enforce the safe and secure operation of the entire power system. This first line of defence actions covers major intervention on the voltage and active power set-points of the generating units on the transformers (blocking of on-load tap changers on transformers, reduction of voltage references of on-load tap-changers)

or sometimes on the load (manual load shedding). These actions are followed in the situation where transmission equipment overloads, risks of continuous tripping occurs, and in the event of relatively slow voltage collapse phenomena.

The second line of defence plan is the system's final protective barrier against major collapses. This includes automatic devices that control the consequences of dynamic phenomena, such as frequency collapses or losses of synchronisms. The idea behind these emergency control schemes is based on the fact that in an emergency, it is preferable to voluntarily shed some loads (under frequency load shedding) or to isolate weakened areas (under frequency islanding); thus not losing everything by letting the network collapse [56].

### 2.5.3 How to Design a Defence Plan

Unlike conventional operational security studies, the failure investigations for defence plan designs are much more complicated than N-1 contingencies studies. Various specific dynamic simulations are considered in the process of defence plan design [57, 58]. The goal of these dynamic simulations is to assess system security following the application of the defence plan, to determine the limits of the adopted defence measures, and to examine their impact.

#### 2.5.3.1 Necessity to Represent an Accurate Model for Networks

In connection to the dynamic simulation, a good representation of the dynamic components such as generators, AVR, governors, and the fast-valving system, SVC and FACTS should be fully ensured. It is important to represent the functioning manner of the protection systems which includes the generation unit's protection, transmission lines protection, and the protection schemes that include the defence plan itself.

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The relevance of the study and the usefulness of the results depend on the accuracy of the system modelling.

### 2.5.3.2 Incident Scenarios

Building incident scenarios, which includes different types of transient phenomena which lead to full system collapse, is one of the important steps in defence plan designing. Therefore, chosen incident scenarios should be complex enough and severe enough to examine the capability limits of the applied defence plan. Often, the network is built so as to have sufficient strength to withstand major disturbances at any normal operational situation. For this reason, the network must be weakened in order to create the situation that is very different from the usual operation conditions. When different weakening operation conditions, such as poor voltage profile, an unbalanced production plan, an abnormal load demand, special import/export conditions and losing an important high voltage line, are taken into consideration, it can help in representing severe transient phenomena that might lead to full system breakdown. Hence, this leads to a feasible defence plan. Incident scenario can be also built by using a statistical analysis technique of probability [59].

### 2.5.3.3 Simulation Tools

A systems' collapse involves complex transients, which are a mixture of slow transient and fast transient phenomena. So, it becomes important to have simulation tools to study the potentiality of the power system to remain in synchronism for just a few seconds after the occurrence of the incident and to represent voltage, frequency and power flow variations [60].

## 2.6 Power System Restoration Plans

### 2.6.1 Overview of Restoration Process

Power system restoration is a unique event. However, there are certain goals, steps and aspects that are common to all restoration procedures. Figure 2-4 shows all the aspects of power system restoration. They involve almost all aspects of power system operation. In this work, power system restoration is dealt with from electromechanical point of view. In another word, all aspects of electromagnetic phenomena are ignored.

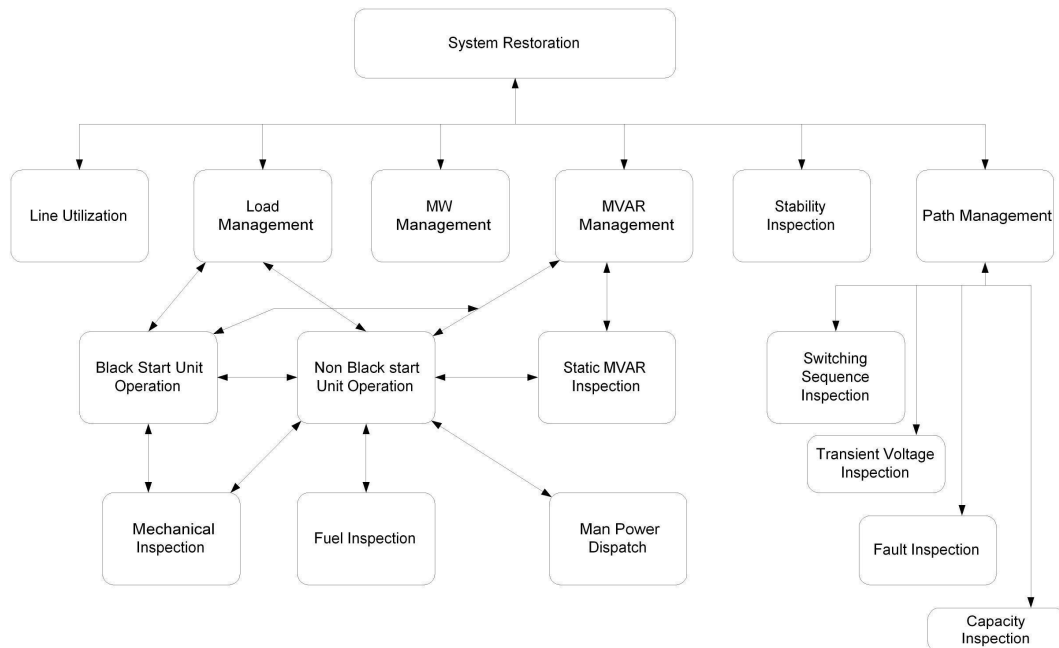


Figure 2-4 Power system restoration aspects

The goals of any power system operator during system restoration can be divided into the following points [61, 62]

- **Determination of system status:** In the beginning of the restoration process, the boundaries of the energized areas are identified, frequencies and voltages are assessed. Moreover, connections to

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neighbouring power systems, generators with black start capabilities and generators without black start capabilities are also identified and critical loads are located. The generators without black start capabilities are supplied with power from other generators to reboot. This process is called *generator cranking*.

- ***Black start of power plants:*** Black start generators are used to restart the big thermal power plants. A specific time is required to restart big power plants. For example, hot reboot of drum type boilers is only possible within thirty minutes. If it can not be achieved, the boiler is not available for four or six hours, a cold reboot has to then be performed. Power plants with black start capability are hydro, gas, or diesel power plants. After such a power plant has been brought to full operation, a high voltage path to a large thermal power station is built, and the thermal unit's auxiliaries are driven by large induction motors which are started. Along the path, ballast loads have to be supplied to maintain the voltage profile within acceptable limits and to prepare a load base for the thermal units. Additional smaller units can also be brought online through the path to improve system stability [63].
- ***Energizing Subsystems:*** In some cases it is beneficial to partition a power system into subsystems. These subsystems are called islands. This is to allow a parallel process of restoration. Within each subsystem, a target network is energized. This network is also called a *skeleton network*. Then, loads are picked and paths to other generation units and load centres are established. At the end of this step the power system should be stable enough and able to withstand transient caused by further load pickup. Following the energization of subsystems, the subsystems are synchronized and connected.

The second and the third steps are the most vital steps. Any error in these phases could lead to blackout reoccurrence as consequence of unwanted generator tripping, load shedding activation or severe voltage variation. This in its turn results in higher impact on public and industry and increased damage to national economy.

### 2.6.2 Active Power and Frequency Control

Different issues of active power and frequency controls can be identified during power system restoration. These are:

- **Frequency excursion in early stages:** during the black start of thermal power plants, large auxiliary motor loads are picked up. This process of picking up could cause large frequency excursions when relatively small generators are rebooted. The consequences of this could be load disconnection or, in worst cases, blackout reoccurrence [64].
- **Generation Load balance:** During the restoration process, it is more than necessary to maintain the load-generation balance. In cases of load generation balance disruption, system frequency decline results in an unwanted activation of system protection, i.e. if this decline is severe. In some cases frequency decline reaches levels that lead to generation units tripping, as consequences of the operation of under frequency protection relays. Thus, great attention has to be given to this balance [65, 66].
- **Load pickup:** this issue is one of the most important issues during the restoration process, as it directly affects restoration time. Picking up a large load increment causes frequency fluctuation. This fluctuation could be severe enough to activate frequency protections systems. This, in its turn, could cause some generators or transmission lines tripping, which might lead to full system collapse.



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On the other hand, picking up load in small increments would prolong restoration time. However, this somehow is compensated by decreasing the probability of re-collapsing, hence increasing system security [67].

- **Optimum sequencing of generation units:** During the restoration process, the operators have to be fully informed about the amount of generation in projected time. Knowing this information would help in optimizing the sequence of generators connection, hence significant enhancement in restoration service and time. The information required is the critical timing of the generators such as time of unit restart up, time of synchronization, time to reach minimum load and time to reach maximum load [68].
- **Spinning Reserve:** the operator has to maintain well spread active power reserve. This feature would be of assistance to the operator to overcome unexpected events. During system restoration, the power system operator might face unexpected problems such as unwanted disconnection of generation unit or transmission line congestion. The well spread spinning reserve could play a very important role in resolving these problems, hence securing the power system [69].

### 2.6.3 Reactive Power and Voltage Control

Similar to the active power balance, it is necessary to maintain a balance in reactive power. High charging currents, started from lightly loaded transmission lines, can cause the violation of generator reactive capability restrictions and to the event of sustained over voltages. These may lead to under excitation, self excitation, and instability. Prolonged over voltages can also lead to the over excitation of transformers and the generation of harmonic distortions.

Transient over voltages are an outcome of switching operations on long transmission lines, or of the switching of capacitive devices, which may result in arrester failures.

Harmonic resonance over voltages is a consequence of system resonance frequencies close to multiples of the fundamental frequency in combination with the injection of harmonics which is mainly caused by transformer switching. These may lead to long-lasting over voltages, resulting in arrester failures and system faults. Due to the small amount of load connected to the system, especially at the beginning of a restoration process, the voltage oscillations are lightly damped and can last for a long time, reaching very high amplitudes. This effect can be aggravated by transformer over excitation as a result of sustained over voltage.

In general, all of the aforementioned events are classified under electromagnetic phenomena. As this study is proposed to focus on the electromechanical side of the design of the restoration plan, all problems associated with electromagnetic phenomena are ignored. However, that does not mean that the reactive power balance is ignored, as it affects sustained voltage profile of the whole system during system restoration [70].

## 3 Optimization and Study Tools

### 3.1 Introduction

In this chapter, the meaning of optimization has been defined with respect to the present research. It also includes discussions over existing optimization techniques, focusing on their advantage and limitations. However, it is not possible to cover all possible optimization techniques, yet a concerted attempt has been made to include a broad consideration of most significant algorithm classes that are quite relevant to the power system security problem. This is done to justify the use of GAs and ESs in this study. Another brief discussion shows potential power system simulators which can be used in this work. Justification of the use of Power System Simulator Engine (PSSENG) is also derived from this discussion. Finally, PSSENG and its capability of dynamic simulation are introduced [124]. A comparison between the PSSENG and another power system's simulator is introduced in order to indicate the capability of the PSSENG.

### 3.2 Definition of Optimization

Optimization could be generally defined as the process of finding the best solution to a problem. However, this definition is quite ambiguous as the term of the best solution is not clear. In the engineering world the term of best solution can be somehow flexible. This is due to the fact that one problem might have many good solutions as the definition of best solution might vary from person to person. However, all good solutions share the features of being practically feasible and achievable. The process of finding the feasible and achievable solutions could be very difficult by considering the fact that most of the power system optimization problems have more than one objective. For example, in the design of a stability

scheme, the goal is often to find a stable and economical operation point. This kind of problem is called a multi objective problem [71].

Optimization has been one of the most powerful areas in power system planning and operation over the last 20 years. It helps in the achievement of very good electrical and financial performance. Some valued contribution of optimization is in the economic operation, and security. Generally the optimization method is divided into two main categories.

➤ **Mathematical Optimization (MO)**

In this type of methods, mathematical models are used. The main objective of these models is to minimize undesirable things such as cost, losses or even errors, or to maximize things such as profit and security. It is always subject to many constraints [72].

➤ **AI optimization**

Over years, nature has been a major source of inspiration and metaphors for scientific and technical developments. It is easy to distinguish the strong relation between the bat and the sonar system, the camera and the eye, the brain and neural network system, and so forth. In the same manner the process of natural selection and evolution has inspired the GA method [72].

### 3.3 Optimization Methods

Electrical power systems are huge, complex, and geographically widely distributed. These factors have made power system optimization problems very difficult to solve. Moreover, modern power systems are linked to

unexpected problems and events; and they are more exposed to faults. All of this has added many uncertainties to problems of power systems. It is therefore essential to utilize the most efficient optimization methods to take full advantage of these optimization methods.

As mentioned before, the optimization methods can be divided into two main categories, which are the MO and AI Optimization.

### 3.3.1 Mathematical Optimization Methods

#### 3.3.1.1 Linear and Quadratic Programming

Linear and quadratic programming is used when the objective and the constraints are linear. These have the ability to handle problems with thousands of variable and constraints. One advantage of it is the high computational efficiency. However, the number of iterations used can be exponentially increased with the size of the problem. Linear programming methods have been used in many fields such as optimal load flow, reactive power planning and active power dispatching [73, 74].

#### 3.3.1.2 Nonlinear Programming

Nonlinear programming is applied when the objective function and the constraints are nonlinear. They normally use approaches that start from an initial guess to find the right direction to decrease the objective function in case of minimization problems. There are many nonlinear programming methods which are distinguishable by their definition and step length. The main drawback of these methods is the conversion of the real power system problem to a set of equations or matrixes. They have been used in many fields of power systems such as load flow and hydrothermal scheduling [75, 76].

### 3.3.1.3 Integer and Mixed Programming

These methods are proposed to optimization problems where some variables are restricted to integer values and some others can take any values. For example, the tap changers of the transformers and power electronics are restricted to integer values. Using this method, it is possible to solve optimization problems with hundreds of variables. Integer and mixed programming methods have been used in many power system problems such as optimal reactive power planning and power system planning, unit commitment and generation scheduling [77, 78].

### 3.3.1.4 Dynamic Programming

Dynamic programming is a method of solving complex problems by breaking them down into simpler steps. It is applicable to problems that exhibit the properties of overlapping subproblem and optimal substructure. When applicable, the method takes much less time than naive methods. It is based on the principle of optimality states that the sub-policy of an optimal policy must, in itself, be an optimal sub-policy. For instance, for a problem of  $n$  generators with potential  $S$  output level each, exhaustive enumeration would require  $S^n$  potential combination to be tested, where dynamic programming test fewer than  $n^2S^2$  combination. Dynamic programming is a very robust technique where it is applicable, but suffers from the problem of dimensionality. It has been helpful in many areas such as reactive power control, transmission planning and unit commitment [79, 80].

## 3.3.2 Artificial Intelligence Techniques

### 3.3.2.1 Expert Systems

ESs are built based on the knowledge acquired from domain experts. The knowledge of an ES may be represented in a number of ways. One common method of representing knowledge is in the form of IF-THEN type rules. ESs have been widely used to automate many kinds of processes in power systems. However, they are not designed to deal with uncertainties. This is always considered one of the ESs drawbacks. The uncertainties may arise in the input data to the ESs and even the knowledge-base itself. Much of human knowledge is heuristic, which means that it may only work correctly part of the time. In addition, the input data may be incorrect, incomplete, and inconsistent and have other errors. Algorithmic solutions are not capable of dealing with situations like these. Depending on the input data and the knowledge-base, an ES may come up with the correct answer, a good answer, a bad answer, or no answer at all. Therefore, the main drawback of ES is the inability to learn and adapt to new solutions. Another drawback of ES is the inability to deal with uncertainties. However, this can be overcome by upgrading the ES to deal with uncertainties. The ES, in this context, is called *fuzzy* ES [81].

For the past twenty years, a great deal of ES applications has been developed to help plan, analyze, manage, control and operate various aspects of power generation, transmission and distributions systems[82,83].

### 3.3.2.2 Artificial Neural Networks

The Artificial neural network was started by designing a training algorithm that presents how a network of neurons could reveal learning behaviour. They are mainly categorized by their topology and architecture

and learning regime. The main powerful points are their speed, capability to adapt to data, their robustness, and the ability to deal with the non linear problem. However, they also have disadvantages such as selection of the optimum configuration, the choice of the training methodology and the fact that they always output even though the input is unreasonable. They have been applied in many areas in power systems. For example, they have been used in long and short term power system planning, voltage control dynamic security assessment, hydro scheduling and transient stability studies [84, 85, 86, 87].

### 3.3.2.3 Genetic Algorithms

GA is the name given to an optimisation process which has been developed from the observation of the process of evolution in the natural world.

The principle of natural selection is simple. Given a population of individuals (solutions), some will be more suited to their environment (problem domain) than others. These highly fit individuals thrive in the environment, and have a higher probability of reproduction than less fit individuals, resulting in more offspring (new solutions) from highly fit parents. As each member of the next generation inherits at least part of its characteristics from its two parents, the offspring of highly fit parents have a higher probability of themselves being highly fit than the offspring of less fit parents. Following this process, it can be seen that the expected fitness of a fixed size population will increase as the number of generation's progresses.

The main advantages of the GAs are:

- The ability to search the solution space even with rough information about the problem.



- The method uses a group of solutions from one iteration to another, rather than using one single solution. This makes it more likely to find the optimal solution.
- GA techniques can explore the solution space to greater extent and are therefore less likely to be trapped in a local minimum. However, with GA it can be difficult to ensure when the global minima has been achieved.

The main disadvantage of GAs is that it requires very long time to converge. GAs have been widely applied to power systems. For example, voltage and reactive power control unit commitment, economic dispatch, transmission expansion and planning, and system security [88, 89, 90, 91].

#### 3.3.2.4 Ant Colony Search

Ant colony search is inspired by the behaviour of real ant colonies. The main features of this method are the positive feedback for recovery of good solutions, a well distributed search which helps in avoiding rash convergence and the utilization of positive greedy heuristic to find acceptable solutions in the early stage of the search process. The main disadvantage of this method is the poor computational capability. Unlike the previous optimization methods, the ant colony search is not widely used in power systems. However, one of its applications is finding the shortest route for the transmission network [92].

### 3.3.3 Summary of the Optimization Methods

MO algorithms have been applied for many years in power system problems such as power system planning, operation, and control. Generally, many assumptions must be made in order to apply MO algorithms to practical power system problems. Yet with these assumptions, which are not sufficiently accurate, the solutions for large-scale problems are not simple. Also the solutions found by MO methods

are optimum locally, while the solution is strongly desired to be optimum globally. Due to these facts, it is very difficult for MO methods to deal desirably with real-world power system optimization problems.

In spite of the successes of mature MO techniques, they could not appropriately deal with real-world power system problems, which require the optimization technique to have the following capabilities:

- The ability to store and use human knowledge to judge the solutions.
- The ability to learn and adapt from one solution point to another.
- A high likelihood of searching most of the solution space.

All aforementioned facts make the AI, which promises global optima and has a high ability to use the human knowledge as well as the ability to learn and adapt, capable of playing the main role in solving power system optimization problems.

This survey has been of great assistance in deciding which optimization method should be used to design the security scheme for the Libyan power system. Due to the mentioned advantages of the GAs, it is used as the main optimization method in the problem of designing the Power system security scheme. Due to the fact that the problem of design, the security plan for a power system is characterized by huge solution space, ES is used to constrain the solution space.

## 3.4 Optimization Methods Used in the Study

### 3.4.1 Genetic Algorithm

During the decade of 1960-1970, GAs were first proposed by John Holland. These are numerically optimized algorithms which base

themselves upon the patterns of genetics as well as evolution mechanisms found in natural habitat and living beings [93, 94, 95]. These are generalized methods and they are extensively used due to two fundamental features.

- Although the computational code for implementation of GAs is very simple, yet it facilitates a useful and strong searching mechanism.
- GAs are a flexible as well as powerful method which can be applied to diverse optimization problems.

The indigenous design of GAs differentiates them from other optimization schemes. These differences can be summarized in the following points.

- GAs search among a group of solutions and are not limited to processing single solutions. This keeps them from getting trapped in local optima.
- GAs utilize probabilistic rules of transition instead of deterministic ones.
- GAs use payoff information of objective functions only. With this data, they proceed toward the global optimum. They are not dependent upon other information like the occurrence of derivatives.
- GAs operate with a coding of problem parameters instead of the parameter list itself.
- GAs simulate the natural procedure of evolution.

Besides a number of advantages, Genetic Algorithms possess some disadvantages. These disadvantages are mentioned below

- GAs require a number of functional evaluations which makes execution time unnecessarily lengthy.
- There is no definitive method to determine whether the solution is optimal or not.

The method is frequently employed in the fields of power systems [96, 97, 98].

Figure 3-1 shows overall structure of GA. The GAs are implemented in three steps. These steps are:

- Generating the population in the beginning
- Evaluating fitness
- Genetic procedures and operations

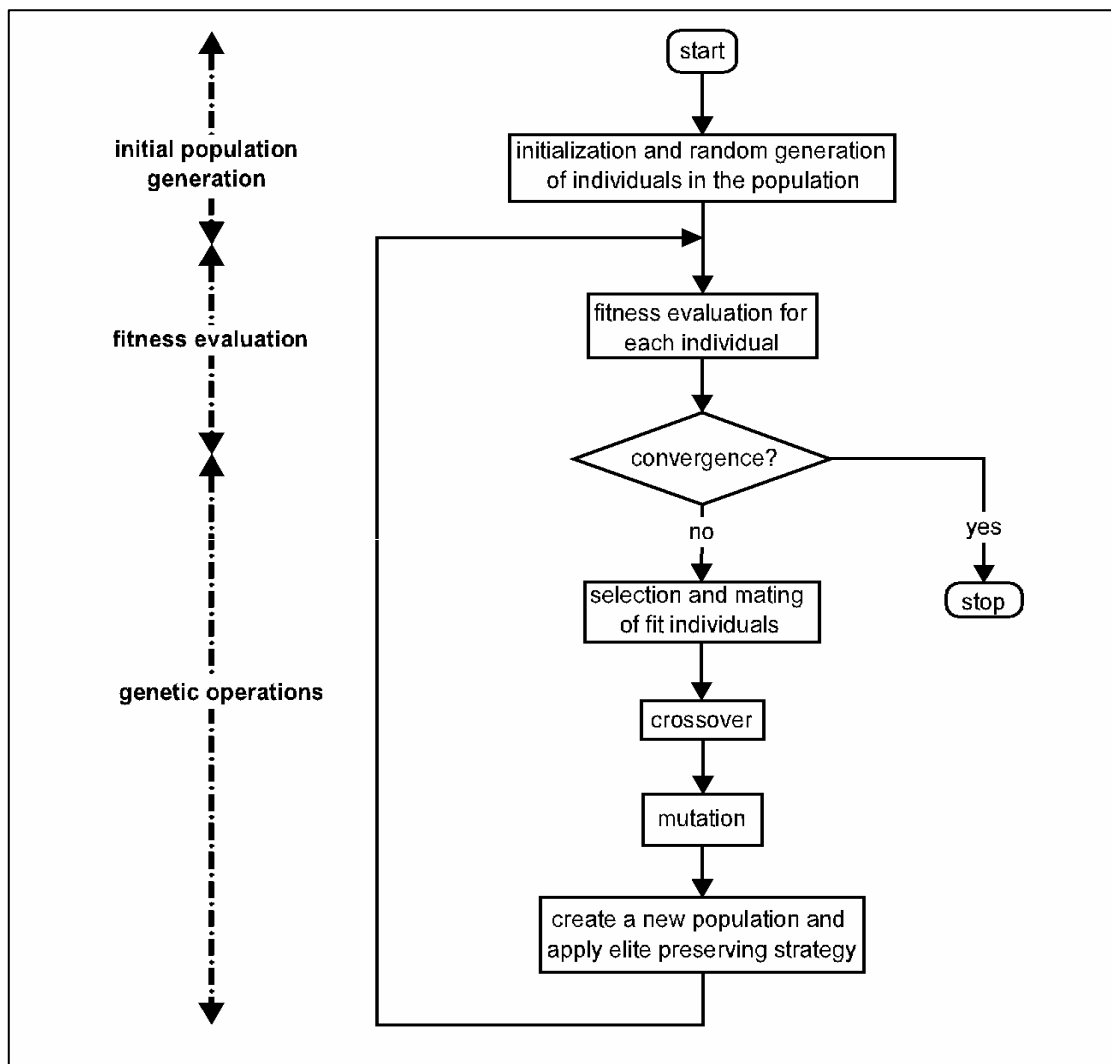


Figure 3-1 Flow chart of conventional GA.

### 3.4.1.1 Initial Population Generation

Figure 3-2 shows a comprehensive diagrammatic representation for the encoding of GA solutions and how they form the main population. Commonly, the encoding is divided into two types, binary and real valued encoding.

Binary encoding of GAs deals with binary string data type provided that the cardinality of bits of each string activates the gene of a chromosome.

A couple of such individuals constitute a population. A given set of parameters is coded and transformed into a series comprising of symbolic strings usually from binary digits. The strings possess fixed lengths and are treated with concatenation to form full length strings called chromosomes. Substrings of designated length can be extracted from the string achieved by concatenation. The substrings are decoded subsequently and mapped onto a value within concerned search space.

Another type of encoding technique is real-valued encoding. In this mechanism, real numbers are utilized to take the form of chromosomes [99,100]. Currently, there exists no specific set of guidelines for the prediction of most appropriate encoding.

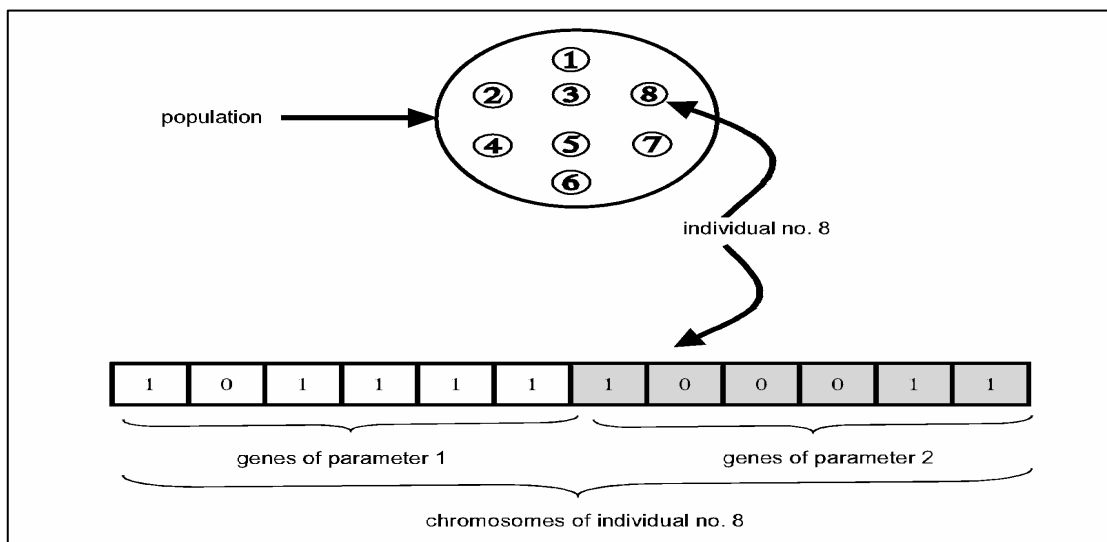


Figure 3-2 Comprehensive diagrammatic representation.

The controlling parameter list for the GAs like the size of population, the probability of a crossover, and the likelihood of mutation are chosen. Then, a population of strings (solutions) possessing a finite length is

prepared to start with. Every solution string is decoded in order to achieve a certain control variable for computing particular fitness.

### 3.4.1.2 Fitness Evaluation

Every solution must be checked. The fitness function should be used for evaluating it. This shall lead to a value which can determine the respective quality of solution. Hence, the values of maximum fitness, minimum fitness as well as average fitness for all members of a generation are calculated. If a predefined criterion of convergence has not been met so far, then the process moves to genetic operations dealing with selection and reproduction, crossover and mutation.

### 3.4.1.3 Selection and Reproduction

This technique deals with whole populations to select solutions that contribute in the production of next generations. This process imitates natural selection adopted by biological systems. A fresh population or generation is prepared from which poor performers are removed and the remaining fit members are chosen for the sake of passing information to next generations. Figure 3-3 shows the selection scheme.

There are many possible ways in which an operator is implemented. Frequently used methods are stochastic tournament and roulette wheel selection [99,101] which is stated as follows.

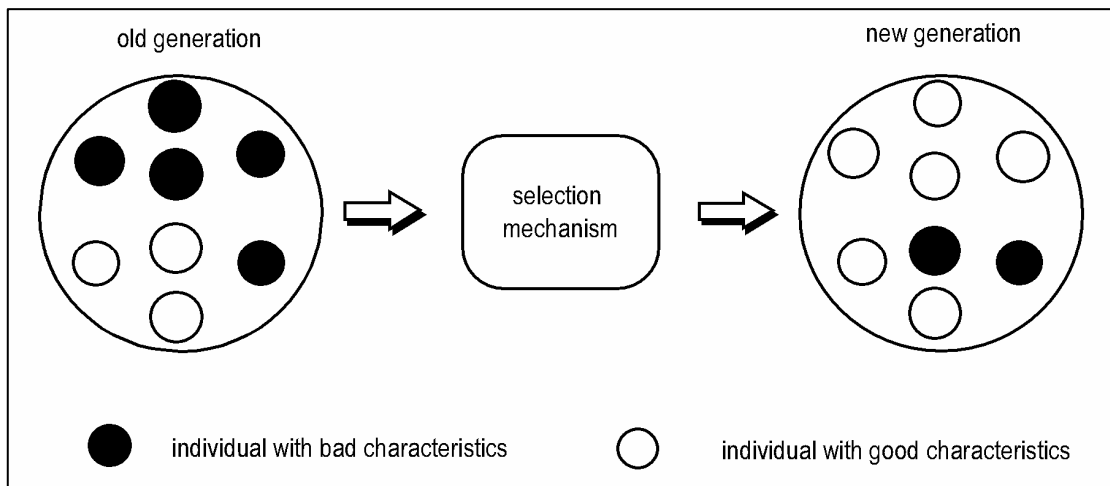


Figure 3-3 Selection strategy

#### ➤ Roulette Wheel Selection

In this method, members of each generation are chosen for inclusion into the subsequent generation as decided by the probability value. The value is in proportion with the ratio of solution fitness to whole population fitness. Those solutions that possess high values of fitness have a high likelihood of being chosen. A roulette wheel is rotated having portions of its area corresponding to proportion of solution's fitness in total fitness.

An illustration of the method is presented in figure 3-4. It shows a population comprising of a total of 6 members. Among those, solution number 4 possesses the biggest contribution to total fitness and it has the highest probability to be chosen. Hence, it is represented in subsequent generation. The chosen solutions are put in a provisional mating pool and are considered fit for more processing.



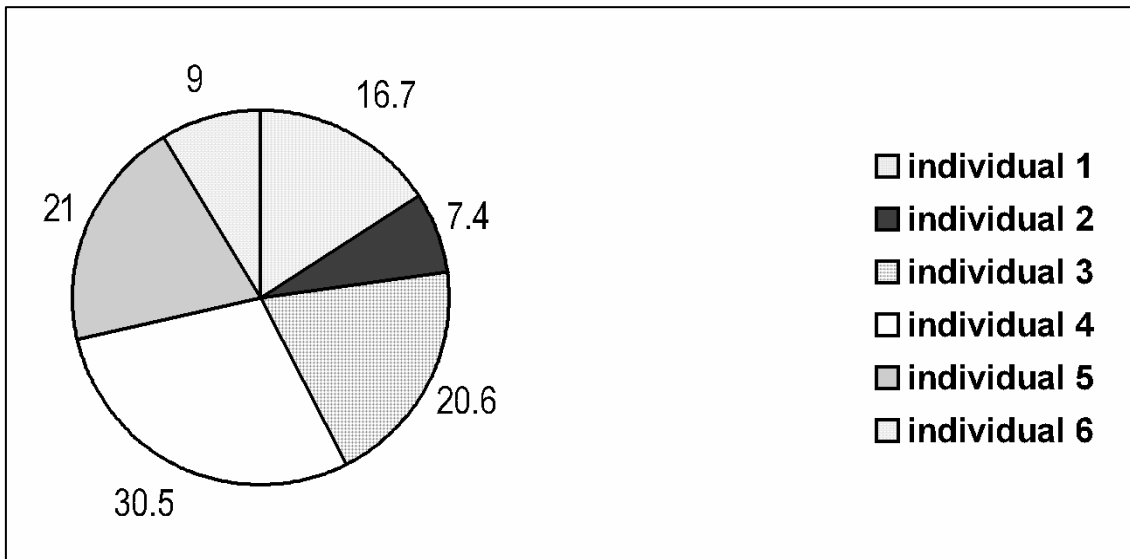


Figure 3-4 Roulette wheel selection strategy

### ➤ Tournament Selection

This is computationally efficient and effective method, used to select mates. Pairs of individuals are chosen at random from the population and the most fit of each pair is allowed to mate. Each pair of mates creates a child having some mix of the two parents characteristics according to the crossover method discussed ahead. The pair is then returned to the original population and can be selected again. The process of randomly selecting pairs and mating the stronger individuals continues until a new generation of the same number of individuals is reproduced. This method can be illustrated as in figure 3-5 with a population comprising of 8 individuals.

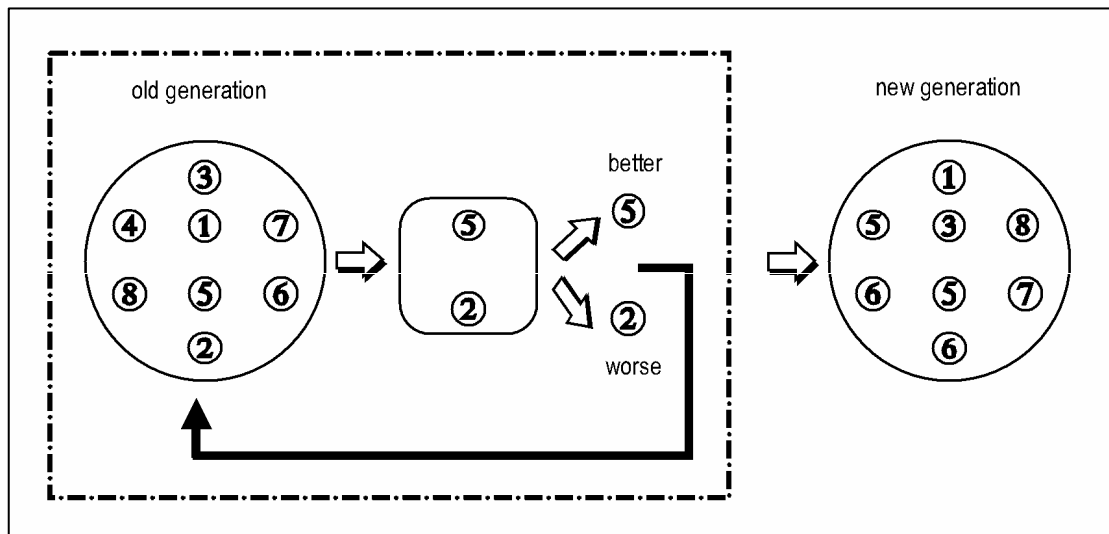


Figure 3-5 Tournament selection strategy

#### 3.4.1.4 Crossover

It is the major genetic operator capable of exploring new horizons within the search space. It is an event of exchange of information between solutions. Random selection of two of the individuals from the mating pool is carried out. Following that, a crossover junction is chosen. Information originating from one solution is propagated to the other solution up to the designated junction point. In this way, a pair of fresh solutions is generated for subsequent generation which comprises of a mixture of old solutions. Three widely used crossover mechanisms employed in GAs are as follows.

- **Single point crossover** selects a point at random along solutions. Then bits existing on right side of point are swapped between the solutions strings in order to produce a pair of offspring solutions, as illustrated in figure 3-6 [102].

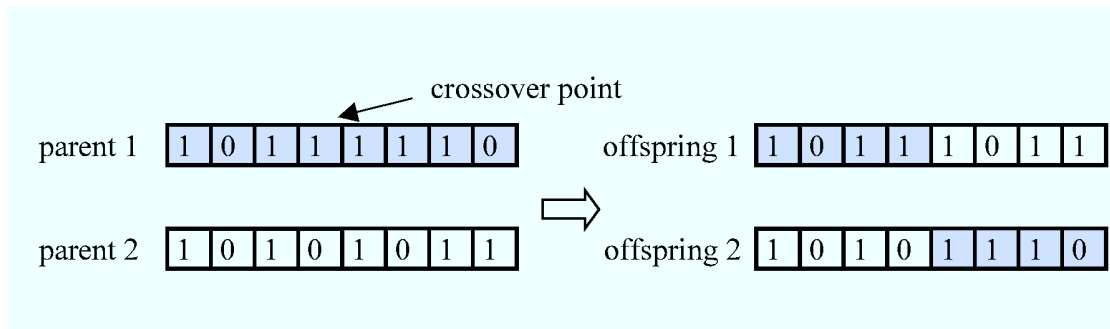


Figure 3-6 Single point crossover

- **Two point crossover** is similar to single point crossover, but differs in that it works with two randomly selected crossover positions and bits between those positions are swapped in order to produce two offspring solutions, as illustrated in figure 3-7[103].

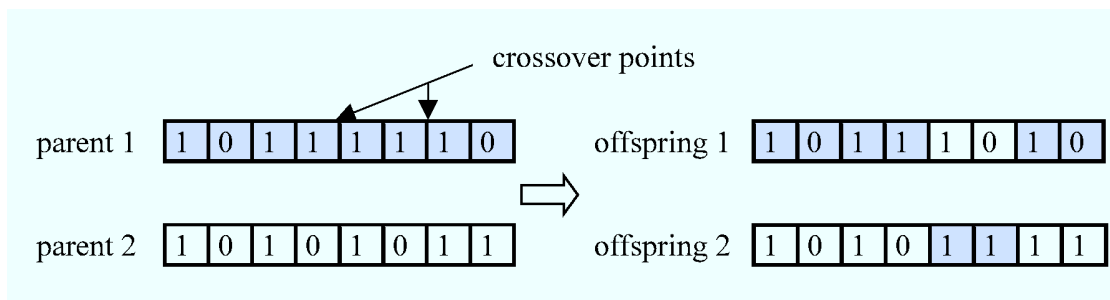


Figure 3-7 Two points crossover

- **Uniform crossover** uniformly selects positions and bits are exchanged at relevant coordinate pairs possessing the same probability as illustrated in figure 3-8. It is possible that it turns out to be highly disruptive especially in nascent generations. This is remedied by parameterized uniform crossover [74, 99,101,104].

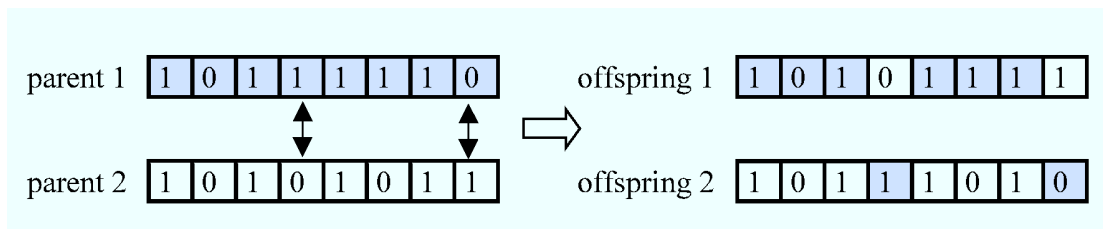


Figure 3-8 Uniform crossover

### 3.4.1.5 Mutation

Mutation is a procedure involving random alteration of information to produce a new modified solution. It is a way to assure the maintenance of search diversification for the population. Generally, it is believed to be a secondary operator which extends the search space. This technique is employed carefully and moderately. It involves random selection of a solution as well as bit locations and then, for example, switching 1s to 0s and vice versa, as illustrated in figure 3-9. The scheme is utilized in order to avoid sticking in local optima when applied carefully with selection and crossover [105].

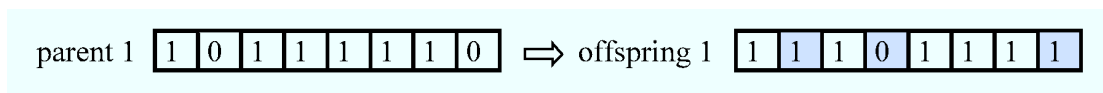


Figure 3-9 Mutation operation

### 3.4.1.6 Elitism

The probabilistic nature of process of generation carries a possibility that the fittest solution of the population is destroyed by the utilization of genetic operators. In order to remedy the situation, an elitist scheme is employed. It makes sure that the fittest solution is passed into the next generation. The GA verifies the desired replication of best

solution. If this requirement is not met, a set of fittest solution is mapped onto that selection. It is possible that this facilitate a super solution in dominating the whole of the population. However, this phenomenon is balanced by the quick increase in the performance of GAs by means of utilizing the best solution as the key to subsequent generation. This speeds up the convergence to global optima [106].

### 3.4.1.7 Treatment of Constraints

In a couple of optimization methodologies, for example real and reactive power dispatch, a set of constraints is required to be satisfied. The following steps make GAs capable of application to constraint optimization problems [107,108].

- Those solutions which are not feasible should be discarded as soon as they come into existence. This kind of exclusion has been utilized by many AI optimization methods such as GAs, and simulated annealing.
- Specially designed schemes of recording the produced solutions in order to reduce or eliminate the likelihood of production of non-feasible solutions via standard genetic operators.
- Curing and approximating invalid solutions can also be worthwhile. The resultant valid solutions can be largely dissimilar to the original solution set. Besides that, in a specific category of problems, searching for a feasible approximation of non feasible solutions can be as difficult as the optimization problem.
- Specially designed recombination and permutation operators can be used. They yield feasible solutions only. These types of operators are usually hard to construct. They are mainly problem dependent.

- Many terms are introduced in the fitness function. So, infeasible solutions may not be discarded. Instead, their fitness values are reduced in accordance with the constraint violation they tend to incur. This is a frequently used technique for the sake of treating constraints. It has various implementations [99,101,107,108].

### 3.4.1.8 Control Parameters

GAs utilize some control parameters, like other problems of optimization. These parameters include population size, maximum number of generations, types of genetic operations (crossover and mutation) and an elitist scheme. They should be chosen very carefully due to the fact that the performance of GAs is highly dependent on the values and the types of these operators. Usually, low population size and high crossover, but low mutation probability, are the recommended values to be used [101]. However, the size of population is directly proportional to the difficulty level of the problem. Generally, the crossover rates vary from 0.5 to 1 and the mutation rate is usually very small.

There are no specific best operator's values. Most of the authors and researchers have reported that they used values which are suitable for their problems. De Jong [109] concluded that the generally optimal value for mutation rate was 0.001 per bit, population size was 50 to 100 solutions and the single point crossover rate was 0.6 per solutions pair. The settings were frequently used in the area of GAs. However, the efficiency of his parameter settings outside his test suit was not clear. Later, a mutation rate of 0.01 per bit, population of 30 solutions and a crossover rate of 0.95 per solutions pair were determined to be an optimal setting [110]. These parameter settings introduced a significant performance improvement as compared to that of DeJong's settings.

It was noticed that there was no general principle for the values of the operators of GAs. This is owing to the fact that there are a variety of problem types, encoding patterns and performance criteria.

Some researchers tried to treat this uncertainty by adapting the values of these operators during the GAs run. So, the size of the population, crossover rate and the rate of mutation may alter during a single run. Researchers tried to design methods which allow the operator's values to adapt to the proceeding search in real-time. There are many schemes for self adaptation of parameters of GAs [111].

#### 3.4.1.9 Convergence Criteria

The processes stop as soon as the criterion of convergence is satisfied. Extensively used convergence criteria in GAs are:

- Stopping the algorithm after a designated number of generations
- Stopping the algorithm when the yielded solution does not show any improvement after a certain number of generations
- Stopping the algorithm when the average value of the fitness of the population becomes satisfactory.

#### 3.4.2 Expert Systems

ES, or knowledge-based systems, are designed in order to emulate the problem-solving pattern of human experts in a specified domain. The problem-solving pattern refers to the experience, heuristics, rules and strategies utilized by human experts in the course of solving the problem. Characteristic for the structure of ES is thus, the consistent separation of the inference mechanism from the specialized domain knowledge stored in the so-called knowledge base. The separation of knowledge-base from the inference engine facilitates enhancements or modification to the

knowledge-base without affecting the inference engine. Knowledge can be depicted in ESs by use of single or multiple knowledge structures like rules, frames, networks and objects [112,113,114].

### 3.4.2.1 Benefits of Expert Systems

ESs provide the following benefits [115,116,117,118]:

- Logical structures can be well presented because of the correspondence which exists between production rules and logical implications.
- Using if-then rule structures makes it easy to set up the knowledge-base as well as maintain it.
- Tracing application of rules makes it easy to prepare an explanation subsystem. This introduces transparency in the reasoning.
- Knowledge can be collected and accumulated from multiple human experts.
- The knowledge-base is fixed on permanent bases. Thus it can be reproduced.
- ESs operate unaffected by emotion sectors like stress or time pressure.
- ESs are inexpensive to operate after they are in place.

It is worth mentioning that ESs have some shortcomings as compared to human intelligence. For example, ESs possess limited knowledge, lack of sense, absence of creativity, limited adaptation and learning ability. ESs are very useful as decision support tools.

### 3.4.2.2 Knowledge Base

The knowledge of a certain area of interest can be classified as follows.

1. It can be classified into structured or data oriented knowledge comprising of all concerned information and relations, and data or factual figures about the system under observation. It can be further



broken down into dynamic knowledge and static knowledge. With respect to power systems, a major volume of data oriented knowledge can be acquired from the process database of the concerned control system [119]. This involves constant data like the components of power system, their physical parameters and topological junctions as static data. This is because they undergo a change only when the model of respective power system in process database is updated for the sake of reflecting changes in actual system.

2. It can also be classified as methodical knowledge in disguise of algorithm models of rules. Basically it serves to distinguish between exact formulation (like causation model, algorithm, and if-then rules) and a heuristic formulation which can also be provisioned by if-then rules. For example, the knowledge about the physical behaviour of a certain device in a certain situation or the ability to determine from the network connectivity and switching states the actual topology are examples of methodical knowledge.

Complex ESs employed in the field of power system control utilize a fine combination of static as well as dynamic data, algorithms, physical models and symbolic representations and computations. In this context, logical and heuristic rules can be applied in order to aid high-level decision making.

Acquisition of knowledge is an important step in the design and implementation of ESs due to the fact that the usability and effectiveness of the system is highly dependent upon the knowledge introduced into the system.

## 3.5 Simulation Tools

### 3.5.1 Power System Simulators for Dynamic Studies

In order for GA to have adequate knowledge about the dynamic performance of solutions in the problem domain, a dynamic power system simulator has to be used. The following section gives brief descriptions about some dynamic power system simulators.

#### 3.5.1.1 Eurostag

This program was developed by Tractable and EDF to cover the domain of mid term and long term transient stability by using an automatically and continuously variable step size integration algorithm. The program allows a complete simulation of stability study. It has a considerable components library which includes models for transformer on-load tap changing, dynamic loads, field current limiters, etc. [120].

#### 3.5.1.2 Exstab

Tokyo Electric Power Company and General Electric have developed Exstab for dynamic simulation over extended range of time domain. It uses an explicit and implicit integration technique. The program has detailed models of automatic generation control with frequency and interchange control, power plant, dynamic and thermostatically controlled loads [121].

#### 3.5.1.3 SICRE

This program was developed by CESI power system to cover a dynamic simulation in a wide range of time. The program could be used for dynamic and static simulations of electrical power systems, including short term and long term stability studies. This program is also extended to cover the electromagnetic phenomena caused by switching and lightning events. This program has a considerable library of components.

Moreover, this program allows an introduction of new models by the user [122].

#### 3.5.1.4 PSS/e

This program was developed by Siemens to cover many aspects including dynamic and static studies. PSS/E is an integrated, interactive program for simulating, analysing, and optimizing power system performance. The program has a considerable library beside the capability to introduce new models [123].

#### 3.5.1.5 PSSENG

Is a dynamic power system simulator which was developed by the Electrical and Electronic department at the University of Bath to cover the area of stability studies and contingencies analysis. PSSENG has a considerable library of power system dynamic elements. As PSSENG was developed for contingency analysis, it was upgraded by having a sophisticated stability index which can rank unstable and stable cases in accordance with their degree of stability or instability. Since the PSSENG was proposed for online dynamic power studies, a great deal of attention was given to its simulation speed [124].

#### 3.5.1.6 Summary of Power System Simulators

There are many dynamic power system simulators that can be used in the process of designing a power system security scheme. However, the main consideration which should be taken into account is the simulator speed and the capability to be controlled.

Amongst these simulators PSSENG was well known for its simulation speed. PSSNG could dynamically simulate 30 times faster than ordinary simulators. Another important feature of PSSENG is its ease of being used

as a slave program. So it can be easily controlled from a master program. Finally PSSENG is open source software. It means it can be modified to meet the need for any programmer.

## 3.5.2 PSSENG

### 3.5.2.1 Overview

For the simulation and stability evaluation, PSSENG is used to decide whether the system is stable or not since it is able to give clear assessments of the stability or instability of a system. The stability evaluation algorithm on PSSENG, which is based on time domain simulation output, can classify the simulation cases into the following categories:

- Transiently unstable class
- Oscillatory unstable class
- Poorly damped stable class
- Well damped stable class

For the two unstable classes the stability index is expressed by the severity index. Unstable cases with a detection of pole-slipping are classified in the transiently unstable class. The time taken for the system to pole-slip is used as the severity index in this class. Other unstable cases, without a detection of pole-slipping, are classified as being in the oscillatory unstable class. In this class, the calculation of the severity index is more complicated than in the previous one. The maximum magnitude of the rotor swing among all other generators is used as the main indicator of the severity index. Moreover, the frequency deviation and generator's active power are also used as auxiliary measurements in addition to the maximum rotor swing of the machine in order to give an accurate severity index. For the stable classes, the examination of the machine's rotor swings can give a decent indication of how stable the

system is. The swing amplitudes can help to identify the extraction of the envelopes of the rotor swing curve for all machines. The swing of the envelopes, presented in figure 3-10, can be approximately defined as an exponential function

$$S(t) = A e^{bt} \tag{3-1}$$

The value of b is the system time decay which is used as an index for the degree of stability. If b is less than 12 second the case is classified as being in the well damped stable class, or, if more than 12 second, as being in the poorly damped stable class [124,125].



Figure 3-10 Swing envelop

### 3.5.2.2 Validation of PSSENG Output

Having decided to use PSSENG as the power system simulator, it was fundamental to confirm the capability of the PSSENG to simulate and perform the Libyan power system.

The 8<sup>th</sup> of November 2003 Libyan blackout is chosen as the validation case study to show the capability of the PSSENG.

Years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 kV transformer on a power production plant on the west side of the Libyan power system, Tripoli west plant. This occurred while the Libyan power system was connected to the Egyptian power system with zero power exchange and the power transfer from the west to the east was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The incident caused the west and the east of Libyan power system to separate. The east side was able to survive while the west collapsed [2].

For studies purposes, this incident was simulated by the experts of General Electricity Company of Libya (GECOL) using SICRE Simulator [122]. The output of their simulation is presented in figure 3-12.

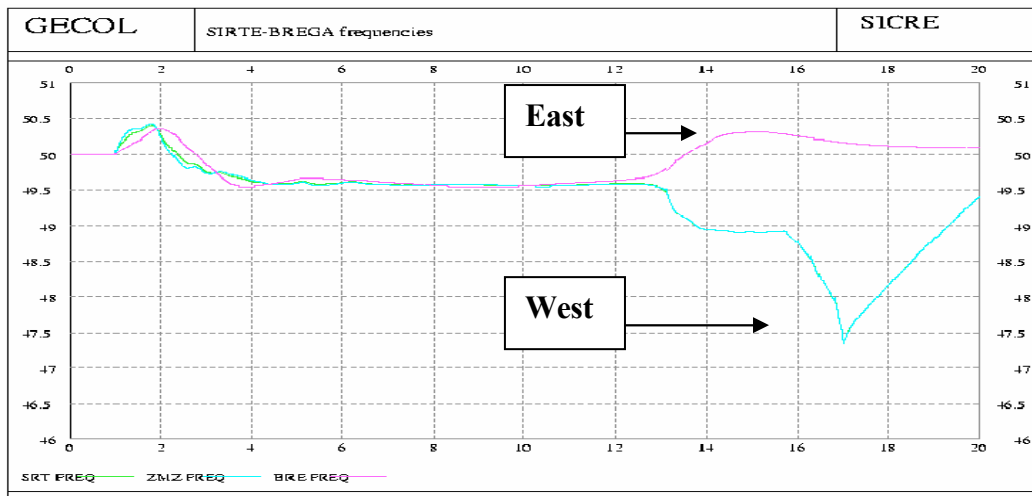


Figure 3-11 Libyan blackout using SICRE

Using PSSENG, the simulation of the Libyan blackout is presented in figure 3-13.

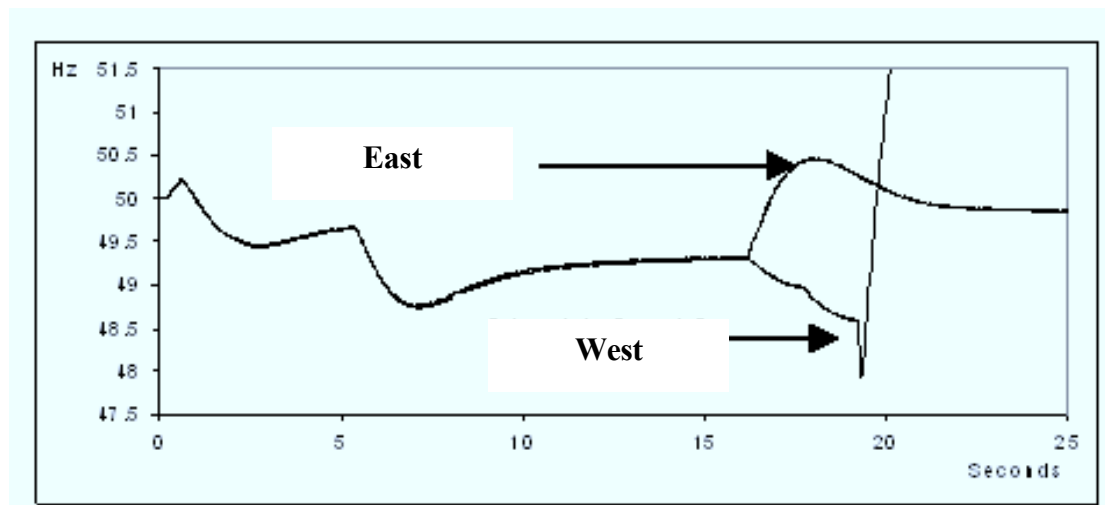


Figure 3-12 Libyan Blackout using PSSENG

Comparing the two figures 3-11 and 3-12, it can be noticed that the PSSENG is successful in simulating the incident. However, some differences between the two dynamic performances of the outputs can be realized. These differences include the dissimilarity in the system separation time. Taking into consideration the fact that this is a complicated industrial case, these differences can be considered minor in dissimilarity.

In conclusion, the analysis of this comparison has indicated that the PSSENG gives promising performance in the process of designing the power system security scheme.

## 4 Algorithm Application to the Design of Defence Plan

### 4.1 Introduction

This chapter covers the design and the implementation of defence plan algorithm.

Owing to the complexity of modern power systems, the design of defence plans can be very challenging. Human experience and observation have been used as the main keys in designing the necessary measures. Although using the experience of engineers can be of assistance in designing a good quality defence plans, the optimality of the defence plans can not be guaranteed. This heightens the necessity of using optimization methods to obtain more ODP. As mentioned in chapter three, MO methods have been used over years for power system control problems. However, the solution for large-scale power system is not easy to obtain by way of ordinary MO methods. This is due to the fact that there are many uncertainties in power system problems due to their complexity, size and geographical distribution. It is also much preferred that the solution for the power system be close to the global optimum solution. However, this can not easily be reached by mathematical methods due to the multi-objective, discontinuous nature of the problem of space. All of these factors therefore make it necessary to use a robust global search technique such as GAs.

In this Chapter, the defence plan includes load shedding and islanding scheme. GA is applied to find the minimum amount of load shedding, following severe faults, at various frequency thresholds that are able to secure the network, or even enhance the dynamic performance. Also, another GA is applied to obtain an optimal islanding scheme to geographically restrict the extent of the fault. Practically, defence plans



are designed to act against incidents which are not covered at the system planning stage. These defence schemes are based on the fact that, in extreme situations, it is better to shed some loads, or parts of the network, rather than to lose the whole network.

## 4.2 Design of the Optimized Defence Plan

### 4.2.1 Overview

Generally, in this study, the same defence plan designing procedures presented in section 2.5.3 are used. Optimization techniques are applied in some critical stages as follows. The first optimization technique is used to obtain a load shedding scheme. At this stage, the optimization technique is used to find the minimum amount of loads that should be tripped in every frequency level. At the second stage, the optimization is applied while obtaining the islanding scheme. Therefore, the optimization technique is of assistance in finding the optimal islanding scheme.

### 4.2.2 The Design Process

In order to be able to represent severe transient phenomena that could lead to full system collapse, a weak operation situation with extreme operation conditions has to be considered.

Also two lists of assessing contingencies have to be prepared. The first one is a list of contingencies that causes a severe frequency decline. This list has to be carefully chosen to cover the whole studied power system. This list, which is used for developing load shedding scheme, is called *load shedding assessing contingencies*. The second list contains more severe contingencies which cause full system collapse by pushing the system frequency to islanding stage. This list, which is used in the design of the low frequency islanding scheme, is called *islanding assessing contingencies*.

The following types of protection are considered in the simulation:

- Under voltage protections for interconnection lines.
- Over voltage protections for interconnection lines.
- Under frequency protections for interconnection lines.
- Over frequency protections for generation units.
- Under frequency protections for generation units.
- Under voltage protections for generation units.

Unlike the ordinary defence plans, an optimization technique is used to find the minimum amount of load shedding that is able to stabilize the network in all frequency thresholds. As mentioned before, the GA is applied to obtain an optimal islanding scheme. The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible.

As a matter of fact the islanding scheme is always applied following the last stage of load shedding. Due to this fact, the best solution produced by the load shedding scheme is considered in the islanding scheme. As mentioned before PSSENG is used to simulate the Libyan power system. And it is embedded inside the GA to perform the solutions given by GA.

## 4.2.3 Genetic Algorithm Implementation for Load Shedding

### 4.2.3.1 Overview

Figure 4-1 shows the Algorithm flowchart. In general, a load shedding assessing list of contingencies is applied, contingency by contingency, to the proposed power system.

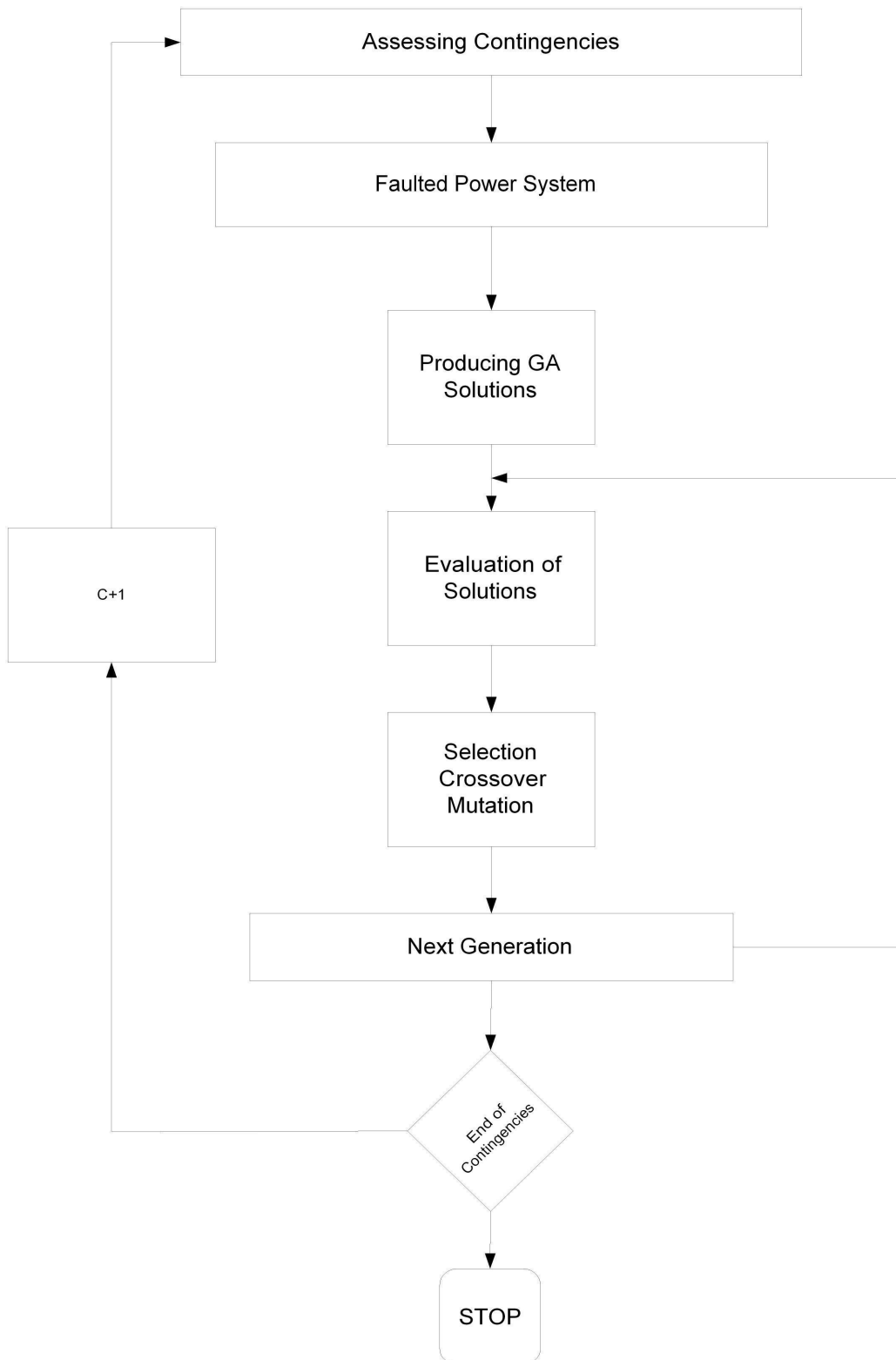


Figure 4-1 Load shedding algorithm

This list of contingencies is presented in appendix I.III. These contingencies are supposed to severely decline the frequency. Having applied the first contingency, GA produces a random set of solutions which presents a sequence of effective control variables.

The PSSENG is operated first with the proposed power system and the first contingency, and then solutions are applied one by one. PSSENG has the ability to provide sufficient knowledge about the performance of the solution against the contingency. This process continues until all solutions in the population are applied. Then, using the fitness function, all solutions are evaluated. In accordance with the evaluation, a probabilistic technique is applied to select the best solution. Having done that, information is exchanged and the change is applied to the whole selected solution. Following the information exchange, the new population is formed and applied again to the proposed power system with the same contingency. These processes are repeated until the best solution for that contingency is obtained. Then, the best solutions are recorded. Again, this process is repeated for every contingency and the solutions are recorded. Once the list of contingencies is applied, the algorithm stops.

#### 4.2.3.2 Control Variables and Encoding

Among many stabilizing actions, load shedding plays an important role. A considerable feature of load shedding is the capability to be applied just following a fault. For this purpose, under frequency load shedding schemes are always considered as the first line of defence plan.

In the implementation of GA to the load shedding scheme, a slightly complicated encoding is adopted. This is due to the function of the load shedding scheme. Load shedding schemes have to be actuated in accordance with five frequencies thresholds. As the frequency declines, it reaches the first threshold, so the assigned loads are shed. If the frequency stops declining, no more loads are shed. Otherwise, the frequency reaches

the second threshold, and more loads are shed. This process is repeated until the frequency reaches the last frequency threshold. If the load shedding scheme could not stop frequency declining, the islanding scheme is actuated. As mentioned before, these frequencies thresholds are explained in section 6.2.4.1.

In the process of choosing the encoding and the control variables of this problem, many trials were applied and then enhanced or eliminated until the best method is achieved.

Generally, the first success in the encoding scheme for the load shedding was designed for just one contingency. This successful trial was published on UPEC 2007[126]. The encoding scheme was not complicated but has shown promising results as the solution obtained was able to stabilize the 14-bus IEEE network following a severe fault. Figure 4-2 presents the power angle of one of the generators in 14-bus just following a severe contingency, while figure 4-3 presents the same incident but with the application of the load shedding solution found by the algorithm. Figure 4-4 presents the fitness average of the solutions used for the 14-bus IEEE network.

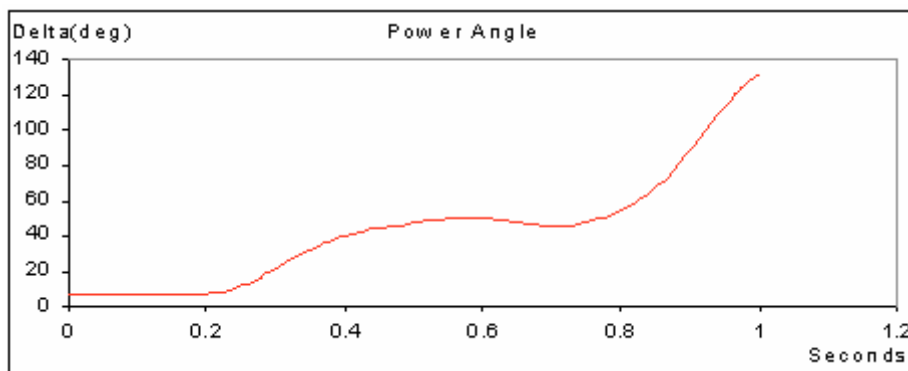


Figure 4-2 Rotor angle of G1 of 14-bus IEEE network without load shedding action

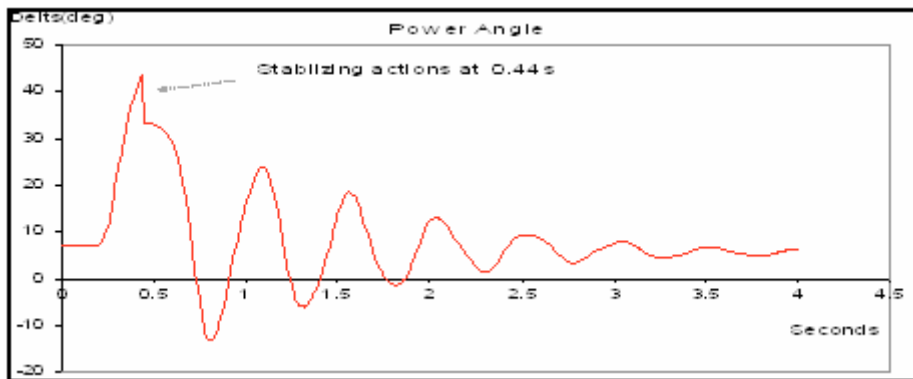


Figure 4-3 Rotor angle of G1 of 14-bus IEEE network with load shedding

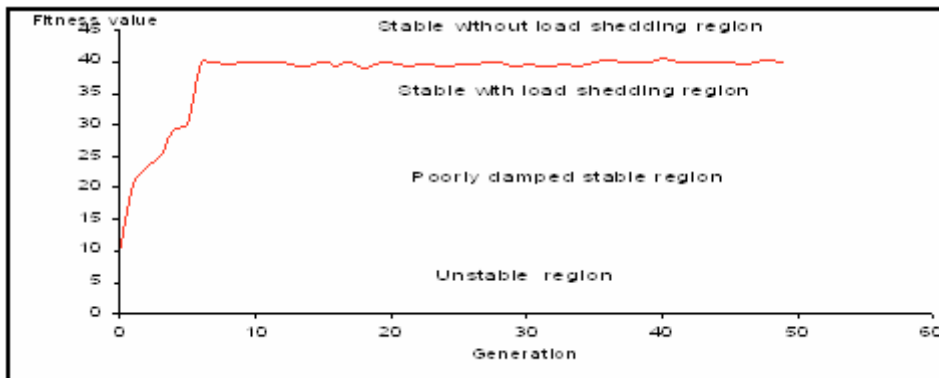


Figure 4-4 Average fitness of solutions for 14-bus IEEE network

The encoding scheme was also applied to UK power system following a severe fault and has shown promising results as the solution obtained was able to stabilize the UK power system.

Figure 4-5 presents the power angle of one of the generator in UK power system just following a severe contingency while figure 4-6 presents the same incident but with the application of the load shedding solution found by the algorithm. Figure 4-7 presents the fitness average of the solutions used for the UK power system. Obviously, the algorithm proves its robustness by ascertaining optimal solutions, for both cases, without any disruption to consumers, i.e., zero load shedding.

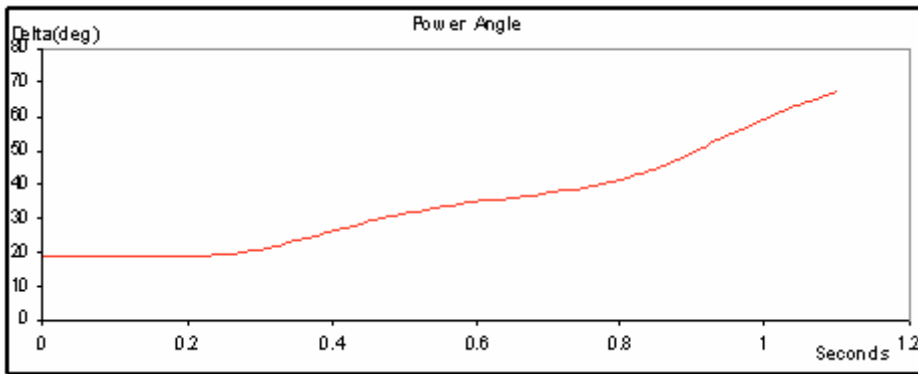


Figure 4-5 Rotor angle of G1 of UK system without load shedding action

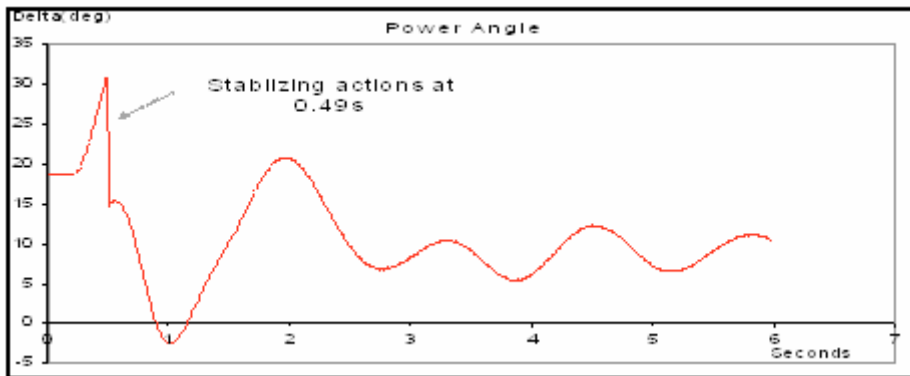


Figure 4-6 Rotor angle of G1 of UK power system with load shedding action

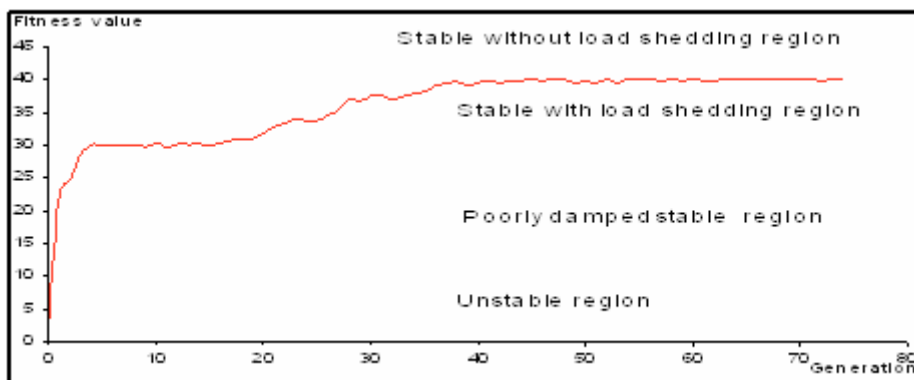


Figure 4-7 Average fitness of solutions for UK power system

In this trial, the generators were also considered with the loads in the structure of solutions. This is due to the fact that the algorithm is proposed to the UK power system where the generator tripping can play an important role in stabilizing the network. Libyan power system suffers from lack of generating capacity available to the system operator within a short interval of time to meet demand in case of supply interruptions. Due to this reason, the system operator would not intentionally trip any generator during a major incident. Therefore, generators were excluded from the solutions structure when the algorithm is proposed to the Libyan power. Figure 4-8 presents the structure of the solution. The structure of solution considered in this trial was as follows: every generator and load is numbered from 0 to K, where  $K = \text{number of generators} + \text{number of loads}$ , and each chromosome is composed of S unique integers ( $S < K$ ), with each integer corresponding to a certain generator or load.

5	2	1	4	3	9
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Figure 4-8 Solution structure of the first successful trial

Following this successful trial, the encoding scheme had to be upgraded to deal with many frequency thresholds.

One thought was to apply the optimization method in every frequency threshold, get the best solution for the first frequency threshold, and then apply the optimization method to the next frequency, and so on until all frequency thresholds are done. This way of applying the GA has a logic disadvantage since it is linked to huge cuts in the solution space. Moreover, by considering only the best solutions in every frequency threshold, many good solutions are avoided, which might not lead to the overall best solution. For example, some solutions have good overall performance but they would have been eliminated because they performed



badly in the first frequency thresholds. In other words, the best solution in first or second frequency thresholds does not mean that the overall solution is the best.

Some enhancements were considered for this method. One of these enhancements is considering the best ten solutions in first frequency thresholds and then using them to obtain the best ten solutions for the second frequency thresholds, and so on, until all frequency thresholds are done.

Following the application of this enhancement, it was clear that there are still huge cuts in the solution space since there are a large number of good solutions in the first frequency threshold. Considering such a number of solutions requires a tremendously huge computation time.

The main formed thought is to use all frequency thresholds in the structure of the solution. Then, evaluate them using one fitness function rather than evaluating the solution following every frequency threshold. This method allows discovery of the majority of the solution space.

One successful test was published on Cigre 2008[127]. The Libyan power system was proposed in this test. The output of this trial was very promising. The used encoding scheme used in this trial is presented in figure 4-9. This encoding scheme is proposed to deal with all frequency thresholds.

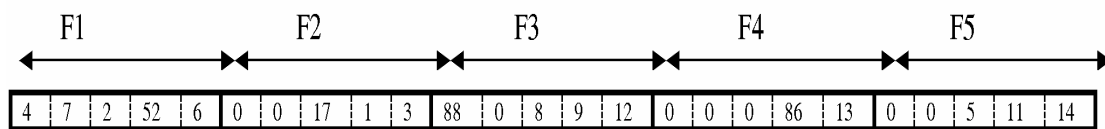


Figure 4-9 Solution structure of the second successful trial

Since the aim of the optimization technique in this stage is to minimize the amount of load shedding in different frequency stages (frequency threshold), the amount of power in every load is considered in the structure of every chromosome. Every solution is divided into five parts (5 frequency thresholds). Every part corresponds to a certain frequency stage, and is hence applied in that frequency stage.

As it can be seen in [127], the load shedding scheme found in this stage was applied to the Libyan power system along with the islanding scheme obtained by the islanding algorithm, which is presented later. The output of this application was compared to the current schemes (load shedding and Islanding schemes), using a case study of the blackout of the 8<sup>th</sup> of November 2003. The dynamic performance of the Libyan power system following the application of the load shedding scheme is presented on figure 4-10, while figure 4-11 presents the dynamic performance using the current load shedding scheme.

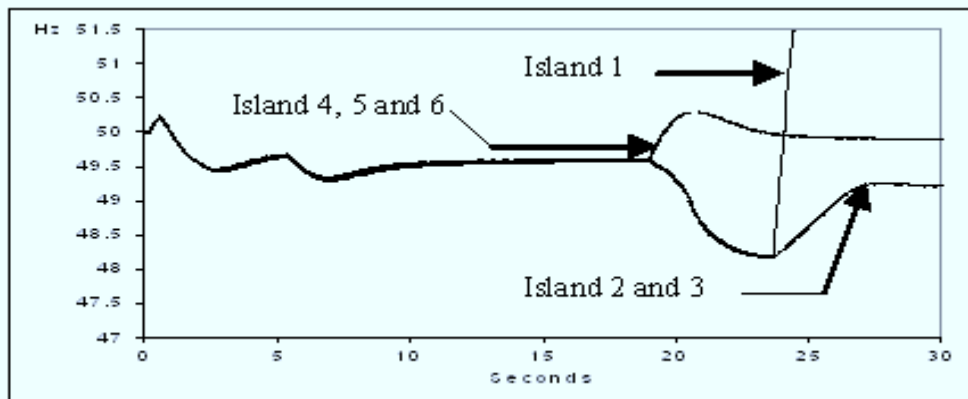


Figure 4-10 Dynamic performance using the obtained load shedding scheme

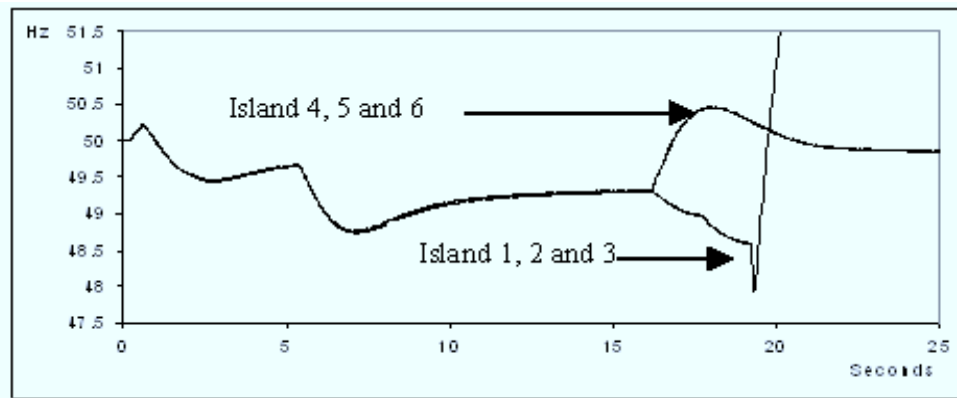


Figure 4-11 Dynamic performance using the current load shedding scheme

Referring to figure 4-10 and 4-11, it can be noticed that the solution found in this stage outperforms the current schemes. The optimized solution was able to preserve more loads than that of the CDP in the case study of blackout of the 8<sup>th</sup> of November 2003. A deep comparison between the two dynamic performances is presented in [127].

The application of this encoding scheme was successful. However, the best solution presents a load shedding scheme with a high amount of load shedding. GECOL recommends obtaining another solution with less amounts of load shedding. Many trials were applied in this encoding scheme to push it to converge to a better solution with less amounts of load shedding but none were successful. Therefore, another solution structure was considered.

Following all of these trials and tests, the last formation of the encoding scheme was considered as follows:

Loads are considered as control variable of this optimization problem. In general, every solution is formed from number of genes. This number is equal to the number of loads involved in the problem. The location of every gene corresponds to a certain load. The genes numbers vary from 0 to 5, where 0 means that the load which the location of the gene corresponds to will not be tripped, 1 means that the load is tripped in the

first frequency threshold, 2 means the load will be tripped in the second frequency threshold, and so on so forth.

Figure 4-12 presents the structure of the solution candidates in this optimization problem.

Fn	Fn	Fn			Fn
L1	L2	L3			Lk

Figure 4-12 Load shedding solution structure

Where: Fn could be any number between 0 and 5, L is a load and k is equal to the length of the solutions, which is equal to the number of loads involved.

This encoding scheme has shown very promising results as seen in chapter 6.

#### 4.2.3.3 Fitness Function and GA Operators

Once all solutions in the GA population have been created, it is needed to evaluate the fitness of the solutions in the problem domain. As the main goal is to stabilize a power system following a major incident with the minimum amount of load shedding, system stability and minimization of load shedding are the main objectives of this problem.

PSSENG has provided the GA with a powerful feature. This feature has the capability of evaluating and ranking stable and unstable solution as in figure 4-13. This provides a good chance for bad performing solutions, which hold valuable information, to contribute slightly in offspring generation.



Figure 4-13 Stability ranking scheme

In order to be able to form a good fitness function, sufficient information about the amount of load shedding must be considered. The fitness function should be able to classify solutions as in figure 4-13. Figure 4-13 shows that solutions are firstly classified in terms of their stability and then classified in accordance with the amount of load shedding.

Equation 4-1 presents a fitness function which is able to firstly classify the solutions in accordance with its stability class, and then evaluate them using their stability or instability degree. Following this classification, the solutions are ranked regarding the associated amount of load shedding.

$$F_F = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} & \text{Stable case} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} & \text{Unstable case} \end{cases} \quad (4-1)$$

Where:

SC: represents the stability class. This helps GA to classify solutions into four classes: well damped stable, poorly damped stable, oscillatory unstable, for transiently unstable.  $N_L$  is the number of predetermined shedding loads. MVI: is the summation of the amount of load reductions. This helps the algorithm to go for the solution with the minimum amount of load shedding. TDR: is the time decay ratio. This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the solution.

SI: is the severity index. This is used only for the unstable classes to specify the degree of instability. This helps the algorithm to have strong recognition of an unstable solution.

Although some solutions carry valuable information, they might not perform well in the solution space. In order to provide a good chance for this valuable information to part of the offspring solutions, these solutions should not be completely eliminated. These solutions should have small chances to contribute in the offspring generation. A roulette-wheel section is one of the probabilistic techniques that take this feature into account. Therefore, this algorithm utilizes roulette-wheel section technique as the selection tool to choose the solution that contributes in the offspring solution.

The information exchange technique used in this algorithm is single point crossover, in which one point of exchange is set randomly at position within the string of parent candidates, and one parent candidate contributes all its code from before that point and the other contributes all its code from after that point to produce offspring.

Mutation as a random change in a random solution is used in this algorithm. An Advanced operator is used to assure that the best solution found so far is always kept, and participate in the production of the next

offspring until a new best solution is found again. This operator is called elitism.

#### 4.2.4 Techniques for Solution Space Reduction

The problem of load shedding scheme is associated with huge solution space. This huge solution space might disturb the search capability of the GA. However, many parts of the solution space could be not valuable to discover. This is due to the fact that these areas could contain poor solutions that do not work at all in the problem domain or perform very badly. Therefore, it would be strong feature for the GA to avoid these parts of the poor solution space.

##### 4.2.4.1 Load Shedding Constraints

The structure of solutions introduced in the previous section means that a certain amount of load is shed at every frequency threshold. As the initial population is randomly produced, some solutions can have an unacceptable amount of load shedding in one of the frequency thresholds or an unacceptable aggregated amount of load shedding. This kind of solutions could be reproduced during GA process. So, it is vital to have an appropriate technique to deal with or eliminate these solutions.

One technique is to avoid these solutions by assigning poor evaluation degree to them, which means that they would have very tiny possibility to appear in the next generation. However, this technique prolongs the simulation time as it runs for unacceptable solutions. Another option is to heal these solutions by mapping them to the nearest good solution as mentioned before in chapter 3.

The mapping technique is used in this part of the research. In order to define which solutions are bad or good, a boundary has to be defined first. The boundary limits between acceptable solutions and unacceptable

solution is the amount of load shedding required by that solution. This amount is 8% of load shedding of the whole network in every frequency threshold. This means that if any solution sheds more than 8% at any frequency threshold, this solution has to be cured. The cure is reducing the amount of load shedding under the load shedding limit. Therefore, a reduction process would be applied to drop the less important loads until the amount of loads shedding is less than the load shedding limits.

#### 4.2.4.2 Load Shedding Localization

One of the most powerful aspects of this algorithm is the optimization against the assessing contingencies. However, considering large numbers of assessing contingencies enlarges the solution space which, in turn, disturbs the GA search capability. By taking into account the fact that the assessing contingencies are chosen to be generic and geographically distributed on the proposed power system, this problem can be solved by using localization technique.

The localization technique is about controlling the production of first random population. The localization technique makes the initial population hold random information only about the frequency-affected area. This helps to avoid solutions that hold ineffective information. This ineffectiveness is mainly due to the geographical distance. So, for example, if a fault occurred in the east of the proposed power system, it would be an inappropriate solution if some loads are shed in the west.

The application of the localization technique in the beginning of the GA makes the structure of the solution changeable as it goes from one assessing contingency to another. However, that structure is fixed for every assessing contingency.



## 4.2.5 Genetic Algorithm Implementation for the Islanding Scheme

### 4.2.5.1 Overview

As a matter of fact the islanding scheme is always applied following the last stage of the load shedding scheme. Therefore, the operation conditions considered in this study are operation conditions obtained after applying the best solution found by the load shedding algorithm. Figure 4-14 shows that; a list of islanding assessing contingencies is applied. These contingencies are reported in appendix I.III. This list is applied contingency after contingency. However, the performance of the solution is evaluated against the entire assessing contingency at once. Then, evaluation degree is assigned to every solution as it performs against all islanding assessing contingencies. In accordance with the evaluation degree, the solutions are selected using a probabilistic technique to contribute to the production of next offspring generation. This is followed by information exchange and changes to produce the new generation. Having done that, a new generation is formed. The same process is repeated with the new generation to produce a new better generation, and so on so forth.

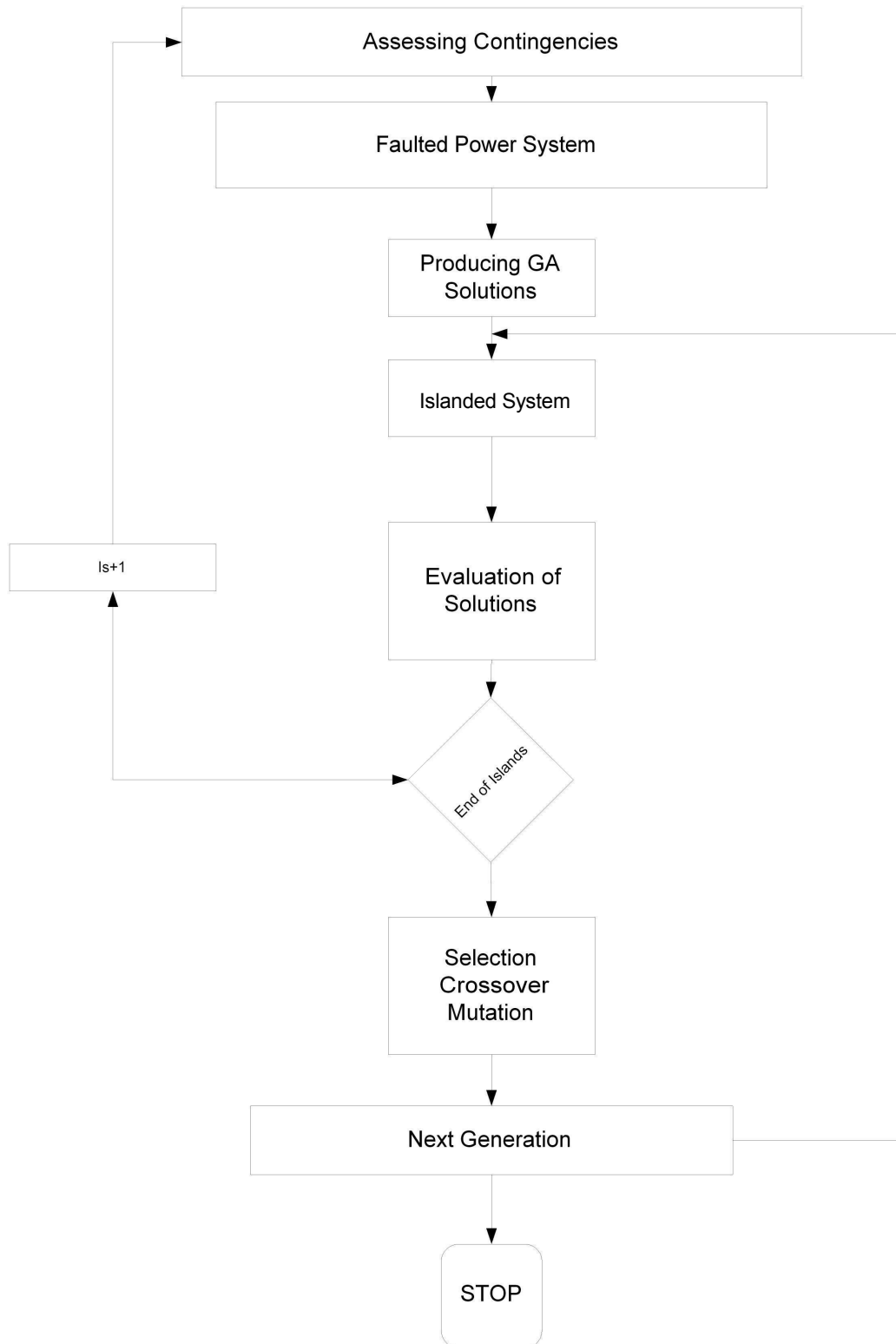


Figure 4-14 Islanding algorithm

#### 4.2.5.2 Control Variables and Encoding

Power systems are mainly formed from a number of parts (islands). These islands are connected through tie lines to operate together as one big power system. The question here is which tie lines could be cut to form the best island formation.

During the process of choosing the structure and the encoding scheme of solutions, all transmission lines were initially considered. This has enlarged the solution space associated with this optimization problem. This was followed by the idea of reducing the number of transmission lines used in the solution structure. Therefore, every transmission line that has a dead end (one bus bar in the end of line) was excluded.

Another vital problem linked to this encoding scheme is the disability of the partitioned islands to survive due to an imbalance in load generation equilibrium. This has been dealt with by adding a segment of balancing load shedding to the structure of the solutions. Figure 4-15 presents the solution structure considered at first. This structure was initially adopted and applied to the 118 Bus IEEE network [49]. The results of the test were published on UPEC 2008 [49]. Using this structure, the algorithm suffered from a converging problem. At that time, this problem has been overcome by seeding some good solutions to the initial population. Figure 4-16 shows the convergence of the algorithm in this trial. In general, it has shown promising solutions which are reported in [49].

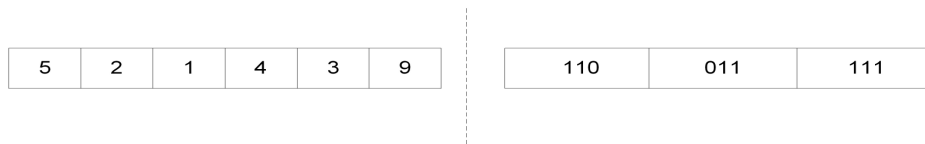


Figure 4-15 Solution structure of the first successful trial

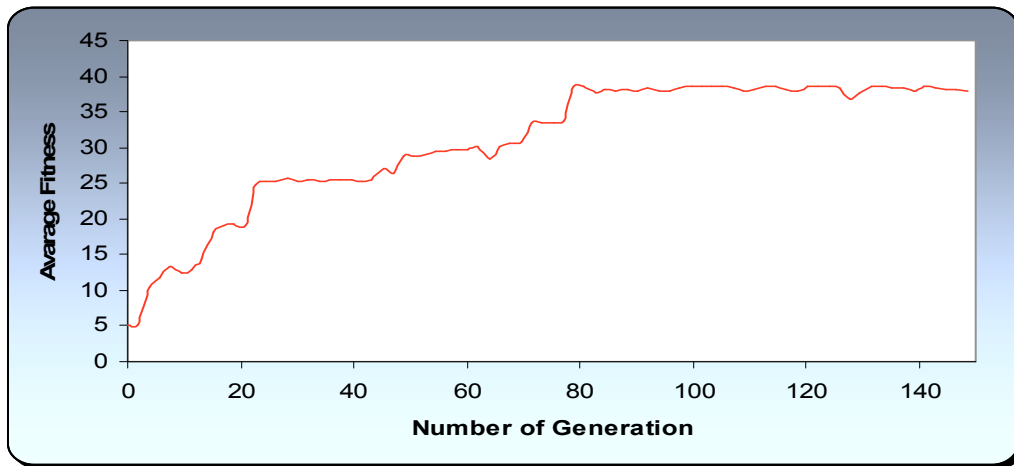


Figure 4-16 Algorithm convergence

Even though the seeding technique has shown promising potential, the ultimate goal is to allow the algorithm to successfully discover the solution space without outside help such as the injection of good seeds (solutions).

This has been overcome by using the load-generation balance investigator which is explained in section 4.2.6.2.

Therefore, the possible tie lines are considered as the control variable of this optimization problem. So, every solution is formed from a number of bits. The location of every bit corresponds to a certain tie line. The number of that line could be 1 or 0. If it is one it means that the line is tripped, otherwise the line is not tripped. Figure 4-17 presents the structure of this encoding scheme.

1	0	0	1	1	0
T1	T2	T3			Tn

Figure 4-17 Islanding solution structure

Where T is a possible tie line and n is the number of tie lines involved in the problem.

#### 4.2.5.3 Fitness Function and GA Operators

Having created all solution in the first population, an evaluation is applied to specify poor and good solutions. The main goal of this optimization problem is to find the optimal and viable islanding formation with minimum load shedding required to maintain the load generation balance for each island.

In order to observe the performance of the solution in the problem domain, PSSENG has to be operated for each solution and each island. The use of PSSENG provides the GA with the viability of every formed island and the amount of load collapsed due to the separation of the islands. Also, the GA is informed about the degree of stability and instability of island. This helps the GA to have a deep insight about the performance of every island. Finally, the amount of load shedding required to maintain the balance between load and generation is subject of evaluation.

Equation 4-2 presents the fitness function of the whole power system which is formed from number of islands, i.e.,  $F_1, F_2$ . whilst 4-3 equation presents the fitness function of every electrical island.

$$F_F = F_1 + F_2 + \dots + F_N \quad (4-2)$$

Where N is the number of the islands and F is the evaluation of that island.

$$F_N = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} & \text{Stable case} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} & \text{Unstable case} \end{cases} \quad (4-3)$$

SC: represents the stability class. This helps GA to classify solutions into four classes: well damped stable, poorly damped stable, oscillatory unstable, for transiently unstable.  $N_L$  is the number of predetermined shedding loads. MVI: is the summation of the amount of load shedding required to maintain load-generation balance in addition to the amount of collapsed load. This helps the algorithm to go for the solution with the minimum amount of load shedding. TDR: is the time decay ratio. This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the solution.

SI: is the severity index. This is used only for the unstable classes to specify the degree of instability. This helps the algorithm to have strong recognition of an unstable solution.

Roulette wheel selection technique, single point crossover, mutation and elitism are used as the operators in the same way and purpose as the use in the load shedding scheme.

## 4.2.6 Techniques to Reduce the Solution Space

### 4.2.6.1 Number of Islands Constraint

During the process of applying the islanding algorithm, some bad solutions with an unacceptable number of islands appeared in the GA populations. Some solutions appeared to have more than 20 islands and some of them had just one island. These solutions could carry valuable information, however, considering these solutions could unnecessarily prolong the computation time. Therefore, a technique to relatively eliminate them has to be applied.

The used technique in this algorithm is by checking the number of the islands in every solution and giving them low evaluation degrees before applying the solution to the PSSENG. By doing this, a considerable amount of the computation time is saved, since this kind of solution might appear during the process of the GA. Any solution that carries more than 10 islands or just one island is given low degree of evaluation.

### 4.2.6.2 Load Generation Mismatch Investigator

An important point is the viability of the formed islands. In order to have a good chance for the island to survive, the balance of load generation has to be maintained. The goal of the load-generation mismatch investigator is to terminate the generation-load mismatch, in the formed islands, by shedding the least important loads. The balancing of load shedding should be roughly equal to the amount of power mismatch between the load and the generation. The amount of balancing load shedding is used in the evaluation of every solution.

# 5 Genetic Algorithm Application to the Design of the Restoration Plan

## 5.1 Introduction

This chapter covers the design and the implementation of the restoration plan.

The design of the power system restoration plan is characterized by huge solution space. Due to this fact, expert knowledge is used to lead the GA in the solution space. This expert knowledge is derived from the experience of the operators of the Libyan power system in power system restoration. Therefore, a joint usage of GA and ES is utilized to find a restoration plan to reintegrate the collapsed power system. The main goal is to find the shortest path to restore a power system while maintaining the security.

## 5.2 Design of the Restoration Plan

### 5.2.1 Overview

When an electrical power system is interrupted by a major disturbance, it is mandatory to promptly restore the power system to a target power system structure (skeleton network). Then, the goal is to restore the whole power system. The definition of the skeleton network depends on the power system situation following a blackout. However, the skeleton network is always proposed to have as many generators as possible. The restoring of the skeleton network is generally complicated and difficult decision for the power system operator to take. This is due to the fact that



different paths of restoring the skeleton network involve different restoration times. These restoration times could vary from short and acceptable times to unacceptable times. Moreover, the operator has to deal with many power system constraints at one time. Therefore, specific restoration procedures can be very helpful for the operator.

The goal here is to find an optimized restoration path to restore the skeleton network and then to pick up the rest of the loads with minimum restoration time, while maintaining power system security constraints. The problem of optimizing the restoration plan is quite indirect. This is due to the very huge solution space associated with this problem. ES is embedded in the GA to reduce the solution space.

The ES is basically an experience of the power system operators of the Libyan power system in restoring their system. This experience is converted to a set of rules to allow the algorithm to bring back and restore the solution given by the GA.

This use of ES allows the algorithm to rebuild the GA-given solution while having a good observation of the restoration time and power system constraints.

As the GA is able just to provide solutions of generators sequence, the ES is used to start these generators and load them in accordance with load priorities. The use of the ES has added a powerful feature to this optimization algorithm. This feature is that of conforming to power system constraints.

In order to be able to conduct a sophisticated power system restoration study, the following factors are completely considered in this study. The number of factors is limited by the capability of our simulator.

1. Max MW output.
2. Generators capability curves.
3. Start-up and house load requirement.
4. Start-up time.
5. Ramping Rates.
6. Frequency response to sudden load pick up.
7. Reactive power balance
8. Load-generation balance
9. Stability limits
10. High and low voltage levels limits
11. MW and MVAR reserve requirement
12. Line transfer capability
13. The size of load to be picked up.

## 5.2.2 Genetic Algorithm Implementation for the Restoration Plan

### 5.2.2.1 Overview

The structure of the algorithm used in this study is unique in terms of the combination of GA and ES. In General the ES is embedded in GA to enhance the knowledge of GA about the solution. So the GA is able to evaluate the solution accurately. As in figure 5-1, the algorithm starts by producing a random set of solutions where each solution presents a different sequence of control variables. In order for the GA to know about the performance of every solution, the ES is used to build up the solution element by element. The ES is provided by expert knowledge to do that. PSSENG is used to evaluate the performance of every solution in every re-integration step.

Having restored the faulted power system, the GA is able to have considerable knowledge of restoration time, the degree of stability, system voltage profile and system transfer capabilities, etc.

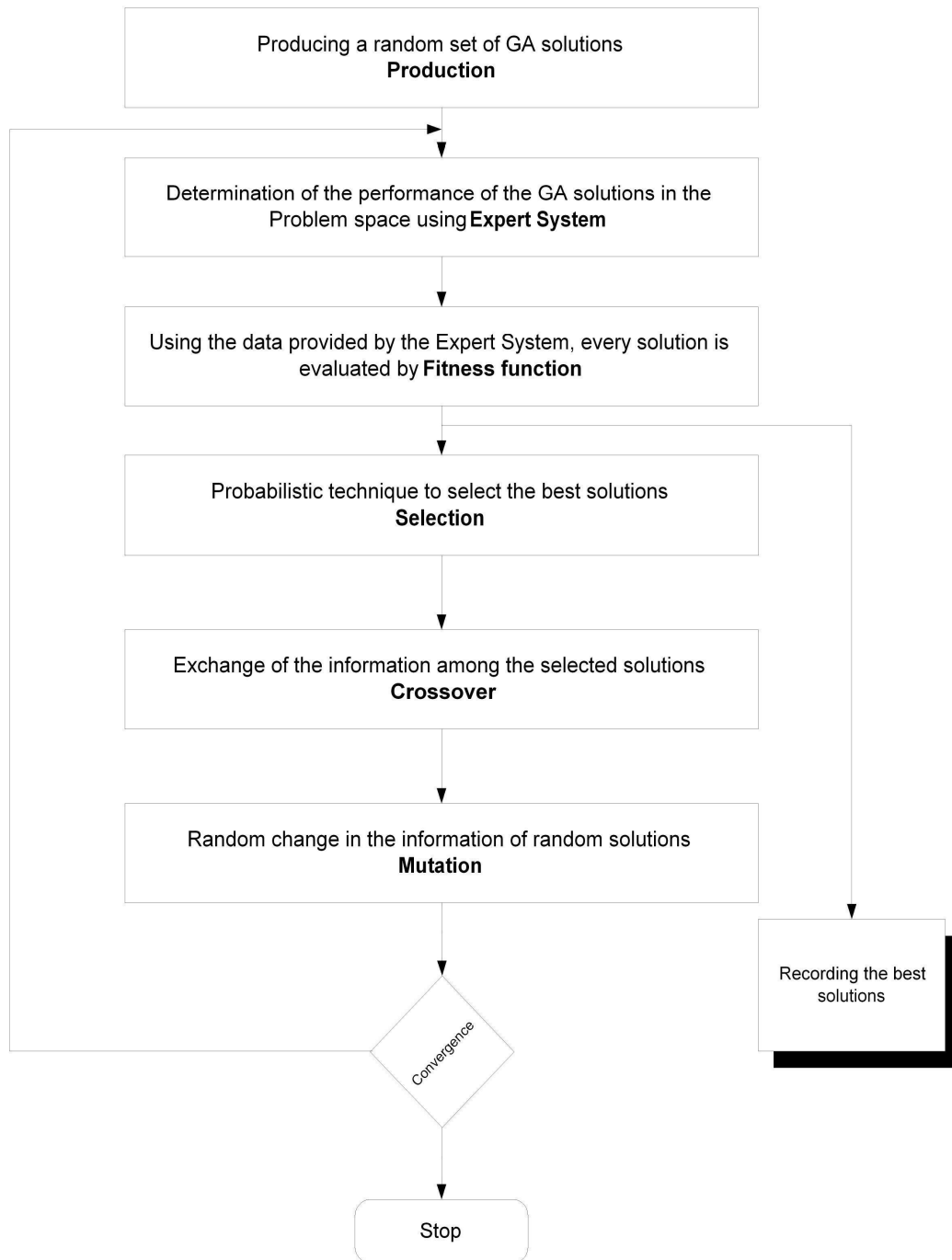


Figure 5-1 Restoration algorithm

Having evaluated the solutions, the best solutions are selected, according to probabilistic technique, to contribute to the production of the next generation. Information exchanged, which is generally called crossover, is applied after the selection stage to produce a new population. In order to guarantee that the solutions are not stuck to local optima, random changes to random chromosomes are applied just after the crossover. Once the new population is produced, the same processes are applied again until the whole populations converge to the best solution.

#### 5.2.2.2 Control Variables and Encoding

The goal of this optimization problem is to find the shortest path to restore the skeleton network and then to pick the loads in accordance with the loads priorities. The skeleton network is always proposed to connect all available generators in the power system. Therefore, for a given power system and operation situation, the ultimate skeleton network looks mainly the same. However, the method used in building the skeleton network could vary from operator to operator. This means that different operators could build and reconnect the generators of a certain skeleton network in different ways, hence different restoration times. As the generators are the main key of the skeleton network, they are considered as the control variable of this optimization problem.

One trial was applied before the achievement of the best encoding scheme of solutions. In that trial, generators and loads were considered in the structure as in figure 5-2. This has greatly enlarged the solution space.

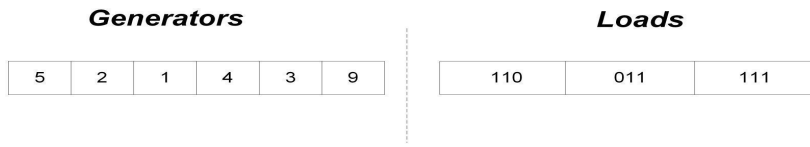


Figure 5-2 Chromosome structure of the first trial

This encoding scheme was adopted before considering the ES. The problem with this structure is that in the majority of the solutions, the loads are not related to the generators because of the geographical distance. Therefore, this encoding scheme is avoided and the expert system is adopted.

The final encoding scheme considered in this part of the research is as following: the sequence of the generators is considered in the structure of the solutions. Every solution is formed from number of segments. Each segment could carry any unique number of any generators. Therefore, the length of the solution is equal to the generators involved in the study. Figure 5-3 presents the structure of the solution.

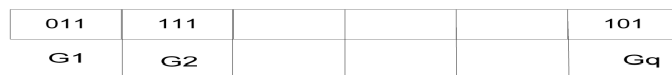


Figure 5-3 Solution structure for restoration problem

Where: G is a generator and q is the number of generators involved in this optimization problem.

### 5.2.2.3 Fitness Function and GA Operators

The fitness function provides an evaluation of the solution performance in the problem domain. In this particular problem, the solutions are graded according to the restoration time and load connected to the skeleton network. Equation 5-1 presents the fitness equation of this particular problem.

$$FF = \frac{1}{RT} + (x * \sum MVI) \quad (5-1)$$

Where RT is the restoration time,  $x$  is the scaling factor and MVI is the connected load. The scaling factor is used to prioritise the loads in accordance with their importance and it varies from 0 to 10.

Roulette wheel section technique, single point crossover, mutation, and elitism are used as the operators in the same way and purpose as the use in the load shedding scheme.

## 5.2.3 ES Implementation for Restoration Algorithm

### 5.2.3.1 Overview

As mentioned before, the ES is used to bring up the faulted system to the target system given by GA. This allows the estimation and observation of the real restoration time, the degree of stability and the observation of the system voltage profile and power to be transferred. Figure 5-4 presents the tools used by the ES:

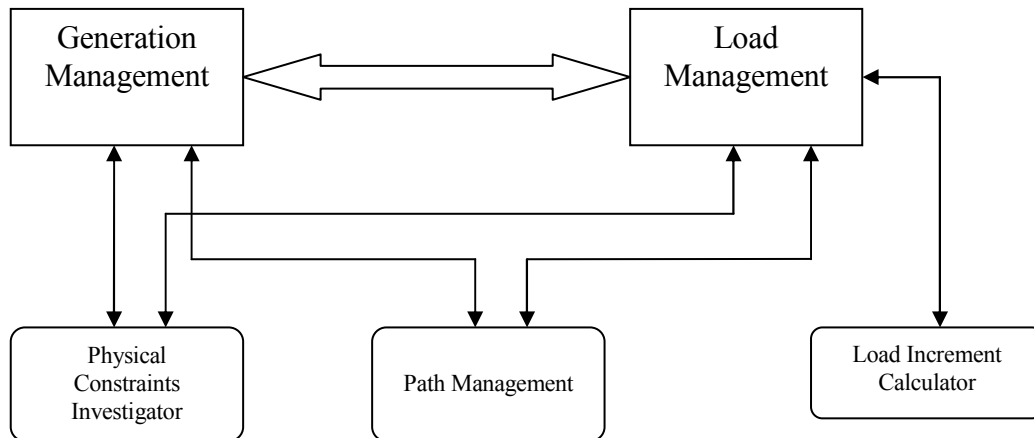


Figure 5-4 Expert system tools

### 5.2.3.2 ES Management

The ES is formed from different management tools. These tools deal with each other in different levels as shown in figure 5-5. These tools are:

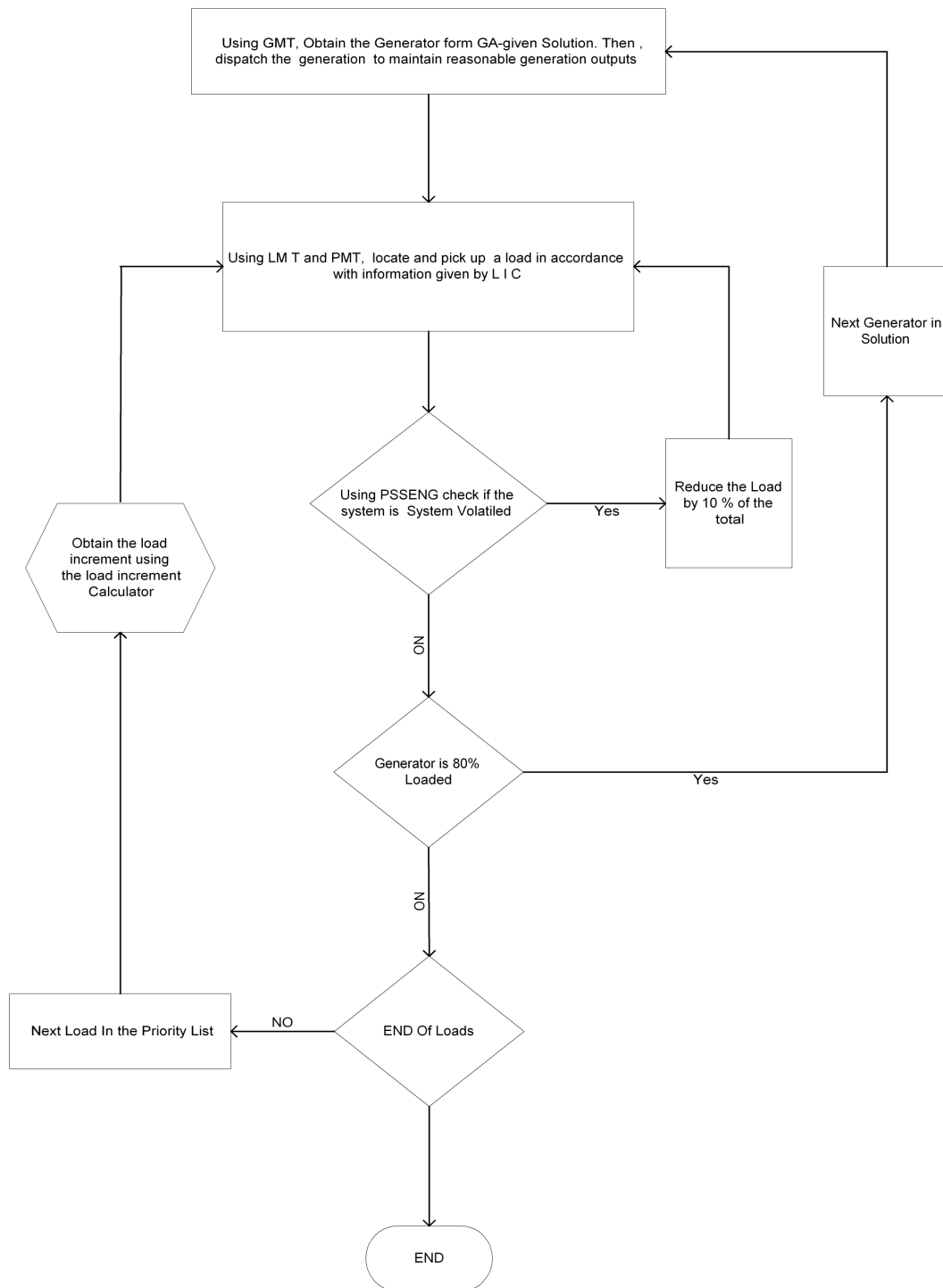


Figure 5-5 Expert system flowchart



1. Generation Management tool (*GMT*)
2. Load Management tool (*LMT*)
3. Load Increment Calculator (*LIC*)
4. Path Management tool (*PMT*)
5. Physical Constraints Investigator (*PCI*)

➤ ***Generation Management Tool (GMT)***

This tool is responsible for connecting and dispatching generators. This tool works in the following sequence:

- The GMT finds out from the GA-given solution which generator is with black start capability. So, the order given by GA is not considered at this stage.
- If the solution has more than one generator with black start capability, the generator with less generation output is considered. This is due to the fact that the generator with less generation capacity can provide power faster than the bigger ones.
- Once the first generator is obtained, the GMT starts loading it to 80% of the total on-line generation. This loading is done, as in figure 5-6, using LMT. This loading level is quite arguable. The main idea is that it does not crank or initiate another generator unless the previously started generator has reached a stable operation or loading level. This loading level varies from one operator to another and from one generator to another. Ideally it should be between 30 to 50% of the total generator capacity, as the generator moves from the manual control mode to the automatic control mode. However, the Libyan power system's operators use a high loading level, 80%. This is due to the fact that this would help in securing the system as the generators

are assured to be far away from the manual control mode even after the process of dispatching.

- If the generator connected is not the first generator, the GMT works as a generation dispatcher to manipulate the generation between the connected generators and not to overload generators.
- The GMT is also responsible for maintaining and spreading a reasonable amount of spinning reserve. This amount is 5% of the total online generation capacity.
- A powerful feature of the GMT is the consideration of the generators ramping in generation connection. The process of generators connections are the most time consuming task and complicated in the restoration process. This process is divided into three phases: time of providing cranking power, preparation and synchronization, and generation- time capability. Figure 5-6 presents the three phases.

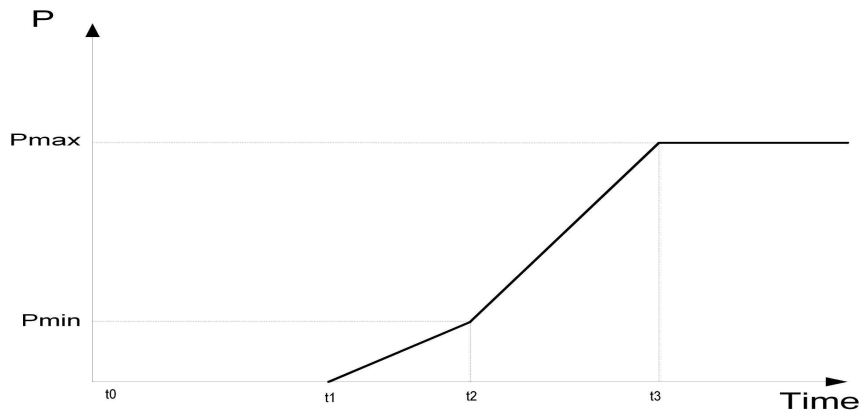


Figure 5-6 Generation ramping curve

$t_0$ : time of unit restart up

$t_1$ : time of synchronization

$t_2 - t_1$ : time to reach minimum load

$t_3 - t_2$ : time to reach maximum load

Therefore, the generators are loaded in accordance with their ramping curves.

➤ **Load Management Tool (LMT)**

The LMT is responsible for preparing a list of load priorities. This list of loads is prepared in accordance with the importance index of every load. The calculation of the importance index in this algorithm is quite indirect. In case of connecting a load, the importance index does not only include the importance of the proposed load, but also the importance of loads that can be connected in the five following connection steps. However, the loads, which can be connected in the following steps, are not contributing in the same degree as the proposed load.

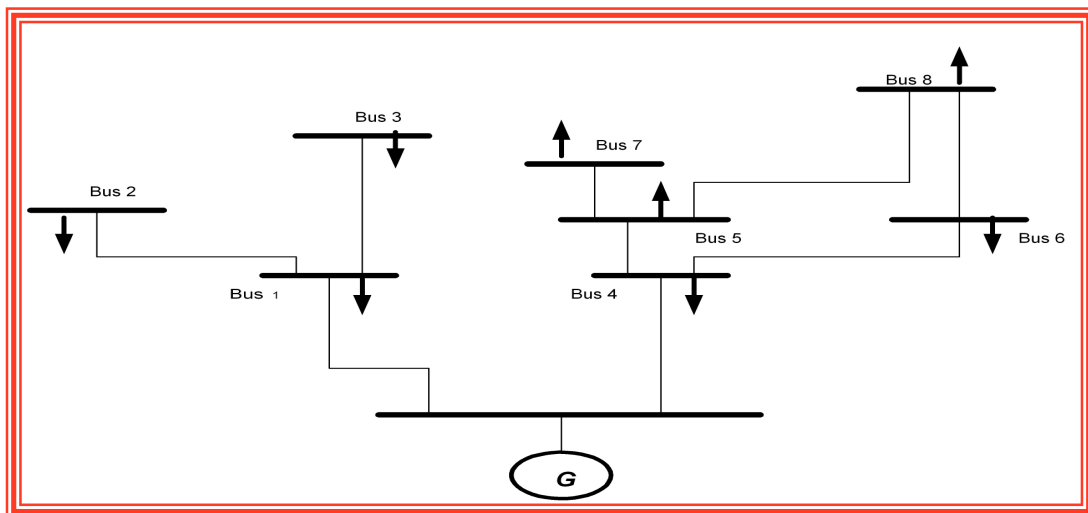


Figure 5-7 Example of importance index

So if the importance index of the load connected to Bus 4, in figure 5-7, is calculated, it is going to include the degree of importance of busbar 5,6,7and 8 . This is done using equation 5-2:

$$IM = \sum_{x=1}^5 \frac{\sum_{i=1}^k D_i MVI_i}{x} \quad (5-2)$$

IM is called the index of importance that denotes the sum of loads which can be connected in a 5 connections step, MVI is the Mega volt-Ampere of the load,  $k$  is the number of loads that can be connected in each connection step,  $i$  is the load number,  $x$  is the connection step and  $D_i$  is the scaling factor. The scaling factor is used to prioritise the loads in accordance to their importance and it varies from 0 to 10.

Once the load is decided and located, the LMT is informed by LIC about the amount of load that can be picked by the connected generators without violating the power system constraints. Also, important information about the lines transfer capability is passed into LMT to help not violate these limits.

This equation is applied every five connection steps. Otherwise, it might be unstable by swinging between two or three areas in the network as their degree of importance swings. Therefore, the importance index is more about area rather than a solo load.

The time tolerance between the connections of two loads is 60 seconds. This is done to provide enough time for the electromechanical transient to disappear.

➤ ***Load Increment Calculator (LIC)***

The Load increment during restoration is an issue. This is due to the difficulty of finding the proper size for the load to be picked up as the

restoration process goes forward. Collecting a large load increment would be helpful in shortening the restoration time, but it might lead to an unacceptable frequency decline which might lead to protection system actuation or system instability. However, collecting small load increments will definitely increase the restoration time.

The following section describes the method used to calculate the load increment in this algorithm. This method was presented in [128].

Following load pick up, it is vital that the system does not fall below a normal operating frequency of the system. Before the moment of load pick up, the generators are ramped up to increase the system frequency to an allowable upper limit. The algorithm uses the following equations to calculate the maximum load that can be picked up without violating the normal frequency.

Power balance equation for a power system can be written as:

$$\frac{2H}{f_o} \frac{d}{dt}(\Delta f) = (\Delta P_G - \Delta P_D) \quad (5-3)$$

Where: H is the system inertia, P<sub>G</sub> is system generation, P<sub>D</sub> is system demand, f<sub>o</sub> is normal operating frequency.

During the restoration the output of generators is function of the ramping rates so the change in generator output can be presented as following:

$$\Delta P_G = R_m t \quad (5-4)$$

Where t represents the time for ramping in minutes and R<sub>m</sub> is the ramping rate of the generator(s).

Practically, the system load is also a frequency-dependent variable so that the system load varies according to the change in system frequency. Considering this fact, the system load can be expressed as follows:

$$P_{DT} = P_{DT_0} (1 + d\Delta f) \quad (5-5)$$

Where  $P_{DT}$  is the total system load at system frequency  $f=f_0+\Delta f$ ,  $P_{DT_0}$  is the total load at system frequency  $f_0$ ,  $\Delta f$  is the change in the system frequency and  $d$  is the coefficient that relates the load at any frequency to the load at nominal frequency.

So that the equation number 5-3 can be rewritten as:

$$\frac{d}{dt} \Delta f + a\Delta f = bt, \quad a = \frac{P_{DT_0} df_0}{2H}, \quad b = \frac{R_m df_0}{2H} \quad (5-6)$$

The solution of this equation is:

$$\Delta f_{up} = \frac{R_m}{P_{DT_0} d} t - \frac{2R_m H}{P_{DT_0}^2 d^2 f_0} (1 - e^{-\frac{P_{DT_0} df_0}{2H} t}) \quad (5-7)$$

Due to the fact that the ramping of the generator will continue even after the load is picked up, the system load pick up ability can be presented as following:

$$P_{L(pick-up)} = R_m t_{up} + R_m t_{down} \quad (5-8)$$

Assuming that  $t_{up}=t_{down}$ , the equation can be rewritten as:

$$P_{L(\text{pick-up})} = 2R_m t_{up} \quad (5-9)$$

So, the amount of load that can be picked up should be less than  $P_{l(\text{pick-up})}$ . In order to obtain the value of  $P_{l(\text{pick-up})}$  in every picking up step, the  $t_{up}$  is determined from equation 5-7 using an iterative method.

➤ **Path Management (PM)**

In every step of connecting a generator or load, an optimized path algorithm is used to find the shortest path.

Moreover PM used to check the loading limits of every line proposed for connection and to inform LMT of the maximum transfer capacity.

➤ **Physical Constraints Investigator (PCI)**

The role of the physical constraints investigator is to check whether the following factors are violated or not.

1. Lines transfer capability
2. Voltage profile
3. Stability limits
4. Frequency response

If any constraints are violated after reconnection of a certain load, the amount of load picked up would be reduced by 10% in every attempt. Every load would have 10 trials to be picked up. If in the 10 trials the constraints are violated, the load number 2 in the load in the priority list prepared by LMT is picked.

### 5.3 Specification of the GA operators and the Fitness Function

#### ➤ GA Operators

It is very difficult to find the proper settings for the GA operators. The operators of GA are strongly influenced by the nature of the problem and the size of the solution space linked to the problem. So, a problem with huge solution space might require huge population and a large number of generations. This kind of problem also requires a high mutation rate to discover as many segments as possible. The size of the solution should roughly be larger than the size of the expected solution.

During the process of choosing the GA operators, many trials were conducted in order to find the appropriate and the best setting for them. These trials include choosing a small number of populations for the load shedding algorithm. This has made the load shedding algorithm unable to find the best solution as in figure 5-8.

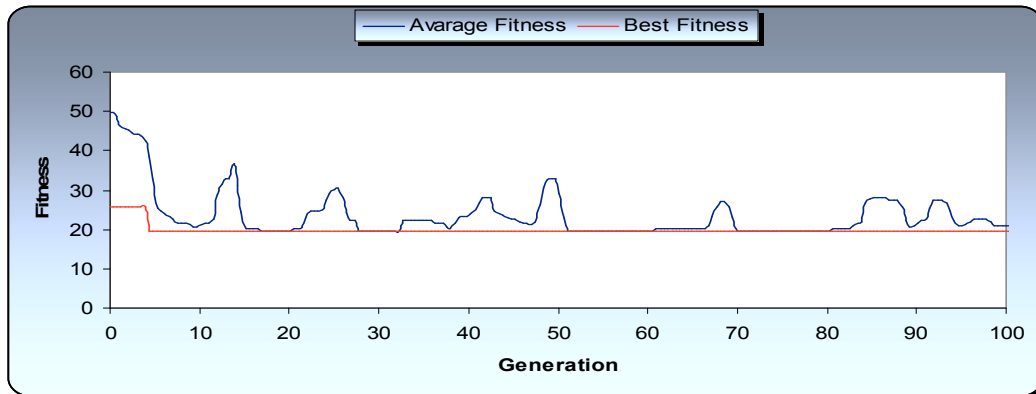


Figure 5-8 Unsuccessful trial of the load shedding algorithm

Another failure was in choosing small mutation rates for the load shedding scheme as in figure 5-9.



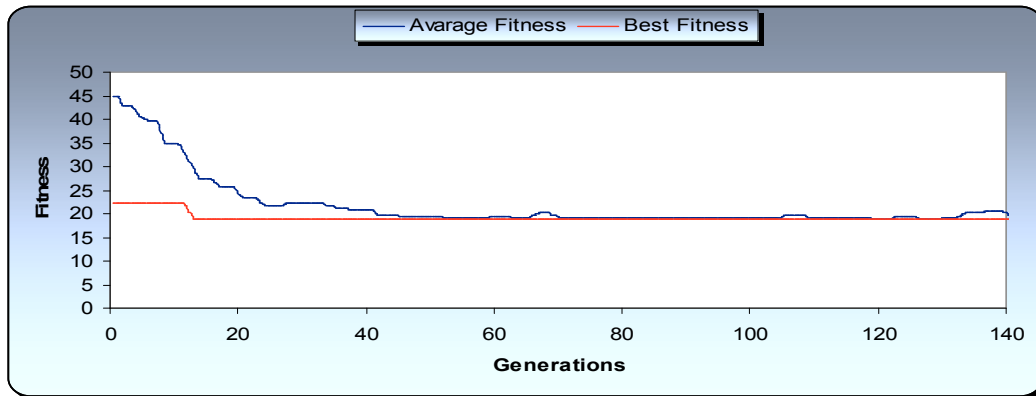


Figure 5-9 Unsuccessful trial of the islanding algorithm

Also another failure was recorded when the elitism was ignored. This has worsened the overall convergence of the solutions.

Following many trials and experiments, general experience was formed about the settings of the GA operators. This includes the recognition of the complexity of the studied problem which requires the consideration of huge population, high number of generation, typical mutation rate and elitism.

Therefore, for the load shedding algorithm, the size of population is set to 100 solutions and the number of generations to 100. The mutation rate is set to 5%. The size of chromosome is equal to number of loads involved in the process. This number is set by the localization algorithm.

Regarding the islanding part, and in a similar way, the size of population is set to 150 solutions and the number of generations to 100. The mutation rate is set to 5%. The structure of the solution used in this problem is formed from two parts.

Regarding the restoration algorithm, the GA operators were selected as follows: number of generations is equal to 100, size of chromosomes is equal to 31, number of chromosomes is equal to 200, and mutation rate is equal to 5%.

➤ ***Fitness Function***

It is recognized that adjustment of the multi objective fitness function for GAs is a complicated task since it requires compromise to obtain the middle ground between the objectives.

The fitness functions used in the defence plan algorithms are very similar since both of them are looking for solutions with the largest stable area. Regarding the fitness functions (4-1) ,(4-2) and (4-3), the main goal is to initially classify the solution into four classes; well damped stable, poorly damped stable, oscillatory unstable, and transiently unstable. Therefore, the part of the fitness function regarding this classification (SC) is the dominating part. Later on, the amount of tripped power (MVI) linked to each solution is considered as the second dominating objective. This factor is multiplied by 10 to produce a greater effect on the fitness function. Finally, the stability indices are considered to make the algorithms able to classify between the stable solution and unstable solutions.

The adjustment of the fitness function was initially carried out for one contingency load shedding scheme [126]. This is done to avoid the complexity of the encoding scheme. Following many trials, the parameters of the fitness function were chosen as follows:

SC represents the stability class and is equal to 30 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable.  $N_L$  is the number of predetermined shedding loads.  $\Sigma MVI$  is the summation of the amount of load reductions. TDR is the time decay ratio and SI is the severity index.

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## 6 Results and Discussions

### 6.1 Introduction

This chapter presents the simulation results obtained by the algorithms for the solution to optimized security scheme problem. For the purpose of showing the results, every part of the algorithm is applied separately. Therefore, the results of the defence plan algorithm are presented in section 6.3, while the results of the restoration algorithm are shown in section 6.4. The Libyan power system is used in this study as a real world case study.

In order to show the validity of the ODP, a comparative study is presented. This comparison is between the ODP and the CDP of the Libyan power system. Two severe contingencies are chosen to conduct this comparison. The first one is a severe load shedding contingency and the second one is a severe islanding contingency. A solid analysis and discussion of the results of the comparative case is presented. This is followed by a discussion of the generic feature of the ODP.

Another comparative study is presented to show the validity of the optimized restoration plan. For this purpose, a pure ES is used for comparison and for purposes of simplicity; IEEE 39-Network is used. The optimized restoration algorithm was also used to restore the western part of the Libyan power system. Finally, a discussion about these results is presented.

### 6.2 Libyan Network (Case Study)

One objective of this research is to apply the power system security algorithms to the Libyan power system. All data of the Libyan power system, including the static and the dynamic data, can be found on the appendix I.II.

### 6.2.1 Overview

The power system in Libya consists of four geographically well-dispersed, totally interconnected major areas systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and a few steam units with some diesel generators located in rural areas of the Libyan desert.

The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length of 442 km, a high voltage transmission level of 220 kV, and a total circuit length of 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV; with a total circuit length of 6,237 km. The total generation capacity of the Libyan power system is about 3880MW and the size of largest generation unit is about 120MW. Geographically, the Libyan network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation, in the south. For study purposes, the Libyan power system is geographically divided into seven electrical areas. These areas are shown in figure 6-1.

### 6.2.2 Interconnection Lines

Currently, the Libyan power system is interconnected to the Egyptian power system through 220kV transmission lines. The maximum power transfer allowed toward both sides is 120 MW. The Libyan power system is also proposed to interconnecting to the Tunisian power system through 220kV with maximum power transfer of 150 MW for both sides. This proposed interconnection is considered in this study. Generally the Libyan power system is formed from two big parts, the west part, and the east part. They are connected through a 220 kV transmission line with maximum power transfer of 65 MW.

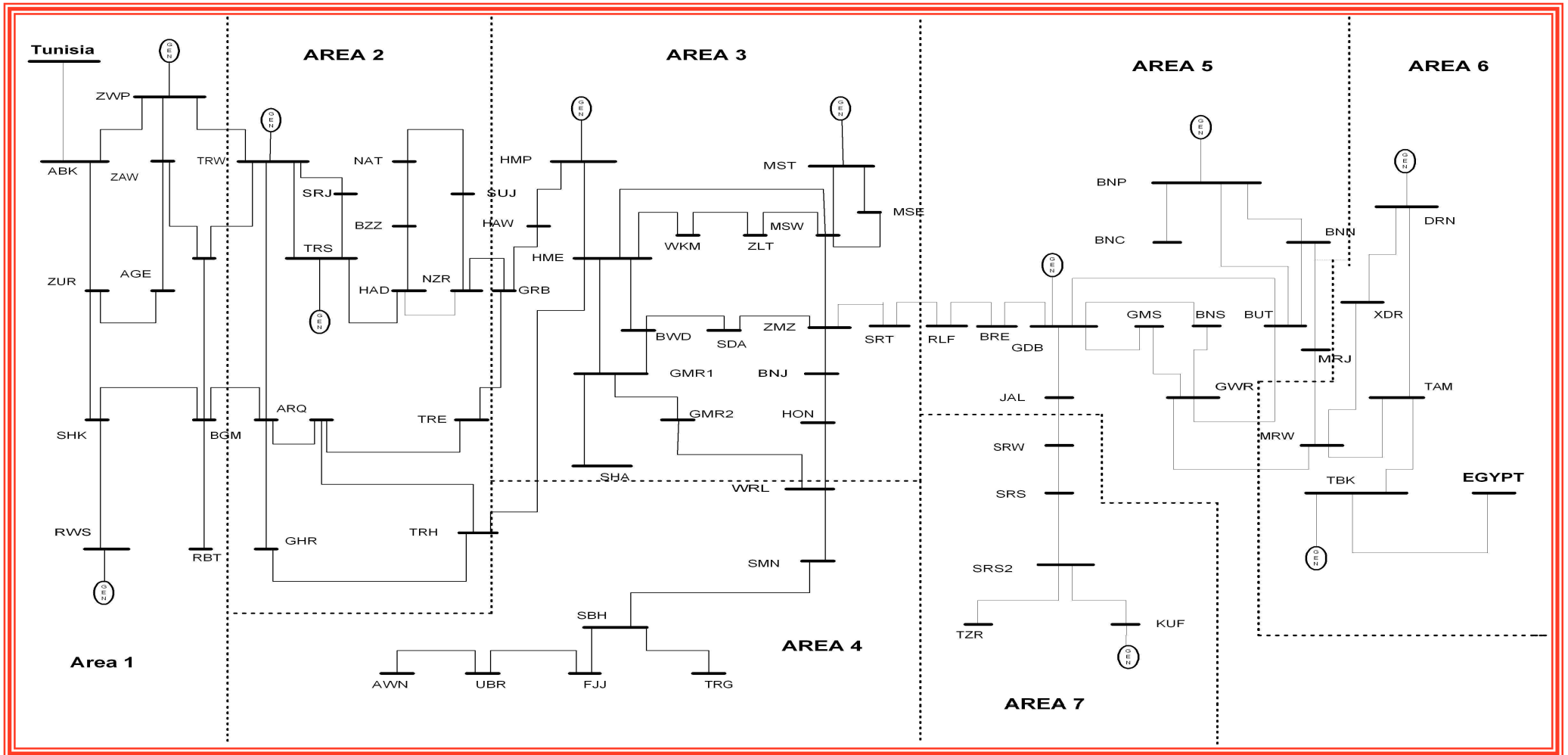


Figure 6-1 Libyan power system

### 6.2.3 Protection Systems

As with any power system, the Libyan power system is equipped with the following protection systems:

- Distance Protections.
- Under voltage protections for interconnection lines.
- Over voltage protections for interconnection lines.
- Under frequency protections for interconnection lines.
- Over frequency protections for generation units.
- Under frequency protections for generation units.
- Under voltage protections for generation units.
- Loss of excitation protection for generation units.

The protection systems adopted in this study are reported in the appendix I.II.III.

### 6.2.4 Defence Schemes

#### 6.2.4.1 Load Shedding Scheme

Based on the Libyan power system topology, the Libyan network was considered as seven areas. Each area has its own load shedding scheme as can be seen in table 6-1. For coordination reasons, General Electricity Company of Libya recommended 49.4, 49.2, 49.0, 48.8, 48.6 Hz as frequency thresholds for load shedding. However, the choice of the first and last threshold is based on the following points.

The first threshold should be fixed so as to avoid load shedding for electromechanical oscillations, even of large amplitude, in case of interconnected systems still being integrated. With the amount of spinning reserve being fixed, it is a good rule to choose the first threshold that is

low enough to allow the regulating energy to recover frequency drops with no load shedding. Therefore, in order to get the reasonable threshold values, the following values should be determined: maximum frequency deviation recovered by spinning reserve, maximum frequency deviation due to electromechanical oscillations and minimum frequency value. The minimum frequency threshold has to be fixed with reference to the under-frequency protection of units.

In addition to the load shedding scheme, further load is shed by line trips for under-frequency protections intervention. Table 6-1 reports the amount of load shed in percentage to the total load and figure 6-2 shows the areas that were shed by line trips protection.

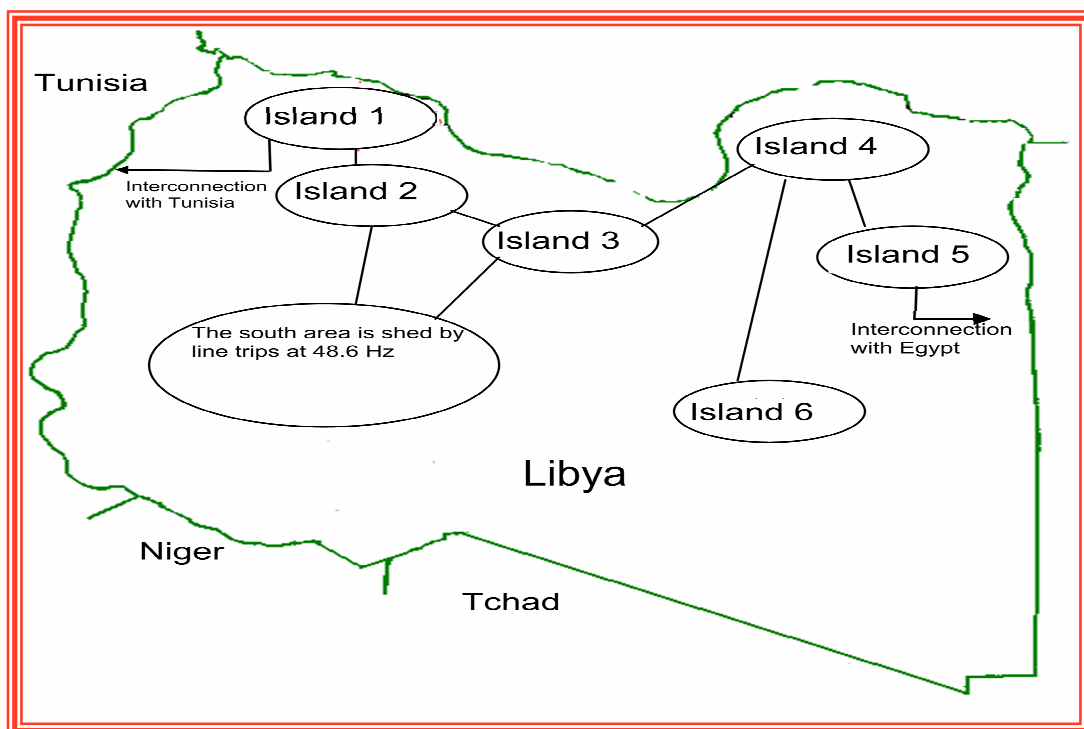


Figure 6-2 Current islanding scheme

AREA	LOAD SHEDDING FOR EACH THRESHOLD					
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	Total
Area 1	3.30%	3.3%	0.00%	0.4%	0.0%	6.9%
Area 2	2.4%	1.8%	4.7%	3.9%	1.3%	14.1%
Area 3	1.60%	1.20%	1.2%	2.30%	1.9%	8.2%
Area 4	0.4%	0.0%	2.8%	1.7%	6.60%	11.6%
Area 5	2.9%	1.5%	2.4%	0.5%	2.1%	9.4%
Area 6	0.00%	0.9%	0.00%	1.6%	1.30%	3.8%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	10.6%	5.6%	11.1%	10.7%	13.2%	54.3%

Table 6-1 Current load shedding scheme

#### 6.2.4.2 Islanding Scheme

The adopted technique of splitting the system into islands for a frequency below the last load shedding stage presents pros and cons. One advantage is to increase the probability of survival of some islanded power plants, with the possibility of accelerating the restoration procedure. One drawback is the diminution of the probabilities of survival of the small areas, along with instability of the units in small areas and a greater difficulty in balancing load and generation. Based on the experience of electrical Engineers from GECOL and the criteria of the designed islanding scheme, the Libyan power system was islanded into six islands as shown in figure 6-2.

#### 6.2.5 Operation Conditions

In order to be able to represent severe transient phenomena that could lead to a full system collapse, the 2005 Libyan network with interconnection with Egypt and Tunisia, and the peak load situation with it has been



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considered. These operation conditions are highly recommend by GECOL to be used in this study. The main figures of the operation state are:

Peak Load =3760 MW

Spinning Reserve=120 MW

Power Transfer from West to East= 60 MW

Power Transfer from Libya to Tunisia =0 MW

Power Transfer from Egypt to Libya =0 MW

## 6.3 Case Study for the Defence Plan Algorithm (Libyan System)

### 6.3.1 Overview

In this case study, the defence plan algorithm is applied to the Libyan system. The adopted conditions and the operation situation of the Libyan power system used in this case are all described in section 6.2. The load flow and the dynamic data used in this study are attached to this thesis in appendix I.II.I and I.II.II respectively.

As the defence plan algorithm is formed from two main algorithms (load shedding and islanding algorithm), both of them are applied separately.

### 6.3.2 *Algorithm Output*

Figures 6-3 and 6-4 show the average fitness of the solutions during the GA process in both parts of algorithm (load shedding and islanding parts). It can be noticed that the GA obtains the best solution for the load shedding problem after generation 45. However, the process of finding the best solution for the islanding scheme takes more generations, which amounts to 84. In terms of real time, the load shedding part took about 203.34 hours, while the islanding algorithm took 295.2 hours. This was due to the large size of the Libyan power system, hence, the solution space. The case studies were performed on a computational platform with 2.8 GHz processor and Linux operating system.

The ultimate solution for the load shedding scheme is reported in Table 6-2. This solution is obtained by the load shedding algorithm. However, the amount of load shedding obtained by the islanding algorithm is added to the last stage of frequency threshold. This is done to cope with real situation of the Libyan power system. The complete solution for the load shedding and islanding schemes are presented in table 6-2, 6-3, 6-4, 6-5, 6-6 and 6-7.

It is interesting to note that the load shedding scheme obtained by GA is similar to the current one in some senses. However, some extra load shedding is required in the new scheme in areas 1, 2 and 4. This makes the total load shedding in the network 57.22%, which is higher than that of the current scheme.

It is worthy to note that the optimized solution shares with the current scheme the necessity of tripping the majority of area 4 by line trips load shedding at 48.6Hz. Also, it can be noted from Table 6-2 that an additional amount of load shedding is introduced in the last stage of load shedding. This additional amount of load shedding plays an important role in saving the system in some critical situations, since it is vital in preparing the network for islanding.

Load Code	Load Shedding for Area 1					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
AZH1	22.5	9.7	0	10	0	42.2
AZH2	22.5	9.7	0	10	0	42.2
BGN1	9	14	0	2	0	25
BGN2	9	14	0	2	0	25
AGL1	6.5	29	0	8	5	48.5
AGL2	6.5	29	0	8	5	48.5
ZAW1	23	17.8	0	10	9	59.8
ZAW2	23	17.8	0	10	9	59.8
ZUR1	17	5	0	6.9	5	33.9

Table 6-2 Load shedding solution in area 1

Load Code	Load Shedding for Area 2					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
GHR1	0	4.5	0	3	25	32.5
GHR2	0	4.5	0	3	25	32.5
HKD1	0	1	15	20	0	36
HKD2	0	1	15.4	20	0	36.4
HRA1	8	7	0	3	0	18
HRA2	8	7	0	3	0	18
NZR1	0	2	34	5	12	53
NZR2	0	2	34	5	12	53
SRJ1	0	4	10	33.2	0	47.2
SRJ2	0	4	10	33.2	0	47.2
TRE1	0	6	6	20	9	41
TRE2	0	6	6	20	9	41
TRH1	7.5	7.2	0	0	2.5	17.2
TRH2	7.5	7.2	0	0	2.5	17.2
TRS1	7.5	17	0	0	0	24.5
TRS2	7.5	17	0	0	0	24.5
TRW1	0	0	6.6	5	8.5	20.1
TRW2	0	0	6.6	5	8.5	20.1
WMG1	14.2	0	5.7	5.4	0	25.3
WMG2	14.2	0	5.7	5.4	0	25.3

Table 6-3 Load shedding solution for area 2

Load Code	Load Shedding for Area 3					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
GAR1	2	6.9	0	2	7	17.9
GAR2	2	6.9	0	2	7	17.9
MSE1	10	10	0	7.2	3	35.8
MSE2	10	10	0	7.2	3	30.2
MST1	2	0	11.5	18	35	66.5
MST2	2	0	11.5	18	35	96.7
MSW1	6	1	1	0	2.5	10.5
MSW2	6	1	1	0	2.5	10.5
SRT1	0	0	0	19	4.5	21
SRT2	0	0	0	19	4.5	23.5
ZLT1	4.6	2	6	0	4	16.6
ZLT2	4.6	2	6	0	4	40.1

Table 6-4 Load shedding solution for area 3

Load Code	Load Shedding for Area 4					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
SBH1	1	0	11	3	0	15
SBH2	1	0	11	3	0	15
SMN1	3.1	0	0.9	4	0	8
SMN2	3.1	0	0.9	4	0	8
WRL1	2	0	0	0	0	2
WRL2	2	0	0	0	0	10
TRG	0	0	42.5	0	0	42.5
ELFJij	0	0	0	63	0	63
GMR1	0	0	0	0	100	100
BNJM	0	0	0	0	148	148
SHT	0	0	27	0	0	27

Table 6-5 Load shedding solution for area 4

Load Code	Load Shedding for Area 5					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
BNN1	4	0	2	0	6	12
BNN2	4	0	2	0	6	12
BNP1	2	3.2	3	0	0	8.2
BNB2	2	3.2	3	0	0	8.2
BNS1	0	13.2	5	0	15	33.2
BNS2	0	13.2	5	0	15	33.2
BUT1	28.5	2	4.1	0	22.5	57.1
BUT2	28.5	2	4.1	0	22.5	57.1
GWR1	4	1	9.4	0	10	24.4
GWR2	4	1	9.4	0	10	24.4
MRJ1	1	0	17.5	0	5	23.5
MRJ2	1	0	17.5	0	5	23.5

Table 6-6 Load shedding solution for area 5

Load Code	Load Shedding for Area 6					
	49.4Hz (MW)	49.2Hz (MW)	49Hz (MW)	48.8Hz (MW)	48.6Hz (MW)	Total (MW)
DRN1	0	0	0	2.8	19.1	21.9
DRN2	0	0	0	2.8	19.1	21.9
MRW1	0	0	0	0	2	2
MRW2	0	0	0	0	2	2
TAM1	0	0	0	0	0.7	0.7
TAM2	0	0	0	0	0.7	0
TBK1	0	0	0	0	13.9	13.9
TBK2	0	0	0	0	13.9	13.9
XRD1	0	18	0	16.5	7	41.5
XRD2	0	18	0	16.5	7	41.5

Table 6-7 Load shedding solution for area 6

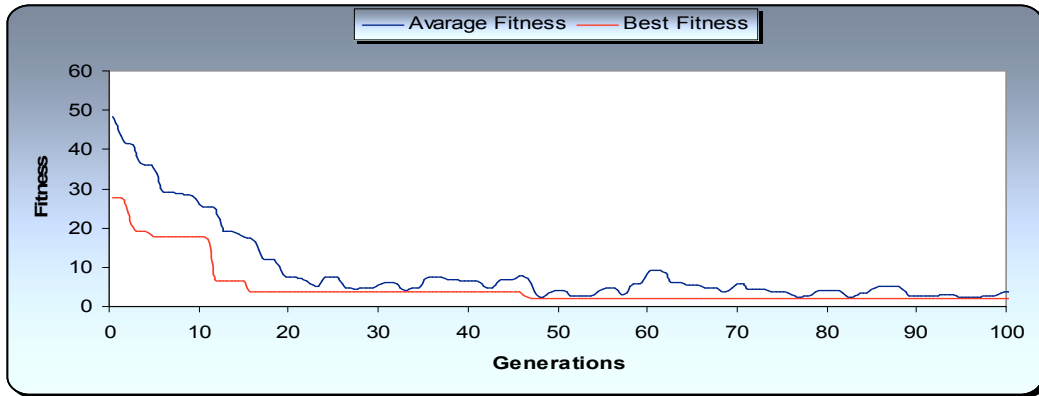


Figure 6-3 GA Performance of the load shedding algorithm

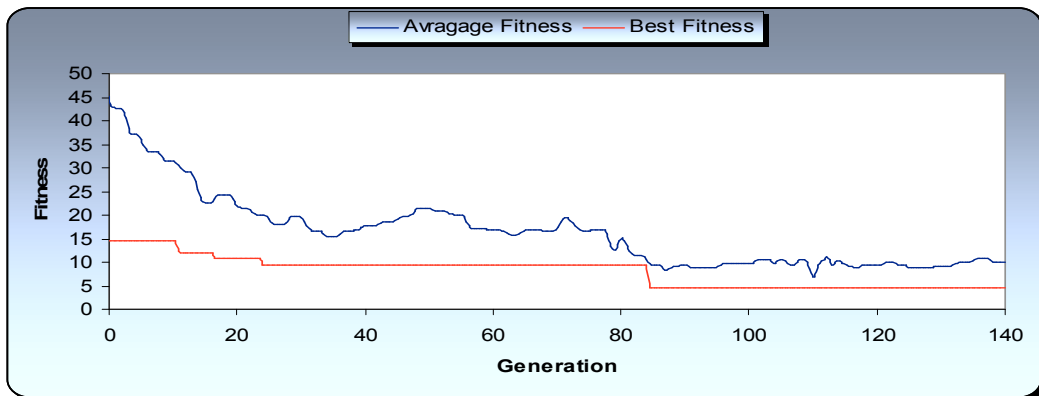


Figure 6-4 GA performance for islanding algorithm

AREA	LOAD SHEDDING FOR EACH THRESHOLD					
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	Total
Area 1	4.20%	3.90%	0.00%	1.90%	0.00%	10.00%
Area 2	1.48%	2.44%	3.10%	4.90%	3.10%	15.02%
Area 3	1.50%	1.00%	0.90%	2.50%	3.10%	9.00%
Area 4	0.32%	0.08%	2.50%	1.10%	7.50%	11.50%
Area 5	2.30%	0.90%	2.10%	0.20%	3.10%	8.60%
Area 6	0.00%	1.20%	0.00%	0.30%	1.40%	2.90%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	9.80%	9.52%	8.60%	11.10%	18.20%	57.22%

Table 6-8 Optimized load shedding scheme

Referring to figure 6-5, in spite of the fact that the GA had a completely free hand to choose the cutting point to form the islands, the GA obtained the same island formation as the CDP. The only change is in combining island 2 and island 3. This happened without any kind of solution seeding. This proves the capability and robustness of the algorithm in obtaining and outperforming the expert knowledge.

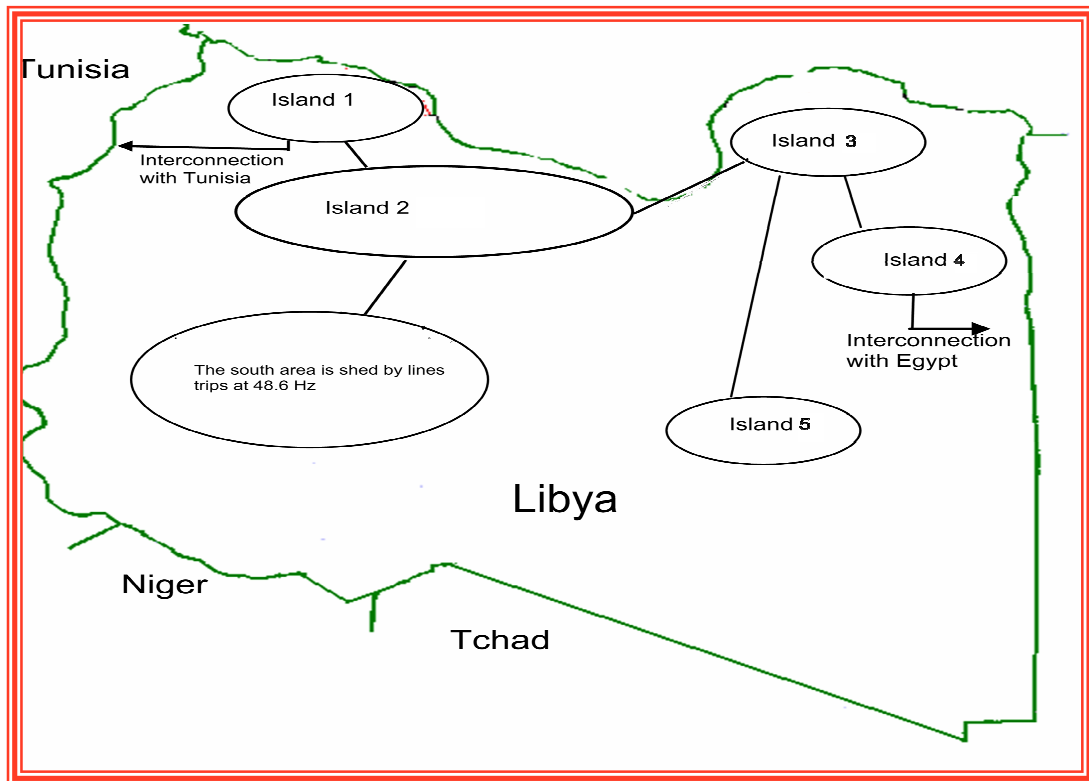


Figure 6-5 Optimized islanding scheme

### 6.3.3 Comparative Case Study for the Libyan Network (ODP Vs CDP)

In order to show the validity of the ODP, it is compared with the CDP for two severe contingencies. These two severe contingencies were recommended by GECOL. This is due to the fact that the CDP badly performs when they are applied. The first contingency is chosen to test the load shedding scheme, as it causes a severe frequency decline. This contingency is called *a severe load shedding contingency*. The second one, which is called *a severe islanding contingency*, is chosen to push the frequency to the islanding stage.



The comparison is conducted in terms of the dynamic performance of the power system against each contingency. Importantly, the amount of preserved loads is taken into this comparison.

### 6.3.3.1 Severe Load Shedding Contingency

*At 1 second:* The incident is initiated by a permanent fault in Tripoli west power plant (TRW). Due to protection system failure, the fault is cleared in the second zone. This causes the loss of five generation units ( $G_{1\text{TRW}}$ ,  $G_{2\text{TRW}}$ ,  $G_{3\text{TRW}}$ ,  $G_{4\text{TRW}}$  and  $G_{5\text{TRW}}$ ). The consequent loss of generation is equal to 207.4 MW. Unit  $G_{6\text{TRW}}$  remains in operation delivering 30 MW. *At 1.80 second,* three units are lost in Tripoli South (TRS) ( $G_{2\text{TRS}}$ ,  $G_{4\text{TRS}}$  and  $G_{5\text{TRS}}$ ). This causes the system to lose 197.61 MW of generation.  $G_{1\text{TRS}}$  and  $G_{3\text{TRS}}$  remain in operation delivering 160 MW. *At 7.2 seconds,* the interconnection lines between Libya and Tunisia are tripped. This was due to a fast drop of the voltage between the nodes connecting the two networks. This can be seen in figures 6-8 and 6-10. Figure 6-6 shows that *at 8.4 second,* The Libyan system is separated into two parts, the east and the west. This is due to the interconnecting line tripping between the two networks. The tripping is because of under voltage protections.

The maximum power flow from the east to the west of Libya is 371 MW prior to system separation. Also, the maximum power flow from Egypt to Libya is 337 MW before tripping the circuit the east to the west of Libya.

At this moment the Libyan System is partitioned into two parts and disconnected from the neighbouring networks. Having the system separated, the Libyan system with ODP and with the CDP performs in different ways.

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**The Libyan System with the current defence plan**

The system separation causes load- generation mismatch in the west part of the network. This mismatch causes the frequency to go through three frequency load shedding thresholds which are 49.4, 49.2 and 49 Hz activating load shedding scheme. The amount of load shedding is reported on Table 6-3.

*At 16.10 second*, Two units in Zawia power plant (ZAP) ( $G_{2ZAP}$  and  $G_{3ZAP}$ ) are lost. The consequent loss of generation is 281 MW.

*At 16.7 second*, a loss of another unit in Zawia ( $G_{1ZAP}$ ) is reported. The consequent loss of generation is equal to 148 MW. The remaining units on the station are  $G_{4ZAP}$  and  $G_{5ZAP}$  delivering 280 MW.

Due to the loss of excitation protections, *at 17.0 second*, sequential loss of four ( $G_{6HMP}$ ,  $G_{5HMP}$ ,  $G_{7HMP}$  and  $G_{8HMP}$ ) generators is reported in Khoms plant (HMP), causing the system to lose 328.8 MW. This can be seen in figures 6-6 and 6-8. Again this generation loss causes the load generation mismatch making the frequency go below 48.6 Hz. This activated the load shedding scheme in two stages. The amount of load shedding is reported in Table 6-3.

The East part of the system does not suffer any load generation mismatch. So, the system is able to survive separated.

**The Libyan System with the optimized defence plan**

Figures 6-7 and 6-9 show that the system separation causes load-generation mismatch in the west part of the network. This mismatch causes the frequency to go through two frequency load shedding thresholds which are 49.4 and 49.2 Hz, activating the load shedding

scheme. The amount of load shedding was not enough to stop the frequency decay. This makes the system go below the third threshold, causing the system to lose more loads in the early stage. For the same reason as with the previous scheme, four generators tripped at Khoms (KHP) plant and Zawia (ZAP) at 16.0s.

Again the East part of the system does not suffer any load generation mismatch. So, the system is able to survive separated.

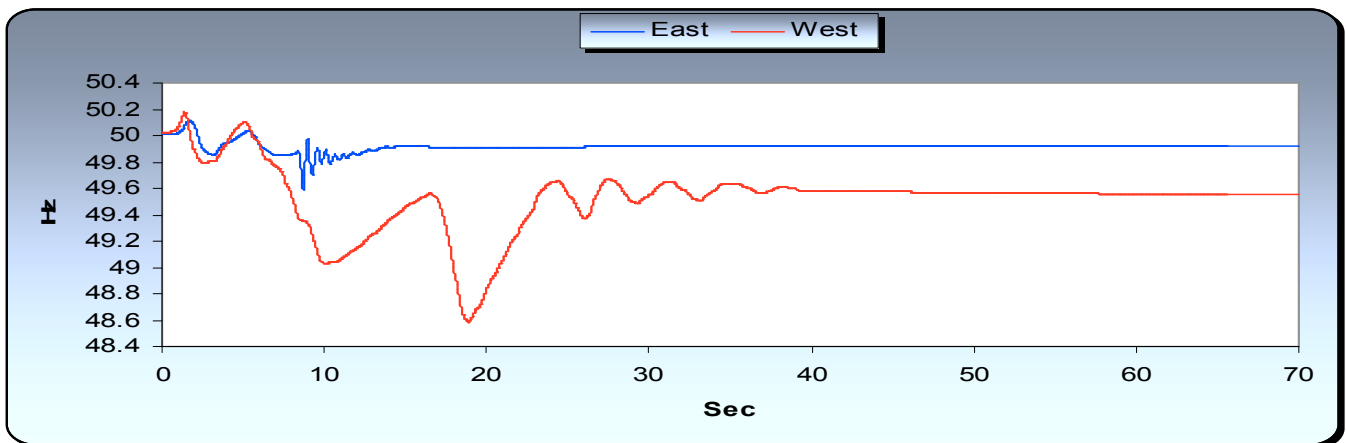


Figure 6-6 System frequency with CDP

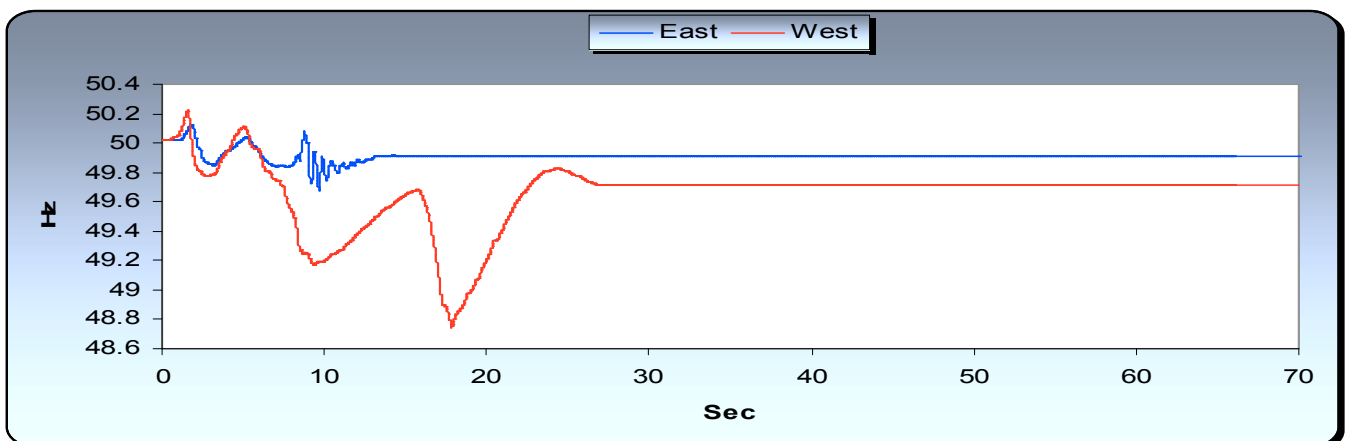


Figure 6-7 System frequency with ODP

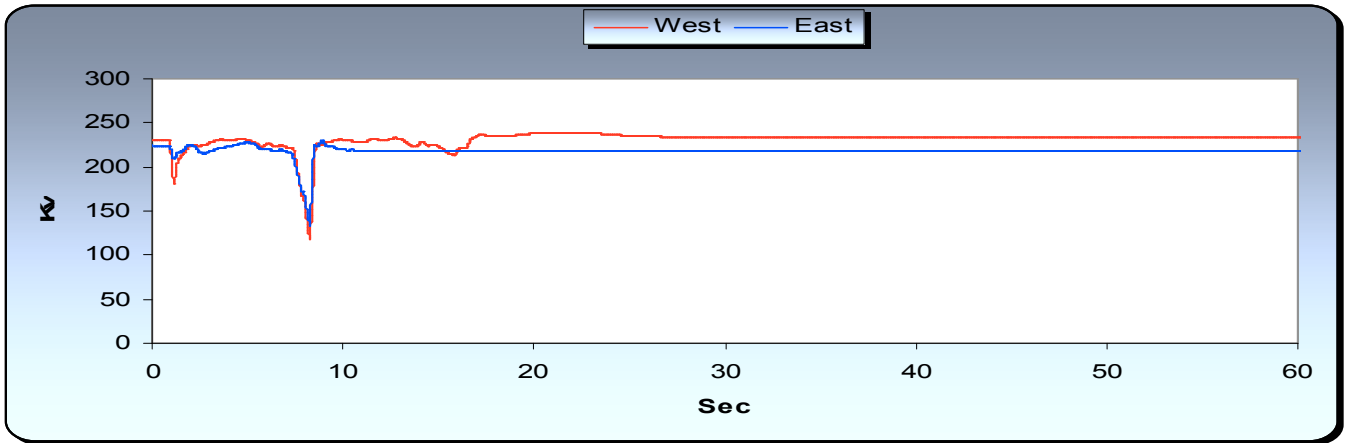


Figure 6-8 System voltage with CDP

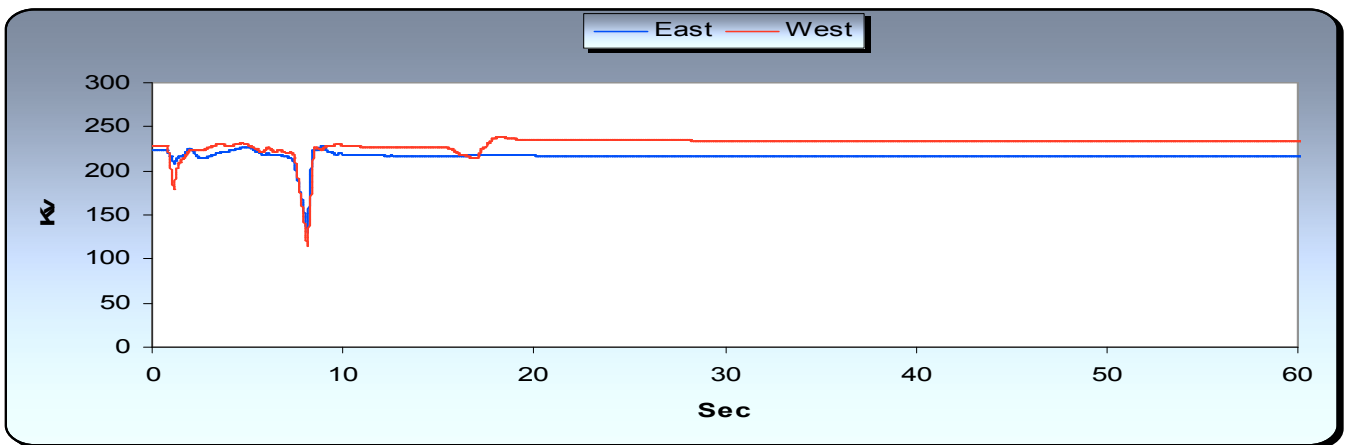


Figure 6-9 System voltage with ODP

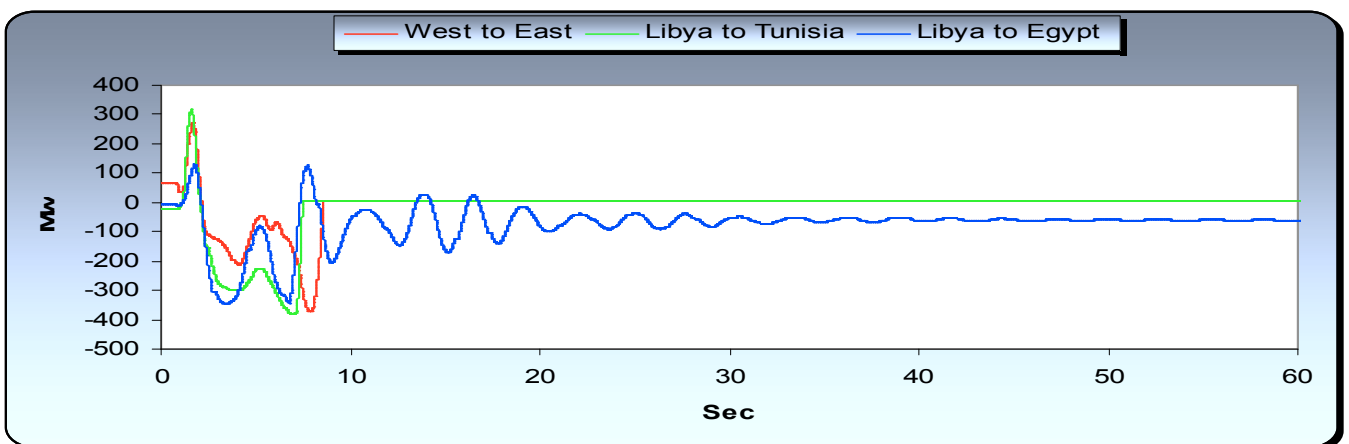


Figure 6-10 Power transfer via interconnections

Hz	CDP				ODP			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
49.4	110	80.02	53.34	13.34	140	49.34	50.01	10.67
49.2	110.2	60.01	40.01	0	130.03	81.35	33.34	2.67
49.0	0	156.7	40.01	93.35	0	103.35	30.01	83.35
48.8	13.34	130.03	76.68	56.68	63.35	163.37	83.35	36.67
48.6	0	43.34	63.35	220.04	0	0	0	0
Total	233.52	470.1	273.34	383.41	333.38	397.41	196.71	133.36

Table 6-9 Amount of load shedding in MW with load shedding contingency

### 6.3.3.2 System Collapse Contingency (Islanding Stage)

At 1.0 second, the incident is initiated by three phase fault with failure in the protection system in Khoms power plant (KHP). The fault is cleared in the second zone. This causes the system to lose three generation units ( $G4_{KHP}$ ,  $G6_{KHP}$  and  $G5_{KHP}$ ) in the same station. The amount of generation loss is 308.79 MW. At 2.0 seconds, A loss of units  $G7_{ZAP}$  and  $G8_{ZAP}$  is reported in the same station. The consequent generation loss is 185.27 MW. At 5.32 seconds, Three units in Zawia Plant (ZAP) ( $G2_{ZAP}$ ,  $G4_{ZAP}$  and  $G5_{ZAP}$ ) are tripped. The consequent loss of generation is 333.48 MW. At 6.0 seconds, Two units also in Zawia ( $G1_{ZAP}$  and  $G3_{ZAP}$ ) are lost with total loss of generation equal to 222.32 MW. Figure 6-14 shows that at 6.7 seconds, The Libyan system is disconnected from the Tunisian System. This is due to under voltage protection which can be seen in figure 6-13. At 7.4 seconds: the Libyan system is partitioned into two parts, which are the west and the east as in figures 6-12 and 6-14. Figure 6-15 shows the power transfers in the interconnection circuits before and after the system separation and also shows that the system is partitioned into two parts at 7.4 seconds. Having the system separated, the Libyan system, with ODP and with the CDP performs in different ways.

**The Libyan System with the current defence plan**

The system separation causes load- generation mismatch in the west part of the network. This mismatch causes the frequency to go through all frequency-load shedding thresholds, activating the load shedding scheme. The amount of load shedding is able to stop frequency decline. However, *at 12.1 seconds*, a generation unit is tripped in Rowis (RWS) causing the system to lose 111.16 MW of generation. *At 13.2 seconds*, there is a loss of one unit at Rowis station. The consequent loss of generation is equal to 111.6 MW. Figure 6-11 shows that *at 15.1 Seconds*, Sebha area (SBH) is disconnected by lines trip. *At 17 seconds*: two generators tripped at Khoms(HMP). The consequent loss is equal to 165.27 MW. Figures 6-11 and 6-13 demonstrate that *at 62.0 seconds*, the frequency reaches the islanding threshold. The whole west is partitioned into three islands (as it was prepared). Island 2 was the only island that survived. The rest of islands do not maintain their stability.

**The Libyan System with the optimized defence plan**

Following the east and the west separation, the west suffers from load-generation mismatch, while the east maintains its balance. This mismatch causes the frequency to go below three frequency thresholds, which are 49.4, 49.2, 49.0 Hz. This decline activates the load shedding scheme. *At 15.0 Seconds*, sequential loss of two generators in Khoms (HMP). The consequent loss of generation is equal to 165.27 MW. Again, this causes the frequency to decline below the last two frequency thresholds. The load shedding associated with these two thresholds is able to stop the frequency decline for a while. *At 76 seconds*, the frequency reaches the islanding threshold, causing the west to split into islands, island 1 and island 2, as it is prepared. Both islands are able to survive and maintain their stability.

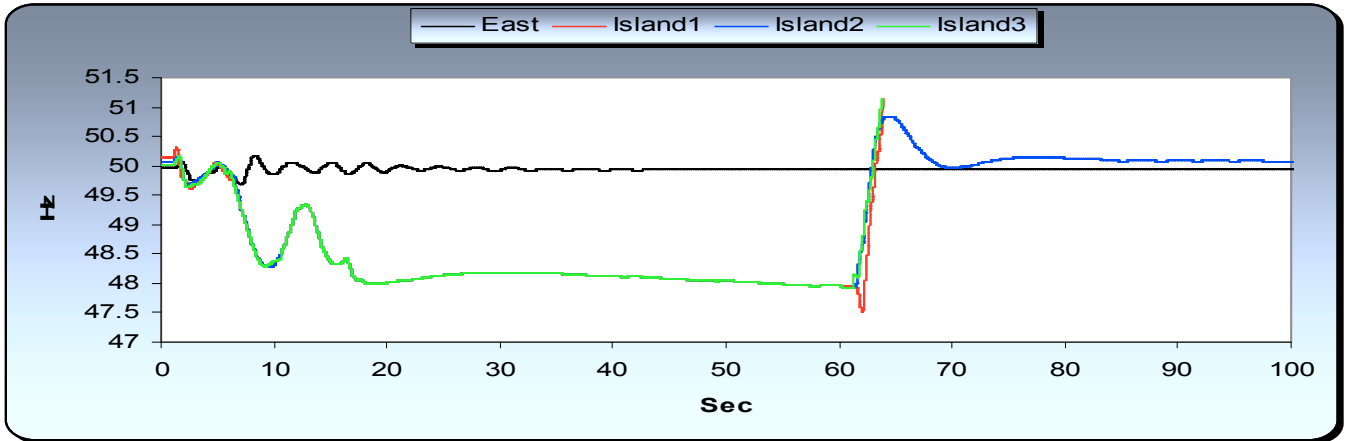


Figure 6-11 System frequency with CDP

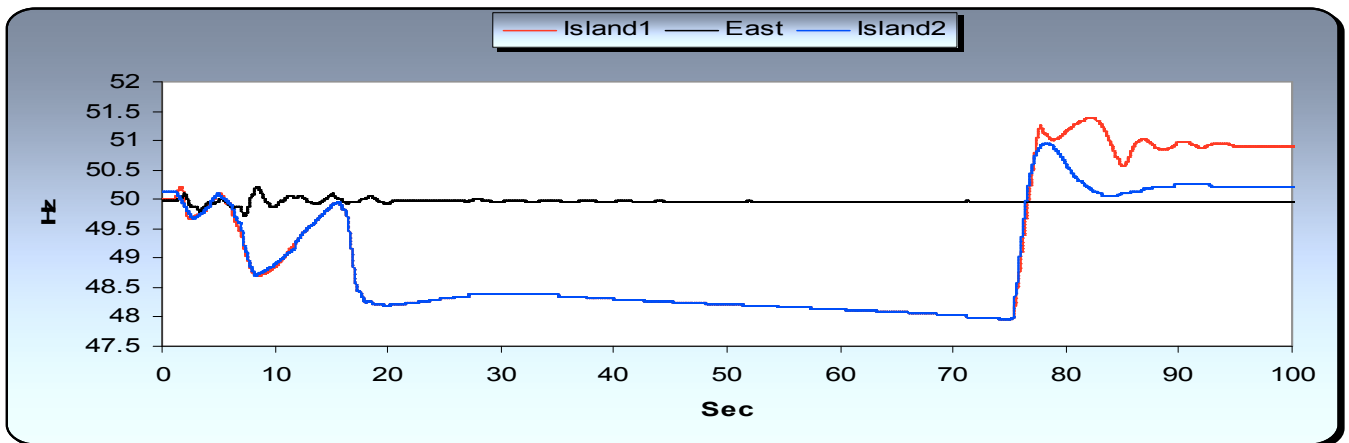


Figure 6-12 System frequency with ODP

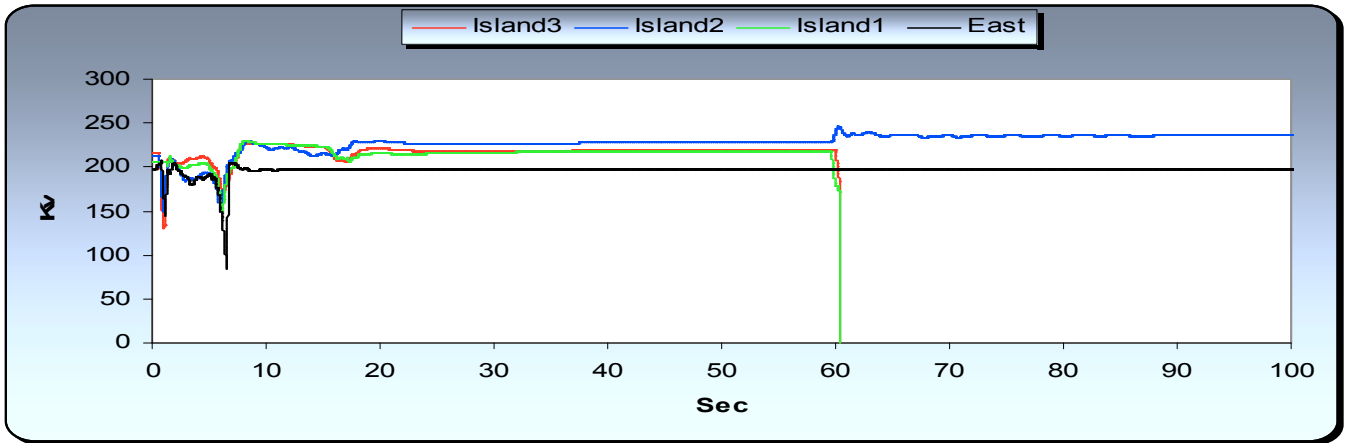


Figure 6-13 System voltage with CDP

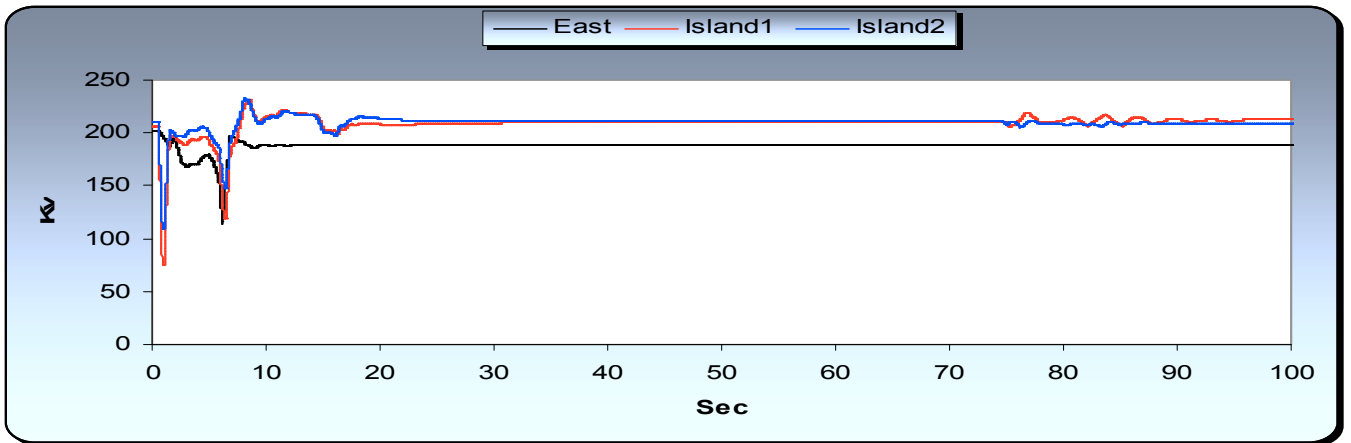


Figure 6-14 System voltage with ODP

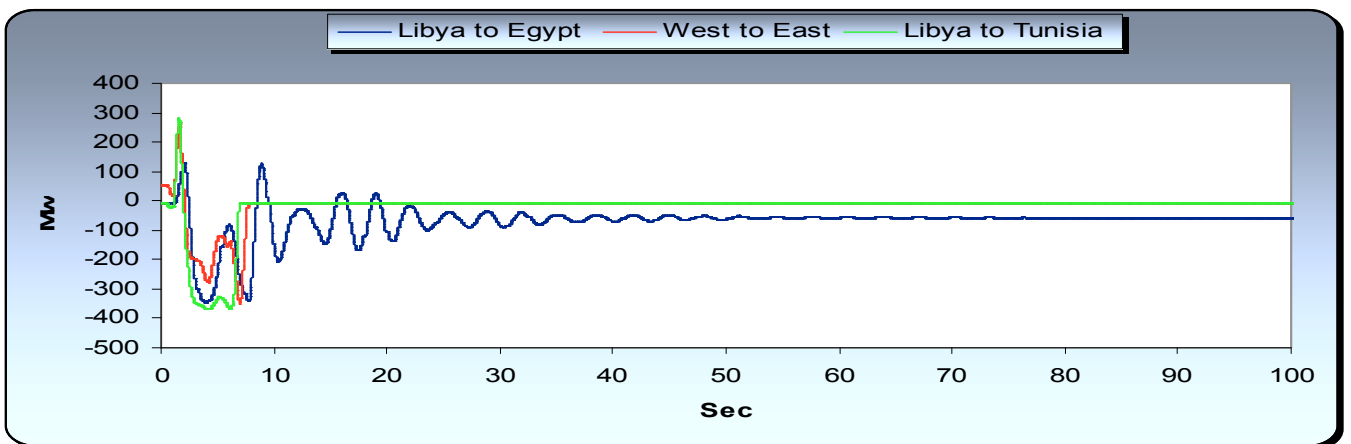


Figure 6-15 Power via interconnections



Hz	CDP				ODP			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
49.4	110	80.02	53.34	13.34	140	49.34	50.01	10.67
49.2	110.2	60.01	40.01	0	130.03	81.35	33.34	2.67
49.0	0	156.7	40.01	93.35	0	103.35	30.01	83.35
48.8	13.34	130.03	76.68	56.68	63.35	163.37	83.35	36.67
48.6	0	43.34	63.35	220.04	0	103.35	103.35	250.05
Islanding	collapsed	0	collapsed	0	0	0	0	0
Total	233.52	470.1	273.34	383.41	333.38	500.77	300.06	383.41

Table 6-10 Amount of load shedding in MW with  
islanding contingency

## 6.3.4 Discussion

### 6.3.4.1 Discussion of the Result of the Comparative Case

Referring to section 6.3.1 of the comparative study, two severe contingencies are applied to the Libyan power system with the ODP and with the CDP.

The first contingency is a severe load shedding contingency. This contingency causes the frequency to decline severely. It was chosen to push the system near its collapsing limits. The Libya power system could not withstand this severe contingency without proper defence plan actuation.

Figure 6-11 and Figure 6-12 shows that the Libyan power system is separated, after 7 seconds following the initiation of the contingency, into two parts which are the west and the east. This separation is not due to the islanding scheme. Under voltage protection, in the tie lines between the

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east and the west, is the reason. As the fault is located in the western part of Libya, the east is able to survive following the separation. Figure 6-15 shows that following the system separation, the Egyptian power system starts feeding the east of the Libyan power system. This has compensated the power transfer from the west to the east and provides good conditions for the east to maintain its stability.

Regarding the west, the load shedding contingency is severe enough to cause critical frequency decline. Using the CDP, the frequency decline is stopped after actuating five stages of the load shedding scheme. The use of the ODP is more helpful, since the frequency recovered after actuating four stages of the defence plan. This means less loads are tripped with ODP.

The second contingency is much more critical than the severe load shedding contingency since it is chosen to push the Libyan power system toward the islanding stage. The Libyan power system could not withstand this contingency without proper defence plan actuation.

The east part of the network is able to survive following the separation due to the same reason that makes it able to survive following the severe load shedding contingency.

Regarding the western part of the network, both of the load shedding schemes are not able to stop frequency decline. However, the ODP performs better than the CDP as the frequency decline is decelerated. Following the actuation of all load shedding stages, the frequency reaches the islanding stages.

With the ODP, the frequency reaches the islanding stage later than that of the CDP. Figure 6-11 shows that the Libyan power system with the CDP is divided into three islands when the frequency reaches the islanding stage. Two islands of the western part of the network could not survive. One

island is able to survive. This is not the case with the ODP where the system separation is successful. Figure 6-12 shows that the western part of the network is separated into two islands. Both of the islands are able to survive.

This reveals that the Libyan network with the ODP dynamically outperforms the Libyan network with CDP. This is the case with the severe load shedding contingency where the optimized scheme is able to stop the frequency decline with less load shedding. The same out performance of the ODP can be noticed with the severe islanding contingency where the disturbed loads are less.

In general, Figure 6-16 presents the results of the comparison which is the percentage of the collapsed area using the two severe contingencies. This has shown that the algorithm is robust and has produced a superior defence plan when compared to the present Libyan defence plan in the two cases of severe system collapsing contingencies. In these particular results, the ODP is able to preserve about 8% of the whole system loads more than that of the CDP.

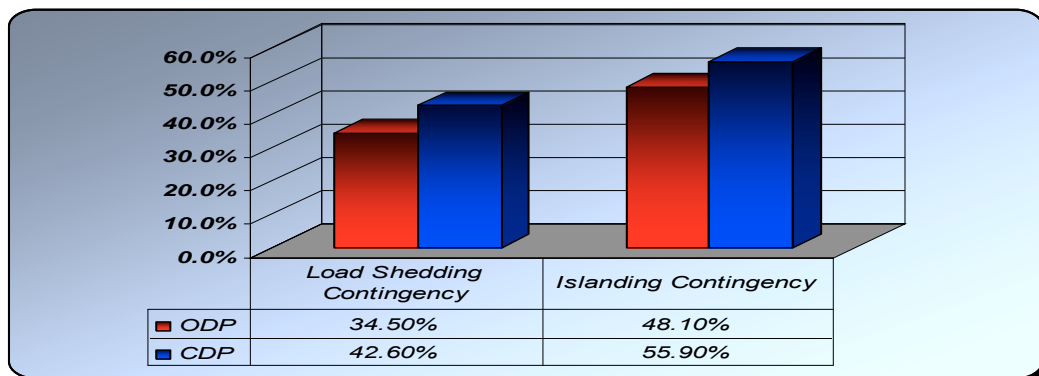


Figure 6-16 Percentage of the preserved areas

#### 6.3.4.2 Discussion of the Generic Features of the Optimized Defence Plan

Referring to the mentioned results, the ODP algorithm is able to produce a robust scheme to prevent a total system collapse. The scheme deals with the system in two stages which are the load shedding and the islanding stages. It is worthy of noting that the optimized scheme shares with the current scheme the necessity of tripping the majority of area 4 at 48.6Hz. This point, in fact, shows that the optimized algorithm is able to search for and obtain good features that were recommended by Libyan power system's experts to preserve the system.

Also, it can be noted from figure 6-17 that an additional amount of load shedding is introduced in the last stage of load shedding. This additional amount of load shedding plays an important role in saving the system in some critical situations, since it is vital in preparing the network for islanding. So, the use of the optimization method has shown the necessity of having an additional amount of load shedding in the last frequency dependent load shedding step; not only to stabilize the network but also to prepare the system for the islanding phase. This can be seen in figure 6-11 of the CDP where Island 1 and 3 suffer from a load-generation mismatch problem. This makes these islands unable to survive. It is not the case with the ODP where the network is prepared for the islanding stage which makes it able to survive.

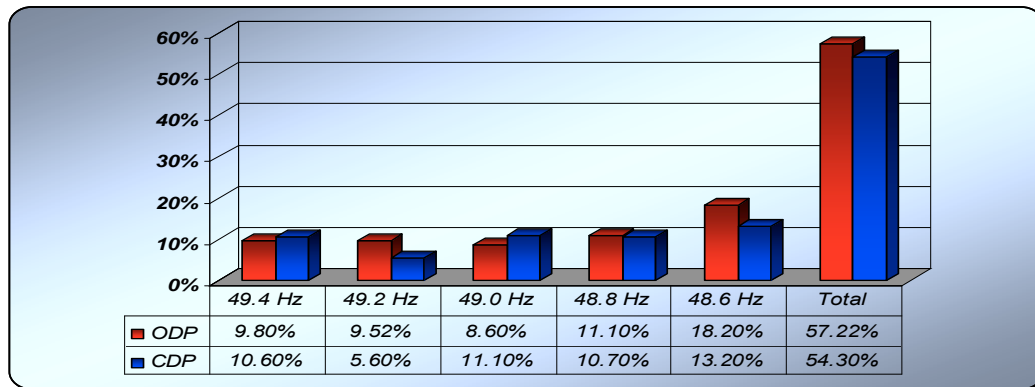


Figure 6-17 Load shedding percentage of the current and optimized defence plan

Referring to figure 6-5 and figure 6-2, in spite of the fact that the GA had a completely free hand to choose the cutting point to form the islands, the GA obtained the same island formation as the CDP. The only change is in combining island 2 and island 3.

## 6.4 Case Studies for the Restoration

### Algorithm

Regarding the restoration algorithm, two cases are presented. The first case is presented as a comparative study to show that the restoration algorithm outperforms ordinary methods of designing restoration plans. The second case is to validate the practicality of the restoration algorithm and to prove that it can be applied to a large real-world power system.

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## 6.4.1 Comparative Case for the Optimized Restoration Algorithm

### 6.4.1.1 Overview

The goal of this comparative study is to show that the restoration algorithm outperforms the ordinary ESs based algorithms. In order to show the advantages of combining the GA and ES to the problem of the design of restoration plan, a comparative case between the restoration algorithm and pure ES method is presented. The comparison between the restoration algorithm and the pure ES uses the New England 39-bus test system. The comparison focuses only on the time required to restore the skeleton network. In other words it focuses on the time required to connect all generators in the network.

The single-line diagram of this test power system is shown in figure 6-18. The system consists of 19 load buses, 10 generators and 46 lines. Base case load is 6150MW and base case generation is 6192MW. The data used for this study is presented in the appendix I.I.

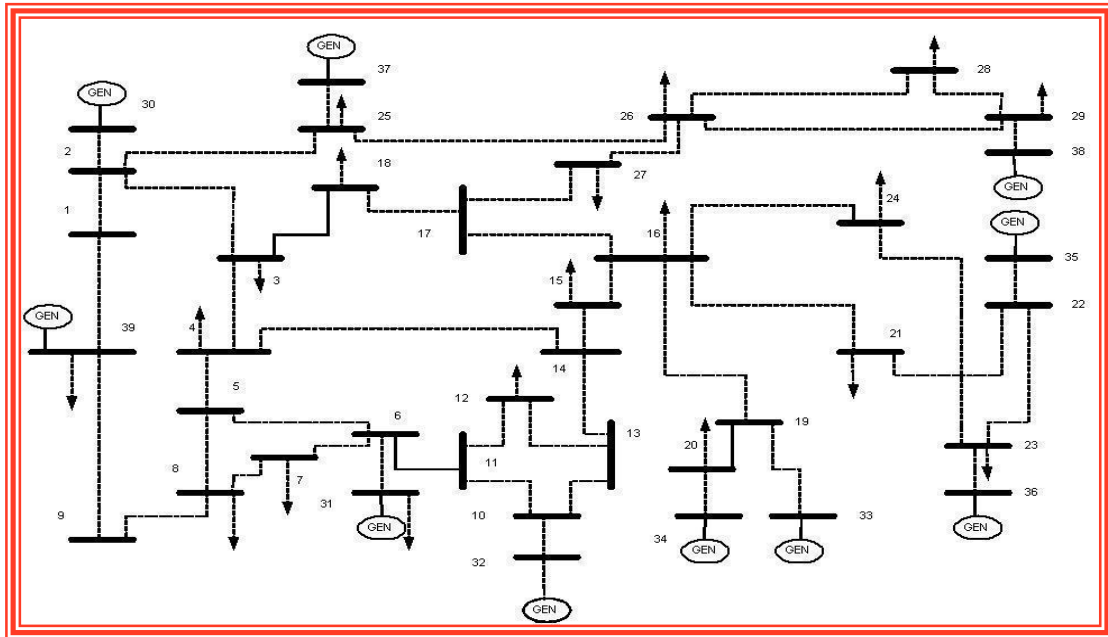


Figure 6-18 New England test network

#### 6.4.1.2 Pure Expert System

The restoration algorithm is compared with pure ES rules which are derived from the work introduced by Chen-Ching Liu and Kan-Lee Liou [24].

Generally, the pure ES used in the comparison contains the similar management tools used in the ES embedded in the GA, except for the generation management tool. Unlike the restoration algorithm, the generation management in pure ES is using heuristic procedures to connect the generators. These procedures are:

Firstly, the black-start units are started. The unit with critical maximum interval are higher in priority to receive cranking power. Once the black-start generators are started and initially loaded, using the path management, non black-starting units are power-cranked and loaded.

If two units or more are urgent, the one with lower MW rating is cranked first. This is due to the fact that a unit with lower MW rating can reach its minimum generation level sooner and generation can be used to crank

other units. If all units with critical maximum intervals are started, then the nearest and highest MW generator is given the higher priority. The load management is also based on load importance. The rest of the management tools are the same. This has been done to have a good ground for comparison.

### 6.4.1.3 Results and Discussions

The best solution obtained by the Restoration Algorithm is presented in figure 6-19. In this solution the skeleton network is built in 440 minutes. Using the pure ES, the skeleton network can be built in 513 Minutes as in figure 6-20.

Figure 6-21 shows the generation ramping curves of the whole system, in both cases. It also shows the fact that the solution obtained by the restoration algorithm reaches higher output faster than the one obtained by the pure ES.

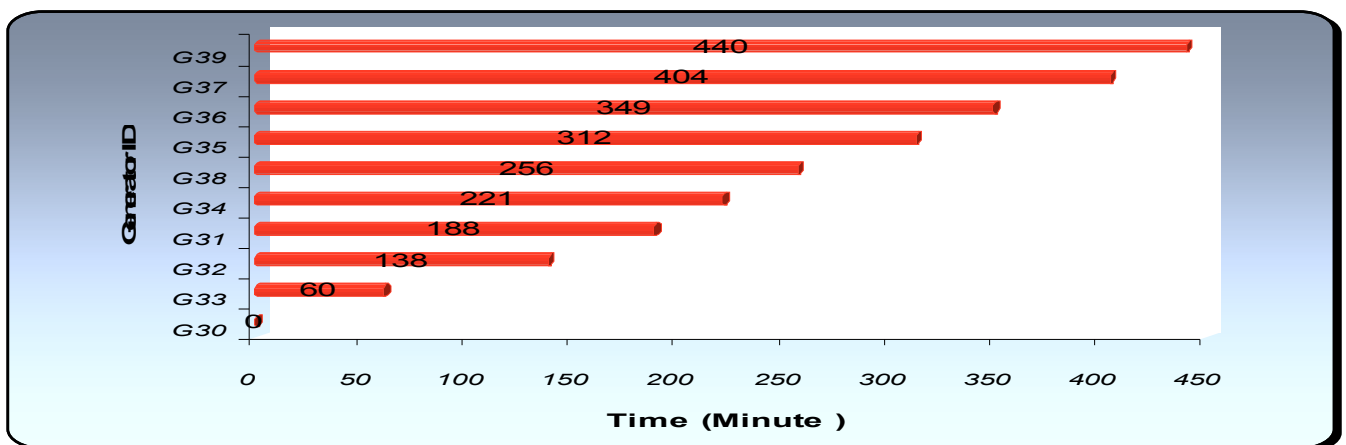


Figure 6-19 Solution obtained by restoration algorithm



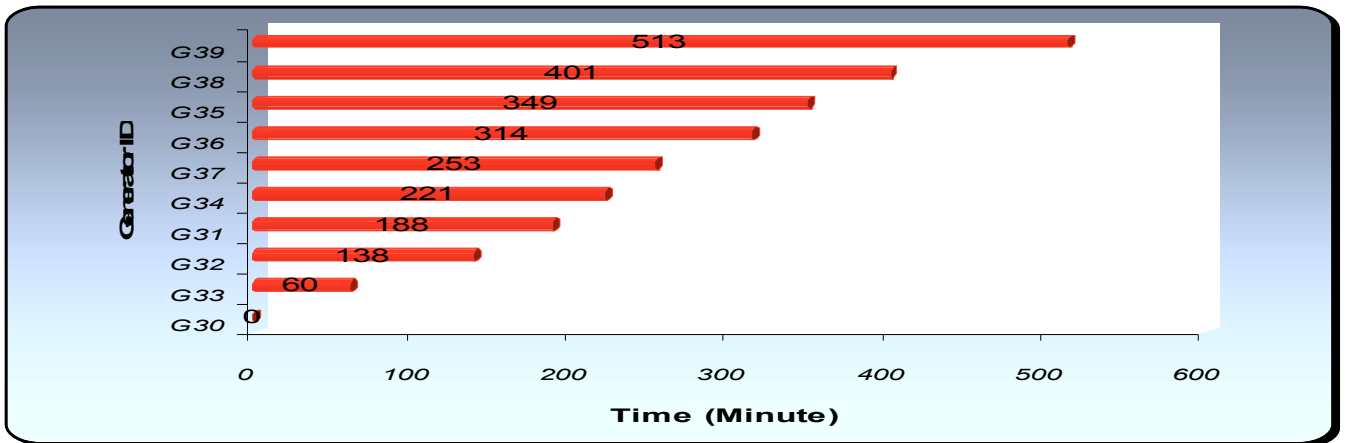


Figure 6-20 Solution obtained by pure ES

As a result, the restoration algorithm has obtained a solution that decreases the restoration time by 14.0% of the one obtained by pure ES. With respect to the size of the network, the reduction percentage is considerable.

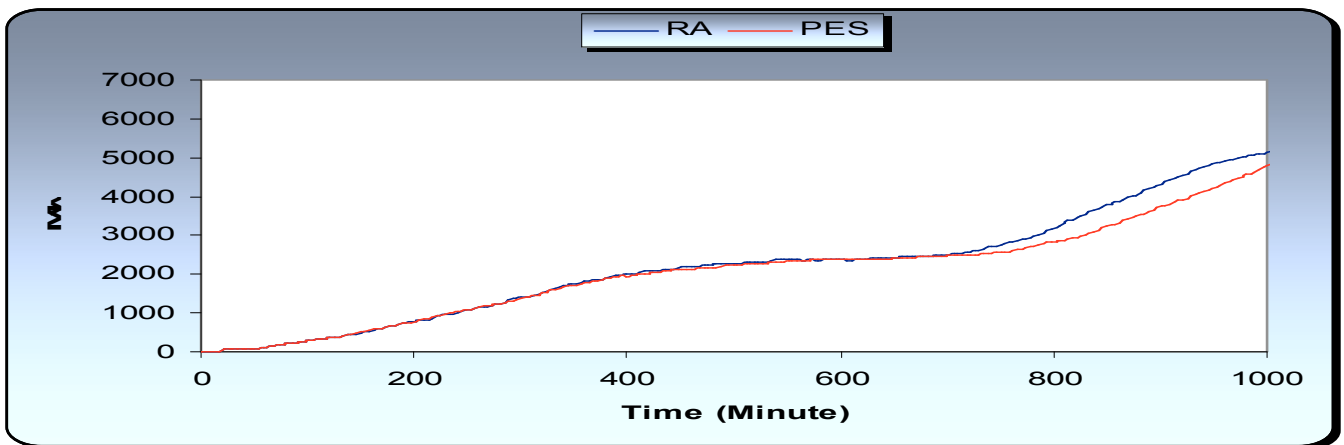


Figure 6-21 Generation ramping curves

Regardless the results of the comparison between the restoration algorithm and the pure ES, this study has a unique feature in terms of considering

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the power system constraints and security limits, which allows a real estimation of the restoration time.

## 6.4.2 The Application of the Restoration Algorithm to the Libyan Power System

### 6.4.2.1 Overview

With the assumption that complete western part of the Libyan network has been completely collapsed and separated from the east and Tunisian power system, the restoration algorithm is applied to the collapsed part of the network. This is to validate the practicality of the restoration algorithm. The western side of the Libyan Network is presented in figure 6-1. The boundaries of this part are RLF busbar from the east and ABK from the west. The dynamic data of the generators can be found in appendix I.II.II.

### 6.4.2.2 Results and Discussions

Referring to figure 6-22, the algorithm is able to find the optimized restoration plan for the western side of the Libyan power system in generation number 64. Figure 6-23 presents the optimal generator sequence found by the algorithm. The main skeleton network for the western side of the Libyan power system can be built in 342 minutes while the whole network can be built in 427 minute. The restoration time is superior for such a big and complicated network. This is due to the fact that the Libyan power system is mainly characterized by the use of simple-cycle-turbine plants and few steam plants. As the simple-cycle can be restarted within minutes, the Libyan power system can be brought back very fast.

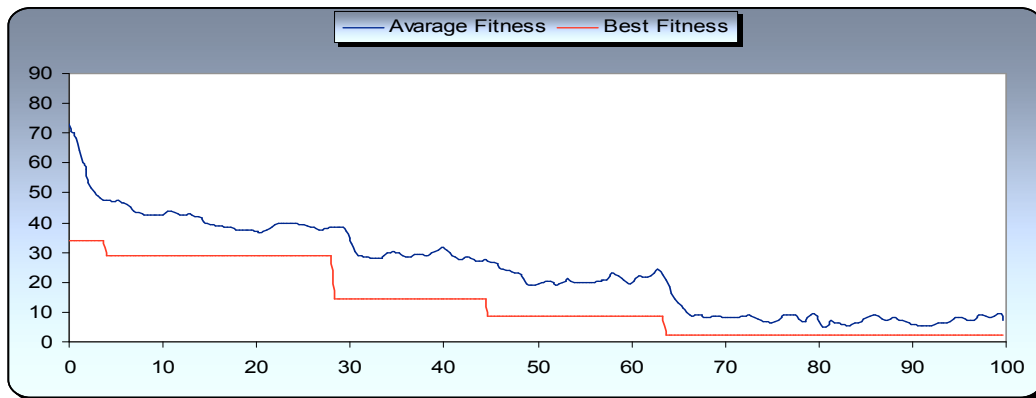


Figure 6-22 GA performance for restoration algorithm

### 1. *Optimized Restoration Plan:*

Referring to figure 6-23, the optimized restoration plan is started by initiating the units in the south of Tripoli (TRS). This is one of the best choices to restore the western side of the Libyan power system. This is due to the following facts:

1. The TRS units have black start units
2. They have the capability to provide the power faster than many other units.
3. The TRS busbar has good access to the most important area in the network, which is Tripoli the capital.

As the  $G1_{TRS}$  and  $G4_{TRS}$  have black start generators,  $G1_{TRS}$  is connected first to pickup the local loads in the south of Tripoli. Ten minute later,  $G2_{TRS}$  is connected. This unit is loaded from the local load in TRS and SRJ. Once both of them are connected and partly loaded, the rest of the three units are cranked at 15, 10, 25 minutes.

As the time required for loading (TRL) for every units in TRS is 25 minutes, the loads in HAD are picked at 35 minute. The time required picking up all of the loads in this bus is about 15 minutes.

During the loading of HAD, the two steam units of TRW ( $G_{4TRW}$  and  $G_{5TRW}$ ) are cranked. The TRL of these units are 90 minutes. The first unit is cranked at 39 minutes and the second unit at 42 minutes.

Following this process, BZZ is picked at 52 minutes. However, in the meantime  $G_{1TRW}$ ,  $G_{2TRW}$  and  $G_{3TRW}$  are cranked at 54, 59 and 67 minutes respectively.

Between 80 and 88 minutes, the local loads at TRW are picked. As the TRW units are sequentially engaged, the loads at NAT, SUK, NZR TRE and ZHR are sequentially picked. As the units on ZWP have Black start capability units, they are assumed to deliver power immediately. So,  $G_{1ZAW}$ ,  $G_{2ZAW}$ ,  $G_{3ZAW}$ ,  $G_{4ZAW}$ ,  $G_{5ZAW}$  and  $G_{6ZAW}$  are connected at 133, 138, 144, 149, 155 and 166 minutes respectively. During this process of connecting, the rest of loads in ZHR, loads in ZAW and AGE are picked.

Once all ZAW units are engaged, loads in TRH, GHR, ELH, BGM, ZUR, SHK and RWS are picked. This starts at 164 minutes and ends at 208 minutes. During this time the two units of  $G_{1RWS}$  and  $G_{2RWS}$  are connected at 194 and 199 minutes. They are supposed to contribute in 45 minutes in accordance to their TRL.

At this moment, mainly all of the west side is connected. At 210 minute, the process of picking up loads at GRB, HMW, HME, BWD and GMR1 is started. This process ends at 274 minute. In the meantime the 4 steam units in HMP are cranked first, then the four gas units in the same bus are cranked. The gas units deliver their power first as their RTL is much shorter than that of the steam units.

This is followed by picking the loads in WKM, ZLT, MSW, MSE and MST. This process starts at 276 and ends at 285 minute. During that the six units of MST are cranked. Using the power delivered from HMP generation units ZMZ and SRT loads are picked.

Having all units of MST fully engaged, the loads in the south are picked in the following order: BNJ, HON, WRL, SMN, SBH, TRG, FJJ, UBR, and AWN.

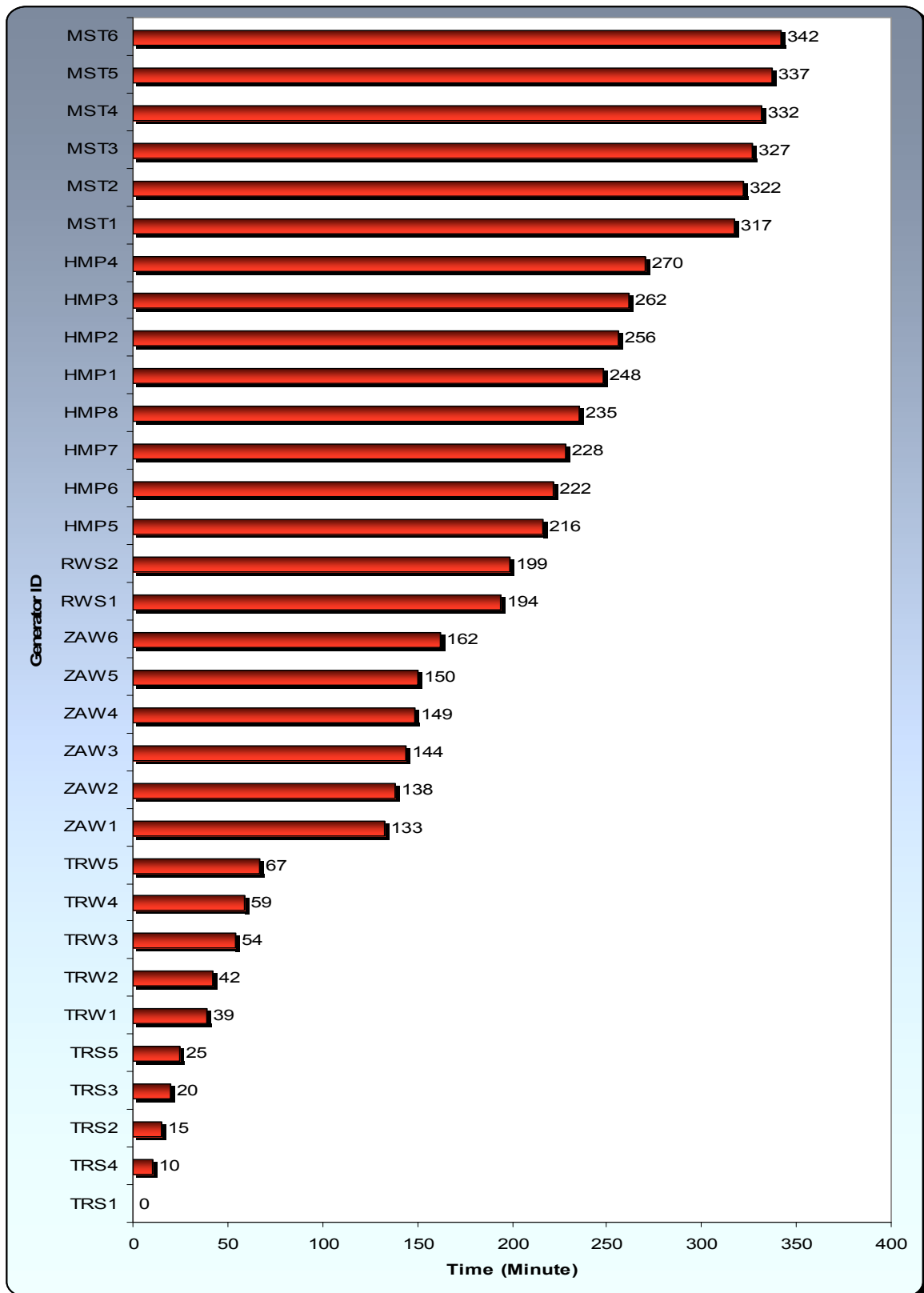


Figure 6-23 Optimized generator sequence

## **2. Generation Ramping Curve**

Figure 6-24 shows the generation ramping curve of the whole system. This curve reflects the over all restoration process. It can be noticed that the curve or restoration process is characterized by fast ramping or fast picking loads process in the beginning and slow ramping in the end. Also, the generation ramping curve slows down in the middle of the restoration process. This can be explained by considering figure 6-25 where the overall system capability to pick up loads is presented. The system capability to pick up loads is reflected on the generation ramping curve. So, when the power system loses its capability to pick up or is able to pick up just small increments of loads, the generation ramping stop increasing or increases in small slope.

Theoretically, a power system's capability to pick up loads depends on the generators picking capability. Practically, this is not true. There are other factors which might disturb power system capabilities to pick up, such as the transfer capabilities of the transmission line, the location of load to be picked and the overall system security. Figure 6-25 is good evidence of that.

Figure 6-25 shows that the overall generator's capability to pick up loads and the actual size of loads that can be picked by the power system as it is affected by constraints. While generation capability to pick up loads smoothly increases with time and number of generators, the overall system capability to pick up is more dynamic with overall power system performance.

For our practical case, the Libyan power system lost its capability to pick up loads in the middle of the restoration process because of power system security constraints. As the ES has to make sure that the system security constraints are not violated, the power system could not pick up any loads until system security was granted. The last segment of the generation

ramping curve is linked to the restoration of the south area (SBH). The SBH area is fed through and from Misrata (MST). However, the Misrata area is initially fully fed from Khoms. So any power transfer to SBH would come initially from Khoms (HMP). This makes the connections from Khoms to Misrata extremely overloaded. Therefore, the ES made a smart decision by waiting for the Misrata generation units to be fully engaged before it started picking up any loads in SBH.

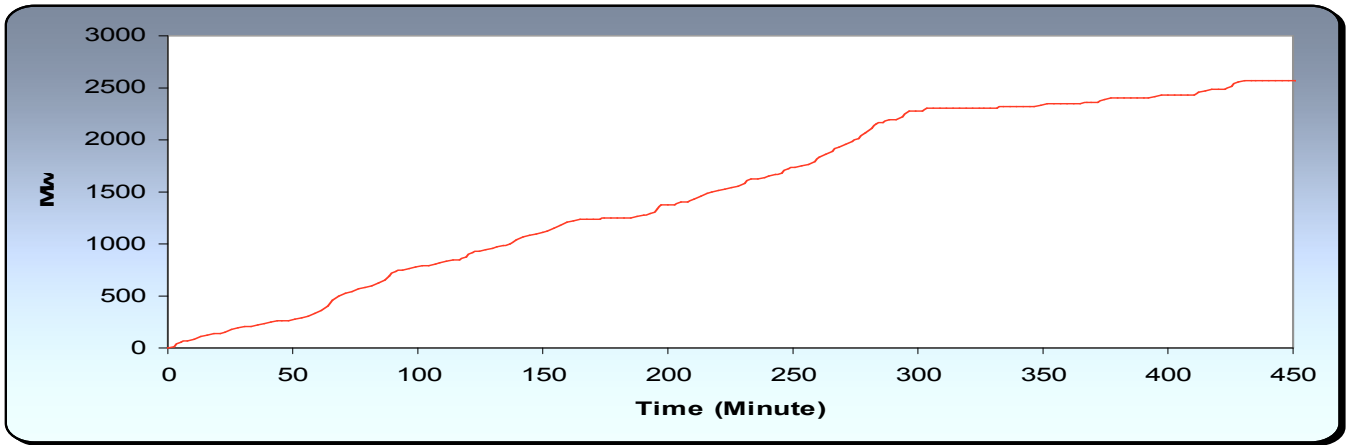


Figure 6-24 Generation ramping curves

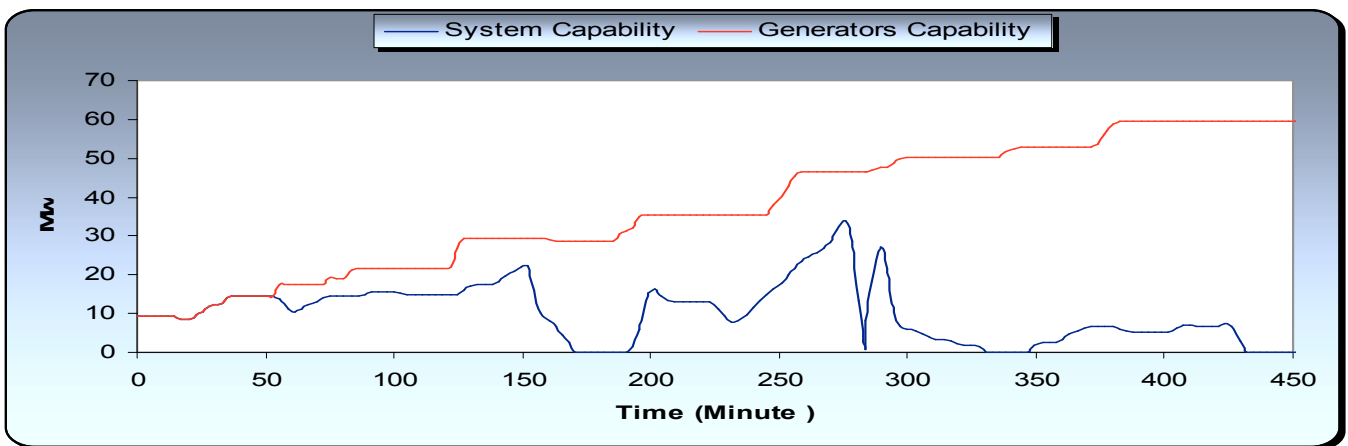


Figure 6-25 Generators and system capability to pick up loads

### 3. Frequency Response

In this section some snapshots were taken during the restoration process to explain how the overall system widely performs, and how the expert knowledge adopted in the ES played a very useful role in maintaining overall system security.

As the size of load to be picked up might be a constant source of disturbance during restoration, great attention has been given to it in the ES. The ES is dealing with that in two levels. Firstly, the ES decide on the size of the increment in accordance with the overall system performance as such it should not be more than the size recommended by equation 5-9 in chapter 5 and does not go above line transfer capabilities. Using PSSENG, the ES makes its second assessment. This is done by investigating frequency response following each pick up. So, if it is lower than the acceptable limit, the ES would decline the size of load picked and it goes for a smaller load.

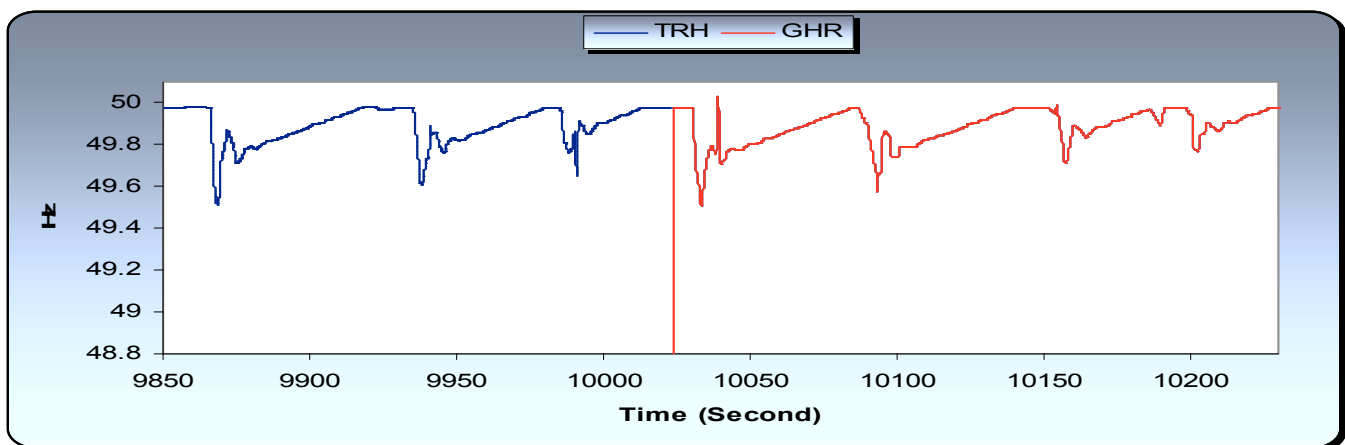


Figure 6-26 Frequency response during restoration (1)



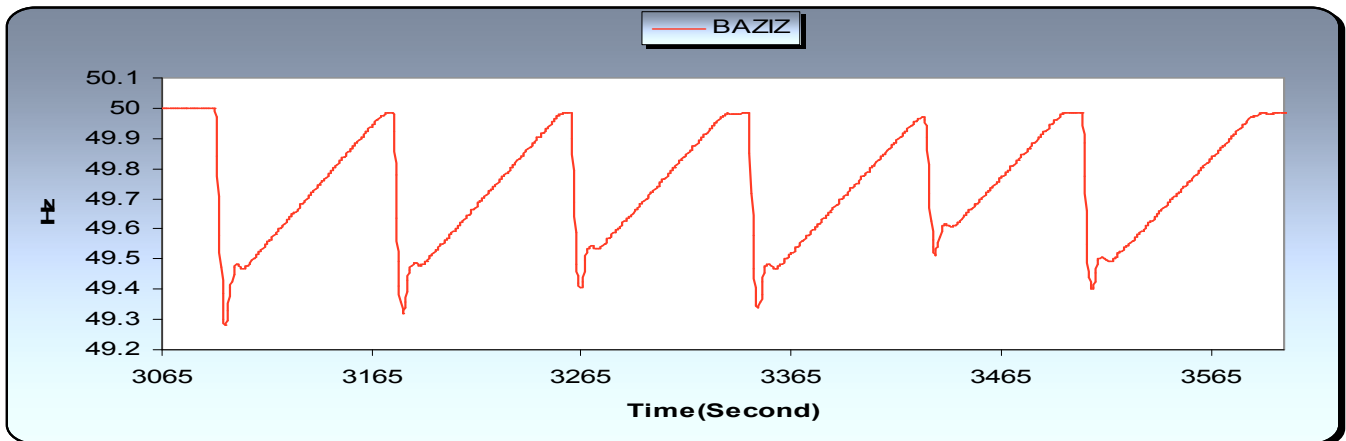


Figure 6-27 Frequency response during restoration (2)

Figure 6-26 presents the frequency of the system in TRH busbar while connecting different sizes of load. At 167 Minutes the GHR busbar is connected. It can be noticed that there are not any kind of transient associated with busbar connections. This is due to the fact that busbar connections do not make any electromechanical transient. In the same way figure 6-27 presents the frequency of BZZ bus bar while some loads are picked.

According to figure 6-26 and figure 6-27, the frequency responses are within the acceptable limits. However, if the ES does not take the right decision about the size of load to be picked up, the first problem could produce unacceptable transient which might lead the system to instability region or to actuate the protection systems. Both of the consequences have a considerable chance to collapse the system again.

Another possibility is to pick a big load and the frequency behaviour is somehow acceptable. However, the amount of picked load violates the transfer capability of certain transmission lines. Of course, this line or lines would trip. This also could lead to system collapse.

#### 4. Active Power Dispatching

A powerful feature of the ES is the capability to dispatch the output of generators whilst maintaining well-spread spinning reserve between generation units. This is very useful for overall system stability. Moreover, this can be helpful for resolving transmission line congestion.

Figure 6-28 presents the generation output of  $G1_{TRS}$  in the beginning of the restoration process while different sizes of loads are picked. At 5.6 minutes  $G2_{TRS}$  is connected. As both generation units are within the same size, the ES decides to load to the same level.

In the same way figure 6-29 presents the generation output of  $G1_{ZAW}$ . At 240.3 Minutes, generator RWS1 starts ramping up to a different generation level. This is due to that they are different generator sizes. So the ES decides to load them to different levels which are related to their sizes.

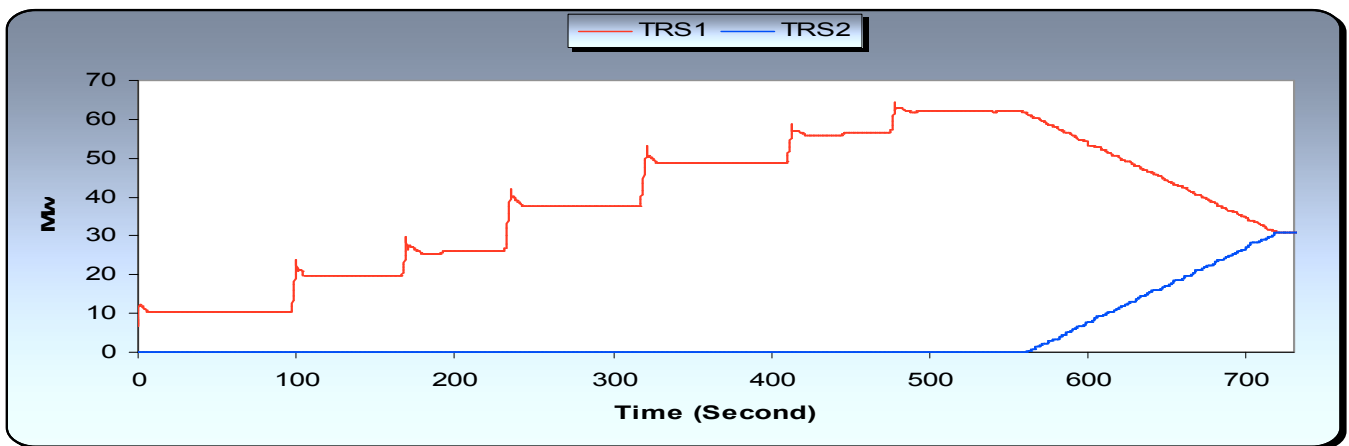


Figure 6-28 Generation output during restoration

(1)

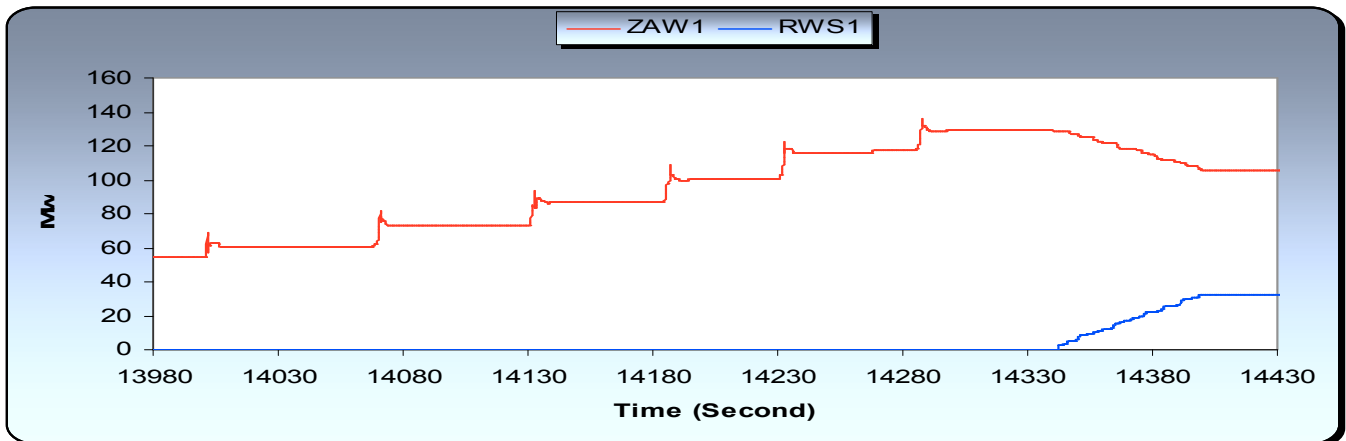


Figure 6-29 Generation output during restoration

(2)

A good example of the effectiveness of this feature is the aforementioned problem of picking the loads of the south area (SBH). The ES slows down the process of picking up the loads in south area until the generators of the Misrata area (MST) are reasonably loaded to a certain level so that some of the loads in Misrata area are fed from the generators in the area. This makes the south area fed from Misrata, not from Khoms. This smart action has avoided a possible problem of tripping tie lines between Misrata and Khoms which might lead to separating and collapsing the system.

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## 7 Conclusion and Further Work

This research is about optimizing the power system security scheme for the Libyan power system. The power system security considered in this study includes the under frequency defence plan and restoration plan.

Regarding under frequency defence plan, the plan is built on the strategy that, during a catastrophic event, losing a part of the network is much better than losing the whole network. The under frequency defence plan is subdivided into under frequency load shedding scheme and low frequency islanding scheme. The application of the low frequency islanding scheme often follows the application of the under frequency load shedding scheme. In both of them, GAs are applied to enhance the overall dynamic performance of a power system following unexpected severe incident. The goal of the GAs application to load shedding schemes is to find an optimized amount of loads that can be tripped, in every frequency thresholds, which can stabilize the proposed power system. Analogous to the load shedding scheme, the GA is applied to the islanding scheme to obtain the optimal boundaries of system islands or parts that are able to survive following unexpected severe incidents.

Regarding the restoration part of the power system security scheme, the main goal is to determine the shortest and most feasible path to restore a collapsed power system. In order to do that, a GA is applied to obtain the optimized optimum sequencing of generating units start up. As this optimization problem is associated with huge solution space, an ES is used to constrain this solution space. In order to do this an expert knowledge of power system operator is used.

The information used to form the ES is gathered from the Libyan power system operators.

The ODP designed in this research is compared to the CDP used in the Libyan power system using two severe contingencies. The new defence plan algorithm can play an important role in obtaining the optimal islanding boundaries and the minimum amount of load shedding required to stabilize the power system after severe faults. The results have shown that the algorithm is robust and has produced a superior defence plan when compared to the present Libyan defence plan. In particular, it recommends the amalgamation of two islands and in doing so it is able to preserve the supply to more loads.

The use of the optimization method has shown the necessity of having an additional amount of load shedding in the last frequency load shedding step, not only to stabilize the network but also to prepare the system for the islanding phase.

This algorithm is more helpful than relying on operator experience in the case of complications where the natural boundaries of the islands are not obvious. Having a proper defence plan not only helps to prevent cascading blackouts but also helps to rapidly restore the network.

Using experience of experts in developing defence plans is vital. However, having an automatic algorithm that contains this experience can be more helpful. This helps in reducing the designing time. In other words, the algorithm is needed to be designed just once and it can produce many defence plans for many power systems.

In order to show the validity of the restoration plan algorithm, it is also compared to a pure ES developed by Chen-Ching Liu and Kan-Lee Liou [24]. The results of this comparison have shown that the Restoration plan algorithm is able to find a better solution at which the restoration time can be reduced by 18% when it is compared to that of the pure ES.

Analogous to the defence plan, the restoration algorithm is applied to the Libyan power system. The results have shown that the Libyan power

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system can be restored in short time. This is due to the nature of the Libyan network and the robustness of the algorithm.

Using a real-life environment has given the restoration algorithm powerful features to find the optimized restoration path. The restoration algorithm considers most of the power system security constraints such as system stability, voltage profile, line transfer capability, system capability to pick up loads during restoration, spinning reserve requirement and load generation balance.

In the restoration algorithm, a load pick increment calculator is used. This increment calculator is based on a method introduced in [128]. The results of the restoration algorithm have shown that this calculator should be used just as load pick indicator since the system capability to pick up is considerably smaller than what is calculated by this method.

A limitation of the method could appear as that by using a specific list of assessing contingencies, the ODP becomes skewed toward these contingences. This makes the defence plan perform much better than one designed for an open list of contingencies. Of course, the list of contingencies can be easily extended and is not in any way restricted. Moreover, using generic lists of contingencies can also help to produce a generic defence plan.

Another limitation regarding the restoration algorithm is the inability to support the islanding or paralleling process during restoration. Someone could argue that the overall restoration time can be reduced by using islanding during restoration and also some generator can be cranked before it falls into the cold mode. This is true even though the operator can not precede more than one control action in the same time. Also, the islanding process during restoration is very important in a large power system. In this sense, the restoration algorithm can play an important role in restoring a power system islands rather than the whole power system if the operator chooses to restore the power system in parallel operations. In

other words, once an operator has decided to restore a power system in, lets say, two islands, the algorithm can be applied twice to obtain the shortest path for both islands.

The computation time might be also considered as a limitation since all algorithms require a considerably long time to produce the optimized solutions. Since the power system security scheme is an off-line scheme, the computation time is not considered as a drawback in the research. However, there are many methods to enhance the computation time such as using parallel computers, even using super fast computer or using artificial neural network.

### *Further Work*

Based on the limitation of this research, further work could be adding the capability of parallel operation to the Restoration algorithm. Therefore, the restoration algorithm would be able to form the islands by itself during the restoration.

The size of the load to be picked up during restoration was determined firstly using the load increment calculator and then was altered in accordance with the power system investigator. This obviously consumes considerable computation time and the optimality is not guaranteed. An application of optimization method inside the main restoration algorithm to obtain the optimal load increment could lead to very interesting further work.

An alteration of the overall security scheme to be an online scheme, by using parallel operation or neural network, could also be an interesting piece of further work.

It is well known that the future of power systems is linked to a high penetration of wind energy which introduces great change on the design

strategies of power systems. The generation load patterns will be varying in accordance with the wind change. This makes the generation pattern significantly variable. Therefore, having a constant load shedding scheme would be very helpful. Moreover, the boundaries of the islands should be more dynamic and varying with the change in wind patterns so that the load generation equilibrium could be guaranteed. Therefore a good enhancement to the security scheme could be the consideration of the wind energy.

More broadly, in this world there are many security critical networks such as trains, transportation and water networks. The security scheme can be somehow adapted to these networks and produce optimal results. For example, the load shedding part can be applied to the water network. This can be done by considering the water input and output as the electrical generation and loads and the loads to be shed as the water consumers. So, in terms of the balance between the water input and output is disrupted, the algorithm should be able to find the optimized number of consumers to be shed.



# I Appendices

## I.I IEEE 10 Generator 39 Bus System

### I.I.I General Outline

This IEEE 39 bus system is well known as the 10-machine New-England Power System. Generators represent the aggregation of a large number of generators. All parameters shown below come from the book titled 'Energy Function Analysis for Power System Stability'.

### I.I.II Basic Load Flow

BBAR	Pg (MW)	Qg (MVAR)	Pl (MW)	Ql (MVAR)	Vm (pu)	Va (rad)	P (MW)	Q (MVAR)
0 1	0.0000	0.0000	0.0000	0.0000	1.0490	-11.0410	0.0000	0.0000
0 2	0.0000	0.0000	0.0000	0.0000	1.0490	-11.1022	0.0000	0.0000
0 3	0.0000	0.0000	322.0000	2.4000	1.0298	-14.7714	-322.0000	-2.4000
0 4	0.0000	0.0000	500.0000	184.0000	1.0045	-16.8028	-500.0000	-184.0000
0 5	0.0000	0.0000	0.0000	0.0000	1.0066	-16.3711	0.0000	0.0000
0 6	0.0000	0.0000	0.0000	0.0000	1.0090	-15.9506	0.0000	0.0000
0 7	0.0000	0.0000	233.8000	84.0000	0.9982	-17.5950	-233.8000	-84.0000
0 8	0.0000	0.0000	522.0000	176.0000	0.9971	-17.8196	-522.0000	-176.0000
0 9	0.0000	0.0000	0.0000	0.0000	1.0275	-13.7461	0.0000	0.0000
0 10	0.0000	0.0000	0.0000	0.0000	1.0179	-13.0927	0.0000	0.0000
0 11	0.0000	0.0000	0.0000	0.0000	1.0136	-14.0587	0.0000	0.0000
0 12	0.0000	0.0000	8.5000	88.0000	1.0010	-13.9207	-8.5000	-88.0000
0 13	0.0000	0.0000	0.0000	0.0000	1.0151	-13.6529	0.0000	0.0000
0 14	0.0000	0.0000	0.0000	0.0000	1.0124	-14.9232	0.0000	0.0000
0 15	0.0000	0.0000	320.0000	153.0000	1.0154	-14.5024	-320.0000	-153.0000
0 16	0.0000	0.0000	329.0000	32.3000	1.0317	-12.7406	-329.0000	-32.3000
0 17	0.0000	0.0000	0.0000	0.0000	1.0333	-13.6564	0.0000	0.0000
0 18	0.0000	0.0000	158.0000	30.0000	1.0307	-14.5098	-158.0000	-30.0000

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0 19	0.0000	0.0000	0.0000	0.0000	1.0498	-7.5757	0.0000	0.0000
0 20	0.0000	0.0000	628.0000	103.0000	0.9912	-8.5676	-628.0000	-103.0000
0 21	0.0000	0.0000	274.0000	115.0000	1.0317	-10.3334	-274.0000	-115.0000
0 22	0.0000	0.0000	0.0000	0.0000	1.0498	-5.8845	0.0000	0.0000
0 23	0.0000	0.0000	247.5000	84.6000	1.0448	-6.0827	-247.5000	-84.6000
0 24	0.0000	0.0000	308.6000	-92.2000	1.0373	-12.6210	-308.6000	92.2000
0 25	0.0000	0.0000	224.0000	47.2000	1.0567	-9.8475	-224.0000	-47.2000
0 26	0.0000	0.0000	139.0000	17.0000	1.0514	-11.4436	-139.0000	-17.0000
0 27	0.0000	0.0000	281.0000	75.5000	1.0371	-13.6136	-281.0000	-75.5000
0 28	0.0000	0.0000	206.0000	27.6000	1.0498	-7.9298	-206.0000	-27.6000
0 29	0.0000	0.0000	283.5000	26.9000	1.0497	-5.1695	-283.5000	-26.9000
1 30	250.0000	144.7273	0.0000	0.0000	1.0475	-8.6831	250.0000	144.7273 - 500.0000 800.0000
1 31	200.0000	159.5065	0.0000	0.0000	0.9821	-12.8566	200.0000	159.5065 - 500.0000 800.0000
1 32	650.0000	201.7064	0.0000	0.0000	0.9831	-5.1028	650.0000	201.7064 - 500.0000 800.0000
1 33	632.0000	110.0404	0.0000	0.0000	0.9972	-2.3583	632.0000	110.0404 - 500.0000 800.0000
1 34	508.0000	165.8103	0.0000	0.0000	1.0123	-3.3780	508.0000	165.8103 - 300.0000 400.0000
1 35	650.0000	212.5604	0.0000	0.0000	1.0493	-0.9228	650.0000	212.5604 - 500.0000 800.0000
1 36	560.0000	101.2466	0.0000	0.0000	1.0635	1.7701	560.0000	101.2466 - 500.0000 800.0000
1 37	540.0000	4.2326	0.0000	0.0000	1.0278	-3.0589	540.0000	4.2326 - 500.0000 800.0000
1 38	830.0000	24.4184	0.0000	0.0000	1.0265	1.8947	830.0000	24.4184 - 500.0000 800.0000
2 39	1312.8794	75.0398	1104.0000	250.0000	1.0300	-10.9610	208.8794	-174.9602

### I.I.III Generators

Parameters for the two-axis model of the synchronous machines are shown in tables as follows. All values are given on the same system base MVA.

Unit No.	H	$R_a$	$x'_d$	$x'_q$	$x_d$	$x_q$	$T'_{do}$	$T'_{qo}$	$x_l$
1	500	0	0.006	0.008	0.02	0.019	7	0.7	0.003
2	30.3	0	0.0697	0.17	0.295	0.282	6.56	1.5	0.035
3	35.8	0	0.0531	0.0876	0.2495	0.237	5.7	1.5	0.0304
4	28.6	0	0.0436	0.166	0.262	0.258	5.69	1.5	0.0295
5	26	0	0.132	0.166	0.67	0.62	5.4	0.44	0.054
6	34.8	0	0.05	0.0814	0.254	0.241	7.3	0.4	0.0224
7	26.4	0	0.049	0.186	0.295	0.292	5.66	1.5	0.0322
8	24.3	0	0.057	0.0911	0.29	0.28	6.7	0.41	0.028
9	34.5	0	0.057	0.0587	0.2106	0.205	4.79	1.96	0.0298
10	42	0	0.031	0.008	0.1	0.069	10.2	0	0.01

Table I-1 Generators dynamic data for 39-IEEE

### I.I.IV Generators Ramping Data

Generators	Time Required from off-status to synchronization(minute)	Time Required from synchronization to min load (minute)	Time Required from min load to max load (minute)
1	90	96	186
2	90	96	186
3	240	270	390
4	240	270	390
5	54	84	204
6	240	270	390
7	240	300	390
8	240	300	390
9	240	330	420
10	240	330	420

Table I-2 Generator ramping data for 39-IEEE

## I.II Libyan Power System

### I.II.I Basic Load Flow

BBAR	Pg (MW)	Qg (MVAR)	PI (MW)	QI (MVAR)	Vm (pu)	Va (rad)	P (MW)	Q (MVAR)
1 TBK1081	24.7000	3.4463	0.0000	0.0000	1.0085	-6.8339	24.7000	3.4463
20.0000	10.0000							
1 TBK1082	41.1700	1.1337	0.0000	0.0000	1.0249	-23.4865	41.1700	1.1337
20.0000	30.0000							
1 TBK1083	41.1700	1.1337	0.0000	0.0000	1.0249	-23.4865	41.1700	1.1337
20.0000	30.0000							
0 ABK2208	0.0000	0.0000	0.0000	0.0000	1.0188	-10.6905	0.0000	0.0000
0 TRG2208	0.0000	0.0000	0.0000	0.0000	1.0021	-35.4695	0.0000	0.0000
0 ZHR3081	0.0000	0.0000	22.7000	14.1000	0.9948	-12.9158	-22.7000	-14.1000
0 BGM3081	0.0000	0.0000	24.2000	14.9000	1.0011	-13.2601	-24.2000	-14.9000
0 BRE3081	0.0000	0.0000	5.7000	3.5000	1.0140	-26.2432	-5.7000	-3.5000
0 DRN3081	0.0000	0.0000	13.9000	8.6000	1.0024	-28.4983	-13.9000	-8.6000
0 HAD3081	0.0000	0.0000	23.2000	14.4000	0.9960	-13.8643	-23.2000	-14.4000
0 HMP3081	0.0000	0.0000	13.7000	8.4000	1.0026	-14.8567	-13.7000	-8.4000
0 HON6681	0.0000	0.0000	8.1000	5.0000	1.0046	-27.0658	-8.1000	-5.0000
0 TRH3081	0.0000	0.0000	10.8000	6.7000	1.0017	-14.2517	-10.8000	-6.7000
0 TRE3081	0.0000	0.0000	51.8000	32.1000	0.9944	-14.3568	-51.8000	-32.1000
0 TRW3081	0.0000	0.0000	15.8000	9.7000	1.0010	-12.3137	-15.8000	-9.7000
0 ZMZ3081	0.0000	0.0000	3.2000	1.9000	1.0110	-21.2164	-3.2000	-1.9000
0 ZAW3081	0.0000	0.0000	62.2000	38.5000	0.9904	-11.6052	-62.2000	-38.5000
0 ZLT3081	0.0000	0.0000	19.4000	12.0000	0.9993	-17.7827	-19.4000	-12.0000
0 ZUR3081	0.0000	0.0000	31.0000	19.2000	0.9986	-13.5336	-31.0000	-19.2000
0 TRS3081	0.0000	0.0000	37.1000	23.0000	0.9802	-15.9422	-37.1000	-23.0000
0 HMP1181	0.0000	0.0000	0.0000	0.0000	1.0071	-14.4567	0.0000	0.0000
0 HON1181	0.0000	0.0000	0.0000	0.0000	1.0158	-26.1112	0.0000	0.0000
0 TRG1181	0.0000	0.0000	0.0000	0.0000	1.0155	-36.4055	0.0000	0.0000
0 TRH1181	0.0000	0.0000	0.0000	0.0000	1.0009	-14.3241	0.0000	0.0000
0 TRW1181	0.0000	0.0000	0.0000	0.0000	0.9998	-12.4199	0.0000	0.0000
0 ZHR1181	0.0000	0.0000	0.0000	0.0000	1.0061	-11.9506	0.0000	0.0000
0 ZLT1181	0.0000	0.0000	0.0000	0.0000	0.9978	-17.9135	0.0000	0.0000
0 ZMZ1181	0.0000	0.0000	0.0000	0.0000	1.0120	-21.1241	0.0000	0.0000
0 ZUR1181	0.0000	0.0000	0.0000	0.0000	0.9962	-13.7432	0.0000	0.0000
0 BNN3081	0.0000	0.0000	16.6000	10.3000	0.9995	-28.2618	-16.6000	-10.3000
0 BNN1181	0.0000	0.0000	0.0000	0.0000	1.0005	-28.1726	0.0000	0.0000

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0 BNS3081	0.0000	0.0000	48.4000	29.9000	1.0040	-28.2700	-48.4000	-29.9000
0 BNS1181	0.0000	0.0000	0.0000	0.0000	1.0031	-28.3727	0.0000	0.0000
0 BUT3081	0.0000	0.0000	37.6000	23.3000	0.9898	-29.9598	-37.6000	-23.3000
0 BUT1181	0.0000	0.0000	0.0000	0.0000	1.0028	-28.8430	0.0000	0.0000
0 BWD6681	0.0000	0.0000	15.2000	9.4000	1.0029	-21.1430	-15.2000	-9.4000
0 BWD1181	0.0000	0.0000	0.0000	0.0000	1.0103	-20.5046	0.0000	0.0000
0 BZZ3081	0.0000	0.0000	45.8000	28.4000	0.9710	-17.9268	-45.8000	-28.4000
0 BZZ1181	0.0000	0.0000	0.0000	0.0000	0.9899	-16.2832	0.0000	0.0000
0 HMS3081	0.0000	0.0000	6.3000	1.6000	1.0228	-15.5928	-6.3000	-1.6000
0 HMS1181	0.0000	0.0000	0.0000	0.0000	1.0284	-15.0487	0.0000	0.0000
0 JAL3081	0.0000	0.0000	12.6000	7.8000	1.0100	-29.1556	-12.6000	-7.8000
0 JAL1181	0.0000	0.0000	0.0000	0.0000	1.0090	-29.2387	0.0000	0.0000
0 NAT3081	0.0000	0.0000	21.0000	13.0000	0.9857	-15.5575	-21.0000	-13.0000
0 NAT1181	0.0000	0.0000	0.0000	0.0000	0.9942	-14.8184	0.0000	0.0000
0 NZR3081	0.0000	0.0000	46.5000	28.8000	0.9719	-18.0349	-46.5000	-28.8000
0 NZR1181	0.0000	0.0000	0.0000	0.0000	0.9912	-16.3698	0.0000	0.0000
0 RBT3081	0.0000	0.0000	0.5000	0.3000	1.0093	-11.4156	-0.5000	-0.3000
0 RBT1181	0.0000	0.0000	0.0000	0.0000	1.0093	-11.4106	0.0000	0.0000
0 RWS6681	0.0000	0.0000	16.8000	10.4000	1.0026	-10.9422	-16.8000	-10.4000
0 RWS1181	0.0000	0.0000	0.0000	0.0000	1.0108	-10.2367	0.0000	0.0000
0 TMM6681	0.0000	0.0000	5.4000	3.3000	1.0081	-27.9079	-5.4000	-3.3000
0 TMM1181	0.0000	0.0000	0.0000	0.0000	1.0107	-27.6823	0.0000	0.0000
0 XRD1181	0.0000	0.0000	0.0000	0.0000	1.0069	-28.9138	0.0000	0.0000
0 XRD6681	0.0000	0.0000	25.0000	15.5000	0.9868	-30.6236	-25.0000	-15.5000
0 TBK6681	0.0000	0.0000	13.0000	8.0000	1.0102	-27.7464	-13.0000	-8.0000
0 TBK1181	0.0000	0.0000	0.0000	0.0000	1.0101	-27.7559	0.0000	0.0000
0 TAZ6681	0.0000	0.0000	1.9000	1.2000	1.0124	-29.6523	-1.9000	-1.2000
0 TAZ1181	0.0000	0.0000	0.0000	0.0000	1.0121	-29.6813	0.0000	0.0000
0 HAD1181	0.0000	0.0000	0.0000	0.0000	0.9958	-13.8994	0.0000	0.0000
1 ZAW1581	111.2700	41.9925	0.0000	0.0000	1.0316	-8.7604	111.2700	41.9925 -
	50.0000	120.0000						
0 TRE1181	0.0000	0.0000	0.0000	0.0000	0.9930	-14.4811	0.0000	0.0000
0 TRS1181	0.0000	0.0000	0.0000	0.0000	0.9990	-14.3298	0.0000	0.0000
1 ZAW1582	111.1600	33.5476	0.0000	0.0000	1.0315	-8.0287	111.1600	33.5476 -
	50.0000	120.0000						
0 ZHR3082	0.0000	0.0000	45.4000	28.1000	0.9917	-13.7438	-45.4000	-28.1000
0 BGM3082	0.0000	0.0000	24.2000	14.9000	1.0000	-13.6218	-24.2000	-14.9000
0 BRE3082	0.0000	0.0000	5.7000	3.5000	1.0140	-26.2432	-5.7000	-3.5000
0 DRN3082	0.0000	0.0000	1.9000	1.1600	1.0091	-27.5657	-1.9000	-1.1600
0 HAD3082	0.0000	0.0000	46.3000	28.7000	0.9786	-17.4846	-46.3000	-28.7000
0 HMP3082	0.0000	0.0000	13.7000	8.4000	1.0047	-15.1020	-13.7000	-8.4000

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0 HON6682	0.0000	0.0000	16.2000	10.0000	1.0052	-27.0647	-16.2000	-10.0000
0 TRH3082	0.0000	0.0000	10.8000	6.7000	1.0000	-14.7650	-10.8000	-6.7000
0 TRE3082	0.0000	0.0000	25.9000	16.0000	0.9916	-15.7707	-25.9000	-16.0000
0 TRW3082	0.0000	0.0000	15.8000	9.7000	0.9985	-13.2922	-15.8000	-9.7000
0 ZMZ3082	0.0000	0.0000	3.2000	1.9000	1.0110	-21.2164	-3.2000	-1.9000
0 ZAW3082	0.0000	0.0000	62.2000	38.5000	0.9900	-12.3280	-62.2000	-38.5000
0 ZLT3082	0.0000	0.0000	6.1300	5.1000	1.0197	-17.7569	-6.1300	-5.1000
0 ZUR3082	0.0000	0.0000	31.0000	19.2000	0.9982	-13.7494	-31.0000	-19.2000
0 TRS3082	0.0000	0.0000	37.1000	23.0000	0.9785	-16.5064	-37.1000	-23.0000
0 HMP1182	0.0000	0.0000	0.0000	0.0000	1.0093	-14.7037	0.0000	0.0000
0 HON1182	0.0000	0.0000	0.0000	0.0000	1.0164	-26.1113	0.0000	0.0000
0 TRG1182	0.0000	0.0000	0.0000	0.0000	1.0155	-36.4055	0.0000	0.0000
0 TRE1182	0.0000	0.0000	0.0000	0.0000	0.9896	-15.9483	0.0000	0.0000
0 TRH1182	0.0000	0.0000	0.0000	0.0000	0.9991	-14.8377	0.0000	0.0000
0 TRS1182	0.0000	0.0000	0.0000	0.0000	0.9973	-14.8884	0.0000	0.0000
0 TRW1182	0.0000	0.0000	0.0000	0.0000	0.9973	-13.3990	0.0000	0.0000
1 RWS1581	111.1600	-2.9523	0.0000	0.0000	1.0273	-7.4512	111.1600	-2.9523
50.0000	120.0000							
0 ZHR1182	0.0000	0.0000	0.0000	0.0000	1.0029	-12.7726	0.0000	0.0000
0 ZLT1182	0.0000	0.0000	0.0000	0.0000	1.0175	-17.8796	0.0000	0.0000
0 ZMZ1182	0.0000	0.0000	0.0000	0.0000	1.0120	-21.1241	0.0000	0.0000
0 ZUR1182	0.0000	0.0000	0.0000	0.0000	0.9958	-13.9591	0.0000	0.0000
0 BNN3082	0.0000	0.0000	16.6000	10.3000	0.9995	-28.2618	-16.6000	-10.3000
0 BNN1182	0.0000	0.0000	0.0000	0.0000	1.0005	-28.1726	0.0000	0.0000
0 BNS3082	0.0000	0.0000	30.2000	18.7000	0.9922	-30.4294	-30.2000	-18.7000
0 BNS1182	0.0000	0.0000	0.0000	0.0000	0.9889	-30.7190	0.0000	0.0000
0 BUT3082	0.0000	0.0000	75.2000	46.5000	0.9877	-29.9737	-75.2000	-46.5000
0 BUT1182	0.0000	0.0000	0.0000	0.0000	1.0007	-28.8522	0.0000	0.0000
0 BWD6682	0.0000	0.0000	15.2000	9.4000	1.0078	-20.3488	-15.2000	-9.4000
0 BWD1182	0.0000	0.0000	0.0000	0.0000	1.0115	-20.0315	0.0000	0.0000
0 BZZ3082	0.0000	0.0000	91.7000	56.8000	0.9677	-17.9601	-91.7000	-56.8000
0 BZZ1182	0.0000	0.0000	0.0000	0.0000	0.9867	-16.3036	0.0000	0.0000
0 HMS3082	0.0000	0.0000	10.4000	5.1000	1.0105	-15.8283	-10.4000	-5.1000
0 HMS1182	0.0000	0.0000	0.0000	0.0000	1.0160	-15.2836	0.0000	0.0000
0 JAL3082	0.0000	0.0000	12.6000	7.8000	1.0100	-29.1556	-12.6000	-7.8000
0 JAL1182	0.0000	0.0000	0.0000	0.0000	1.0090	-29.2387	0.0000	0.0000
0 NAT3082	0.0000	0.0000	42.0000	26.0000	0.9835	-15.5664	-42.0000	-26.0000
0 NAT1182	0.0000	0.0000	0.0000	0.0000	0.9920	-14.8240	0.0000	0.0000
0 NZR3082	0.0000	0.0000	93.0000	57.6000	0.9673	-18.2541	-93.0000	-57.6000
0 NZR1182	0.0000	0.0000	0.0000	0.0000	0.9867	-16.5735	0.0000	0.0000
0 RBT3082	0.0000	0.0000	0.5000	0.3000	1.0108	-11.3881	-0.5000	-0.3000

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0 RBT1182	0.0000	0.0000	0.0000	0.0000	1.0108	-11.3855	0.0000	0.0000
0 RWS6682	0.0000	0.0000	16.8000	10.4000	1.0026	-10.9422	-16.8000	-10.4000
0 RWS1182	0.0000	0.0000	0.0000	0.0000	1.0108	-10.2367	0.0000	0.0000
0 TMM6682	0.0000	0.0000	5.4000	3.3000	1.0155	-28.2541	-5.4000	-3.3000
0 TMM1182	0.0000	0.0000	0.0000	0.0000	1.0203	-27.8951	0.0000	0.0000
0 XRD1182	0.0000	0.0000	0.0000	0.0000	1.0041	-28.9178	0.0000	0.0000
0 XRD6682	0.0000	0.0000	50.0000	31.0000	0.9840	-30.6373	-50.0000	-31.0000
0 TBK6682	0.0000	0.0000	13.0000	8.0000	1.0102	-27.7464	-13.0000	-8.0000
0 TBK1182	0.0000	0.0000	0.0000	0.0000	1.0101	-27.7559	0.0000	0.0000
0 TAZ6682	0.0000	0.0000	1.9000	1.2000	1.0124	-29.6523	-1.9000	-1.2000
0 TAZ1182	0.0000	0.0000	0.0000	0.0000	1.0121	-29.6813	0.0000	0.0000
1 ZWT1181	32.9400	-1.1063	0.0000	0.0000	1.0148	-21.3428	32.9400	-1.1063 - 15.0000 30.0000
1 ZAW1583	111.4500	41.9935	0.0000	0.0000	1.0316	-8.7577	111.4500	41.9935 - 50.0000 120.0000
1 ZWT1182	32.9400	-1.1063	0.0000	0.0000	1.0148	-21.3428	32.9400	-1.1063 - 15.0000 30.0000
1 ZAW1584	111.1600	41.9920	0.0000	0.0000	1.0316	-8.7621	111.1600	41.9920 - 50.0000 120.0000
0 WRL6681	0.0000	0.0000	14.7000	9.1000	0.9965	-30.4424	-14.7000	-9.1000
0 WRL6682	0.0000	0.0000	14.7000	9.1000	0.9965	-30.4424	-14.7000	-9.1000
0 AWN668	0.0000	0.0000	10.5000	6.5000	1.0069	-38.4253	-10.5000	-6.5000
1 ZWT1183	32.9400	-1.1063	0.0000	0.0000	1.0148	-21.3428	32.9400	-1.1063 - 15.0000 30.0000
1 ZAW1585	111.1600	33.5476	0.0000	0.0000	1.0315	-8.0287	111.1600	33.5476 - 50.0000 120.0000
0 AGE22081	0.0000	0.0000	0.0000	0.0000	1.0124	-11.1527	0.0000	0.0000
0 AGE22082	0.0000	0.0000	0.0000	0.0000	1.0141	-10.6823	0.0000	0.0000
0 SHK22081	0.0000	0.0000	0.0000	0.0000	1.0254	-10.4688	0.0000	0.0000
0 SHK22082	0.0000	0.0000	0.0000	0.0000	1.0253	-10.4378	0.0000	0.0000
0 ELH22081	0.0000	0.0000	0.0000	0.0000	1.0073	-12.8104	0.0000	0.0000
0 ELH22082	0.0000	0.0000	0.0000	0.0000	1.0107	-12.1873	0.0000	0.0000
0 SRJ22081	0.0000	0.0000	0.0000	0.0000	1.0018	-12.3422	0.0000	0.0000
0 SRJ22082	0.0000	0.0000	0.0000	0.0000	1.0075	-11.5006	0.0000	0.0000
0 GHR22081	0.0000	0.0000	0.0000	0.0000	1.0047	-13.4331	0.0000	0.0000
0 GHR22082	0.0000	0.0000	0.0000	0.0000	1.0074	-12.8478	0.0000	0.0000
0 ARQ22081	0.0000	0.0000	0.0000	0.0000	1.0048	-13.3590	0.0000	0.0000
0 ARQ22082	0.0000	0.0000	0.0000	0.0000	1.0086	-12.7438	0.0000	0.0000
0 GRB22081	0.0000	0.0000	0.0000	0.0000	1.0101	-13.9951	0.0000	0.0000
0 GRB22082	0.0000	0.0000	0.0000	0.0000	1.0096	-13.6374	0.0000	0.0000
0 GM12208	0.0000	0.0000	0.0000	0.0000	1.0216	-23.9250	0.0000	0.0000

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0 GM22208	0.0000	0.0000	0.0000	0.0000	1.0195	-27.2894	0.0000	0.0000
0 WKM22081	0.0000	0.0000	0.0000	0.0000	1.0180	-15.3244	0.0000	0.0000
0 WKM22082	0.0000	0.0000	0.0000	0.0000	1.0153	-15.1813	0.0000	0.0000
0 MSW22081	0.0000	0.0000	0.0000	0.0000	1.0095	-17.9753	0.0000	0.0000
0 MSW22082	0.0000	0.0000	0.0000	0.0000	1.0092	-17.9584	0.0000	0.0000
0 MSE22081	0.0000	0.0000	0.0000	0.0000	1.0078	-18.0739	0.0000	0.0000
0 MSE22082	0.0000	0.0000	0.0000	0.0000	1.0077	-18.0632	0.0000	0.0000
0 MST2208	0.0000	0.0000	0.0000	0.0000	1.0087	-18.0071	0.0000	0.0000
0 WRL2208	0.0000	0.0000	0.0000	0.0000	1.0189	-28.8348	0.0000	0.0000
0 SMN2208	0.0000	0.0000	0.0000	0.0000	1.0131	-32.2914	0.0000	0.0000
0 SBH2208	0.0000	0.0000	0.0000	0.0000	1.0113	-34.3615	0.0000	0.0000
0 SRT2208	0.0000	0.0000	0.0000	0.0000	1.0288	-23.1825	0.0000	0.0000
0 GDB2208	0.0000	0.0000	0.0000	0.0000	1.0213	-26.2191	0.0000	0.0000
0 GMS2208	0.0000	0.0000	0.0000	0.0000	1.0138	-26.8332	0.0000	0.0000
0 GWR2208	0.0000	0.0000	0.0000	0.0000	1.0087	-27.0318	0.0000	0.0000
0 MRW2208	0.0000	0.0000	0.0000	0.0000	1.0060	-27.9847	0.0000	0.0000
0 MRJ2208	0.0000	0.0000	0.0000	0.0000	1.0013	-27.7065	0.0000	0.0000
0 SRW2208	0.0000	0.0000	0.0000	0.0000	1.0220	-28.5178	0.0000	0.0000
0 SRS2208	0.0000	0.0000	0.0000	0.0000	1.0173	-28.8440	0.0000	0.0000
0 UBR2208	0.0000	0.0000	0.0000	0.0000	1.0157	-36.5086	0.0000	0.0000
1 RWS1582	111.1600	-2.9523	0.0000	0.0000	1.0273	-7.4512	111.1600	-2.9523 -
50.0000	120.0000							
0 AWN2208	0.0000	0.0000	0.0000	0.0000	0.9997	-37.2806	0.0000	0.0000
0 SHA2208	0.0000	0.0000	0.0000	0.0000	1.0220	-25.1261	0.0000	0.0000
0 NBN22081	0.0000	0.0000	0.0000	0.0000	1.0125	-26.3578	0.0000	0.0000
0 NBN22082	0.0000	0.0000	0.0000	0.0000	1.0126	-26.3502	0.0000	0.0000
0 ZAW681	0.0000	0.0000	3.3800	2.5300	1.0147	-9.9939	-3.3800	-2.5300
0 ZAW682	0.0000	0.0000	3.3800	2.5300	1.0146	-9.2624	-3.3800	-2.5300
0 KUF1328	0.0000	0.0000	0.0000	0.0000	0.9857	-29.5449	0.0000	0.0000
1 ABK1181	8.2300	1.1903	0.0000	0.0000	1.0053	-7.6204	8.2300	1.1903 -
3.0000	6.0000							
1 ABK1182	8.2300	1.1903	0.0000	0.0000	1.0053	-7.6204	8.2300	1.1903 -
3.0000	6.0000							
1 ABK1183	8.2300	1.1903	0.0000	0.0000	1.0053	-7.6204	8.2300	1.1903 -
3.0000	6.0000							
1 ABK1184	8.2300	1.4150	0.0000	0.0000	1.0044	-8.6161	8.2300	1.4150 -
3.0000	6.0000							
1 ABK1185	8.2300	1.4150	0.0000	0.0000	1.0044	-8.6161	8.2300	1.4150 -
3.0000	6.0000							
1 ABK1186	8.2300	1.4150	0.0000	0.0000	1.0044	-8.6161	8.2300	1.4150 -
3.0000	6.0000							



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0 SRS1328	0.0000	0.0000	0.0000	0.0000	1.0244	-29.0693	0.0000	0.0000
1 DRN1081	41.1700	8.2422	0.0000	0.0000	1.0138	-22.0436	41.1700	8.2422 -
	20.0000	30.0000						
1 MST1181	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 MST1182	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 MST1183	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 MST1184	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 MST1185	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 MST1186	49.4000	13.6175	0.0000	0.0000	1.0219	-15.1268	49.4000	13.6175 -
	25.0000	50.0000						
1 ZWT1184	32.9400	-1.1063	0.0000	0.0000	1.0148	-21.3428	32.9400	-1.1063 -
	15.0000	30.0000						
1 ZAW1586	111.1600	33.5476	0.0000	0.0000	1.0315	-8.0287	111.1600	33.5476 -
	50.0000	120.0000						
0 ABK1187	0.0000	0.0000	0.0000	0.0000	0.9981	-10.2930	0.0000	0.0000
0 ABK1188	0.0000	0.0000	0.0000	0.0000	0.9951	-11.3733	0.0000	0.0000
0 AGE1181	0.0000	0.0000	0.0000	0.0000	0.9919	-14.5263	0.0000	0.0000
0 AGE1182	0.0000	0.0000	0.0000	0.0000	0.9929	-14.0495	0.0000	0.0000
0 ARQ1181	0.0000	0.0000	0.0000	0.0000	0.9906	-15.9805	0.0000	0.0000
0 ARQ1182	0.0000	0.0000	0.0000	0.0000	1.0103	-15.2884	0.0000	0.0000
0 AWN118	0.0000	0.0000	0.0000	0.0000	1.0120	-37.9868	0.0000	0.0000
0 ELH1181	0.0000	0.0000	0.0000	0.0000	0.9980	-14.1040	0.0000	0.0000
0 ELH1182	0.0000	0.0000	0.0000	0.0000	1.0005	-13.4746	0.0000	0.0000
1 DRN1082	41.1700	6.0719	0.0000	0.0000	1.0221	-21.7727	41.1700	6.0719 -
	20.0000	30.0000						
0 BNSAUX81	0.0000	0.0000	0.0000	0.0000	1.0206	-26.6873	0.0000	0.0000
0 HADAUX81	0.0000	0.0000	0.0000	0.0000	1.0040	-13.2736	0.0000	0.0000
0 ABK3081	0.0000	0.0000	20.0000	12.3000	0.9994	-10.3214	-20.0000	-12.3000
0 ABK3082	0.0000	0.0000	31.5000	19.5000	0.9971	-11.3237	-31.5000	-19.5000
0 AGE3081	0.0000	0.0000	36.2000	22.4000	0.9947	-14.2795	-36.2000	-22.4000
0 AGE3082	0.0000	0.0000	36.2000	22.4000	0.9957	-13.8032	-36.2000	-22.4000
0 GDB1101	0.0000	0.0000	0.0000	0.0000	1.0145	-27.0016	0.0000	0.0000
0 GDB1102	0.0000	0.0000	0.0000	0.0000	1.0145	-27.0016	0.0000	0.0000
0 GHR1101	0.0000	0.0000	0.0000	0.0000	1.0045	-13.8057	0.0000	0.0000
0 GHR1102	0.0000	0.0000	0.0000	0.0000	1.0067	-13.2188	0.0000	0.0000
0 GWR1101	0.0000	0.0000	0.0000	0.0000	1.0042	-28.6459	0.0000	0.0000

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0 GWR1102	0.0000	0.0000	0.0000	0.0000	1.0042	-28.6459	0.0000	0.0000
0 KUF1181	0.0000	0.0000	0.0000	0.0000	0.9888	-29.7068	0.0000	0.0000
0 KUF1182	0.0000	0.0000	0.0000	0.0000	0.9898	-29.7070	0.0000	0.0000
0 SRS1181	0.0000	0.0000	0.0000	0.0000	1.0108	-29.0663	0.0000	0.0000
0 SRS1182	0.0000	0.0000	0.0000	0.0000	1.0108	-29.0663	0.0000	0.0000
0 MRWAUX81	0.0000	0.0000	0.0000	0.0000	1.0130	-27.8529	0.0000	0.0000
0 MRWAUX82	0.0000	0.0000	0.0000	0.0000	1.0157	-27.8534	0.0000	0.0000
0 MSEAUX81	0.0000	0.0000	0.0000	0.0000	1.0093	-17.8510	0.0000	0.0000
1 KUF1183	12.3500	2.1181	0.0000	0.0000	1.0035	-24.6930	12.3500	2.1181
6.0000	8.0000							-
0 KUF6681	0.0000	0.0000	13.7000	8.4000	0.9919	-29.6815	-13.7000	-8.4000
0 ELH3081	0.0000	0.0000	13.7000	8.4000	1.0015	-13.3827	-13.7000	-8.4000
0 SRT3081	0.0000	0.0000	13.4000	8.3000	1.0067	-24.3513	-13.4000	-8.3000
0 ARQ3081	0.0000	0.0000	6.8000	4.1900	1.0119	-15.1052	-6.8000	-4.1900
0 SBH6681	0.0000	0.0000	0.0000	0.0000	1.0148	-34.3615	0.0000	0.0000
0 UBR6681	0.0000	0.0000	11.0000	6.8000	1.0126	-37.6938	-11.0000	-6.8000
1 SRW1181	9.8800	0.9062	0.0000	0.0000	1.0021	-14.5335	9.8800	0.9062
4.0000	7.0000							-
0 SRS6681	0.0000	0.0000	7.9000	4.9000	1.0046	-29.5949	-7.9000	-4.9000
0 MSE3081	0.0000	0.0000	45.2000	27.9000	0.9963	-19.0381	-45.2000	-27.9000
0 MSE1181	0.0000	0.0000	0.0000	0.0000	1.0015	-18.6645	0.0000	0.0000
0 SBH1181	0.0000	0.0000	0.0000	0.0000	1.0148	-34.3615	0.0000	0.0000
0 SMN1181	0.0000	0.0000	0.0000	0.0000	1.0203	-32.1623	0.0000	0.0000
0 SRT1181	0.0000	0.0000	0.0000	0.0000	1.0112	-23.9633	0.0000	0.0000
0 UBR1181	0.0000	0.0000	0.0000	0.0000	1.0221	-36.8906	0.0000	0.0000
0 WRL1181	0.0000	0.0000	0.0000	0.0000	1.0172	-28.6983	0.0000	0.0000
0 NBN3081	0.0000	0.0000	26.3000	16.2000	0.9949	-29.2491	-26.3000	-16.2000
0 NBN1181	0.0000	0.0000	0.0000	0.0000	0.9965	-29.1066	0.0000	0.0000
0 GDB3081	0.0000	0.0000	11.7000	7.2000	1.0106	-27.2339	-11.7000	-7.2000
0 GDB1181	0.0000	0.0000	0.0000	0.0000	1.0144	-26.8974	0.0000	0.0000
0 GDB6681	0.0000	0.0000	11.7000	7.2000	1.0088	-27.4881	-11.7000	-7.2000
0 GHR6681	0.0000	0.0000	13.1000	8.1000	0.9964	-14.1063	-13.1000	-8.1000
0 GHR3081	0.0000	0.0000	13.1000	8.1000	1.0001	-13.9943	-13.1000	-8.1000
0 GHR1181	0.0000	0.0000	0.0000	0.0000	0.9991	-14.0825	0.0000	0.0000
0 GM16681	0.0000	0.0000	10.0000	6.2000	0.9951	-25.0415	-10.0000	-6.2000
0 GM11181	0.0000	0.0000	0.0000	0.0000	1.0000	-24.6139	0.0000	0.0000
0 GM26681	0.0000	0.0000	15.0000	9.3000	0.9976	-28.9453	-15.0000	-9.3000
0 GM21181	0.0000	0.0000	0.0000	0.0000	1.0049	-28.3085	0.0000	0.0000
0 GMS6681	0.0000	0.0000	3.4000	2.1000	1.0084	-27.1556	-3.4000	-2.1000
0 GMS1181	0.0000	0.0000	0.0000	0.0000	1.0110	-26.9290	0.0000	0.0000
0 GRB3081	0.0000	0.0000	21.0000	13.0000	0.9935	-15.6301	-21.0000	-13.0000

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0 GRB1181	0.0000	0.0000	0.0000	0.0000	1.0019	-14.9024	0.0000	0.0000
0 GWR6681	0.0000	0.0000	23.9000	14.8000	0.9924	-29.6665	-23.9000	-14.8000
0 GWR3081	0.0000	0.0000	23.9000	14.8000	0.9959	-29.1383	-23.9000	-14.8000
0 GWR1181	0.0000	0.0000	0.0000	0.0000	1.0040	-28.4336	0.0000	0.0000
0 MRJ3081	0.0000	0.0000	26.3000	16.2000	0.9788	-31.2138	-26.3000	-16.2000
0 RWS681	0.0000	0.0000	3.3800	2.5300	1.0104	-8.6951	-3.3800	-2.5300
0 MRW6681	0.0000	0.0000	13.7000	8.5000	0.9908	-29.9441	-13.7000	-8.5000
0 MRW3081	0.0000	0.0000	13.7000	8.5000	1.0000	-29.1927	-13.7000	-8.5000
0 MSW3081	0.0000	0.0000	26.3000	16.2000	0.9896	-20.8649	-26.3000	-16.2000
0 MSW1181	0.0000	0.0000	0.0000	0.0000	1.0026	-19.7368	0.0000	0.0000
0 SHK6681	0.0000	0.0000	6.3000	3.9000	1.0084	-11.0333	-6.3000	-3.9000
0 SHK1181	0.0000	0.0000	0.0000	0.0000	1.0132	-10.6143	0.0000	0.0000
0 SRJ3081	0.0000	0.0000	44.1000	27.3000	0.9764	-16.3812	-44.1000	-27.3000
0 SRJ1181	0.0000	0.0000	0.0000	0.0000	0.9989	-14.4566	0.0000	0.0000
0 WKM3081	0.0000	0.0000	4.4700	2.7700	1.0239	-16.7512	-4.4700	-2.7700
0 WKM1181	0.0000	0.0000	0.0000	0.0000	1.0265	-16.1522	0.0000	0.0000
0 SRW6681	0.0000	0.0000	6.6000	4.1000	1.0080	-28.2246	-6.6000	-4.1000
0 SRW1182	0.0000	0.0000	0.0000	0.0000	1.0148	-28.4310	0.0000	0.0000
0 RWS682	0.0000	0.0000	3.3800	2.5300	1.0104	-8.6951	-3.3800	-2.5300
1 KUF1184	12.3500	2.1089	0.0000	0.0000	1.0057	-17.0815	12.3500	2.1089
6.0000	8.0000							
0 KUF6682	0.0000	0.0000	13.7000	8.4000	0.9914	-29.6813	-13.7000	-8.4000
0 ELH3082	0.0000	0.0000	13.7000	8.4000	0.9990	-14.0116	-13.7000	-8.4000
0 SRT3082	0.0000	0.0000	13.4000	8.3000	1.0067	-24.3513	-13.4000	-8.3000
0 ARQ3082	0.0000	0.0000	27.8000	17.2000	0.9928	-15.7904	-27.8000	-17.2000
0 SBH6682	0.0000	0.0000	50.6000	31.3000	0.9895	-37.1286	-50.6000	-31.3000
0 UBR6682	0.0000	0.0000	11.0000	6.8000	1.0126	-37.6938	-11.0000	-6.8000
1 SRW1183	9.8800	0.9062	0.0000	0.0000	1.0021	-14.5335	9.8800	0.9062
4.0000	7.0000							
0 SRS6682	0.0000	0.0000	7.9000	4.9000	1.0046	-29.5949	-7.9000	-4.9000
0 MSE3082	0.0000	0.0000	45.2000	27.9000	0.9895	-20.5839	-45.2000	-27.9000
0 MSE1182	0.0000	0.0000	0.0000	0.0000	1.0007	-19.6126	0.0000	0.0000
0 SBH1182	0.0000	0.0000	0.0000	0.0000	1.0259	-34.1303	0.0000	0.0000
0 SMN1182	0.0000	0.0000	0.0000	0.0000	1.0185	-32.1618	0.0000	0.0000
0 SRT1182	0.0000	0.0000	0.0000	0.0000	1.0112	-23.9633	0.0000	0.0000
0 UBR1182	0.0000	0.0000	0.0000	0.0000	1.0221	-36.8906	0.0000	0.0000
0 WRL1182	0.0000	0.0000	0.0000	0.0000	1.0172	-28.6983	0.0000	0.0000
0 NBN3082	0.0000	0.0000	26.3000	16.2000	0.9948	-29.2573	-26.3000	-16.2000
0 NBN1182	0.0000	0.0000	0.0000	0.0000	0.9964	-29.1147	0.0000	0.0000
0 GDB3082	0.0000	0.0000	11.7000	7.2000	1.0106	-27.2339	-11.7000	-7.2000
0 GDB1182	0.0000	0.0000	0.0000	0.0000	1.0144	-26.8974	0.0000	0.0000

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0 GDB6682	0.0000	0.0000	11.7000	7.2000	1.0088	-27.4881	-11.7000	-7.2000
0 GHR6682	0.0000	0.0000	13.1000	8.1000	0.9942	-14.6971	-13.1000	-8.1000
0 GHR3082	0.0000	0.0000	13.1000	8.1000	0.9979	-14.5846	-13.1000	-8.1000
0 GHR1182	0.0000	0.0000	0.0000	0.0000	0.9969	-14.6731	0.0000	0.0000
0 GM16682	0.0000	0.0000	10.0000	6.2000	0.9951	-25.0415	-10.0000	-6.2000
0 GM11182	0.0000	0.0000	0.0000	0.0000	1.0000	-24.6139	0.0000	0.0000
0 GM26682	0.0000	0.0000	15.0000	9.3000	0.9976	-28.9453	-15.0000	-9.3000
0 GM21182	0.0000	0.0000	0.0000	0.0000	1.0049	-28.3085	0.0000	0.0000
0 GMS6682	0.0000	0.0000	3.4000	2.1000	1.0084	-27.1556	-3.4000	-2.1000
0 GMS1182	0.0000	0.0000	0.0000	0.0000	1.0110	-26.9290	0.0000	0.0000
0 GRB3082	0.0000	0.0000	21.0000	13.0000	0.9933	-15.9888	-21.0000	-13.0000
0 GRB1182	0.0000	0.0000	0.0000	0.0000	1.0017	-15.2608	0.0000	0.0000
0 GWR6682	0.0000	0.0000	23.9000	14.8000	0.9924	-29.6665	-23.9000	-14.8000
0 GWR3082	0.0000	0.0000	23.9000	14.8000	0.9959	-29.1383	-23.9000	-14.8000
0 GWR1182	0.0000	0.0000	0.0000	0.0000	1.0040	-28.4336	0.0000	0.0000
0 MRJ3082	0.0000	0.0000	26.3000	16.2000	0.9788	-31.2138	-26.3000	-16.2000
0 HMS4008	0.0000	0.0000	0.0000	0.0000	1.0165	-15.4449	0.0000	0.0000
0 MRW6682	0.0000	0.0000	13.7000	8.5000	0.9983	-29.1009	-13.7000	-8.5000
0 MRW3082	0.0000	0.0000	13.7000	8.5000	0.9973	-29.1993	-13.7000	-8.5000
0 MSW3082	0.0000	0.0000	26.3000	16.2000	0.9898	-20.8806	-26.3000	-16.2000
0 MSW1182	0.0000	0.0000	0.0000	0.0000	1.0028	-19.7529	0.0000	0.0000
0 SHK6682	0.0000	0.0000	6.3000	3.9000	1.0082	-11.0644	-6.3000	-3.9000
0 SHK1182	0.0000	0.0000	0.0000	0.0000	1.0131	-10.6453	0.0000	0.0000
0 SRJ3082	0.0000	0.0000	88.3000	54.7000	0.9693	-17.2948	-88.3000	-54.7000
0 SRJ1182	0.0000	0.0000	0.0000	0.0000	0.9920	-15.3406	0.0000	0.0000
0 WKM3082	0.0000	0.0000	9.1000	4.4400	1.0095	-16.7662	-9.1000	-4.4400
0 WKM1182	0.0000	0.0000	0.0000	0.0000	1.0148	-16.2137	0.0000	0.0000
0 SRW6682	0.0000	0.0000	6.6000	4.1000	1.0080	-28.2246	-6.6000	-4.1000
0 SRW1184	0.0000	0.0000	0.0000	0.0000	1.0148	-28.4310	0.0000	0.0000
0 SHA118	0.0000	0.0000	0.0000	0.0000	0.9980	-26.4978	0.0000	0.0000
0 SHA668	0.0000	0.0000	20.0000	12.4000	0.9881	-27.3609	-20.0000	-12.4000
2 HMPGT10	102.8658	26.6468	0.0000	0.0000	1.0369	-11.7500	102.8658	26.6468
0 SMNU81	0.0000	0.0000	14.0000	8.7000	1.0006	-33.8114	-14.0000	-8.7000
1 HMPGT181	102.9300	25.5171	0.0000	0.0000	1.0309	-11.4732	102.9300	25.5171
-45.0000	120.0000							
1 HMPGT182	102.9300	26.6545	0.0000	0.0000	1.0369	-11.7486	102.9300	26.6545
-45.0000	120.0000							
0 SMNU82	0.0000	0.0000	28.0000	17.3000	0.9989	-33.8170	-28.0000	-17.3000
1 HMPGT183	102.9300	25.5171	0.0000	0.0000	1.0309	-11.4732	102.9300	25.5171
-45.0000	120.0000							

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1 TRS1081	65.8700	29.4768	0.0000	0.0000	1.0263	-9.3234	65.8700	29.4768	-
25.0000	60.0000								
1 TRW1081	24.7000	5.9349	0.0000	0.0000	1.0197	-8.6789	24.7000	5.9349	-
20.0000	30.0000								
1 TRS1082	65.8700	29.4768	0.0000	0.0000	1.0263	-9.3234	65.8700	29.4768	-
25.0000	60.0000								
1 TRW1082	28.8200	7.8796	0.0000	0.0000	1.0200	-9.0862	28.8200	7.8796	-
20.0000	30.0000								
0 FJJ6681	0.0000	0.0000	12.6000	7.8000	1.0079	-37.0284	-12.6000	-7.8000	
0 FJJ6682	0.0000	0.0000	12.6000	7.8000	1.0079	-37.0284	-12.6000	-7.8000	
0 TRG6681	0.0000	0.0000	26.8000	16.6000	0.9916	-38.4170	-26.8000	-16.6000	
0 TRG6682	0.0000	0.0000	26.8000	16.6000	0.9916	-38.4170	-26.8000	-16.6000	
0 BNJ6681	0.0000	0.0000	3.2000	1.9000	1.0114	-23.0784	-3.2000	-1.9000	
0 BNJ6682	0.0000	0.0000	3.2000	1.9000	1.0114	-23.0784	-3.2000	-1.9000	
1 TRS1083	65.8700	29.4768	0.0000	0.0000	1.0263	-9.3234	65.8700	29.4768	-
25.0000	60.0000								
0 GM14008	0.0000	0.0000	0.0000	0.0000	1.0098	-22.7049	0.0000	0.0000	
0 TRW22081	0.0000	0.0000	0.0000	0.0000	1.0072	-11.9086	0.0000	0.0000	
0 ZAW22081	0.0000	0.0000	0.0000	0.0000	1.0176	-10.7314	0.0000	0.0000	
0 ZAW22082	0.0000	0.0000	0.0000	0.0000	1.0202	-10.0100	0.0000	0.0000	
0 ZUR22081	0.0000	0.0000	0.0000	0.0000	1.0149	-11.0755	0.0000	0.0000	
0 ZUR22082	0.0000	0.0000	0.0000	0.0000	1.0156	-10.8620	0.0000	0.0000	
0 RWS2208	0.0000	0.0000	0.0000	0.0000	1.0286	-9.1099	0.0000	0.0000	
0 BGM22081	0.0000	0.0000	0.0000	0.0000	1.0169	-11.5269	0.0000	0.0000	
0 BGM22082	0.0000	0.0000	0.0000	0.0000	1.0189	-11.1697	0.0000	0.0000	
0 RBT2208	0.0000	0.0000	0.0000	0.0000	1.0184	-11.3606	0.0000	0.0000	
0 TRW22082	0.0000	0.0000	0.0000	0.0000	1.0125	-10.9369	0.0000	0.0000	
0 ZHR22081	0.0000	0.0000	0.0000	0.0000	1.0137	-11.2341	0.0000	0.0000	
0 ZHR22082	0.0000	0.0000	0.0000	0.0000	1.0179	-10.4217	0.0000	0.0000	
0 TRS22081	0.0000	0.0000	0.0000	0.0000	1.0028	-12.3784	0.0000	0.0000	
0 TRS22082	0.0000	0.0000	0.0000	0.0000	1.0059	-11.8279	0.0000	0.0000	
0 HAD2208	0.0000	0.0000	0.0000	0.0000	0.9933	-13.4025	0.0000	0.0000	
0 BZZ2208	0.0000	0.0000	0.0000	0.0000	0.9915	-13.5129	0.0000	0.0000	
0 NAT2208	0.0000	0.0000	0.0000	0.0000	0.9912	-13.5339	0.0000	0.0000	
0 NZR22081	0.0000	0.0000	0.0000	0.0000	0.9918	-13.7444	0.0000	0.0000	
0 NZR22082	0.0000	0.0000	0.0000	0.0000	0.9938	-13.5653	0.0000	0.0000	
0 TRE22081	0.0000	0.0000	0.0000	0.0000	1.0007	-13.4955	0.0000	0.0000	
0 TRE22082	0.0000	0.0000	0.0000	0.0000	1.0068	-12.7507	0.0000	0.0000	
0 TRH22081	0.0000	0.0000	0.0000	0.0000	1.0086	-13.8174	0.0000	0.0000	
0 TRH22082	0.0000	0.0000	0.0000	0.0000	1.0098	-13.3073	0.0000	0.0000	
0 HMP22081	0.0000	0.0000	0.0000	0.0000	1.0273	-13.9024	0.0000	0.0000	

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0 HMP22082	0.0000	0.0000	0.0000	0.0000	1.0217	-13.6520	0.0000	0.0000
0 HMS22081	0.0000	0.0000	0.0000	0.0000	1.0239	-14.3287	0.0000	0.0000
0 HMS22082	0.0000	0.0000	0.0000	0.0000	1.0191	-14.0949	0.0000	0.0000
0 BWD22081	0.0000	0.0000	0.0000	0.0000	1.0294	-19.5187	0.0000	0.0000
0 BWD22082	0.0000	0.0000	0.0000	0.0000	1.0336	-19.4827	0.0000	0.0000
0 ZLT22081	0.0000	0.0000	0.0000	0.0000	1.0131	-16.1876	0.0000	0.0000
0 ZLT22082	0.0000	0.0000	0.0000	0.0000	1.0119	-16.0928	0.0000	0.0000
0 ZMZ2208	0.0000	0.0000	0.0000	0.0000	1.0271	-20.9365	0.0000	0.0000
0 BNJ2208	0.0000	0.0000	0.0000	0.0000	1.0303	-22.7333	0.0000	0.0000
0 HON2208	0.0000	0.0000	0.0000	0.0000	1.0247	-26.1865	0.0000	0.0000
0 BRE2208	0.0000	0.0000	0.0000	0.0000	1.0252	-25.7492	0.0000	0.0000
0 ZWT22081	0.0000	0.0000	0.0000	0.0000	1.0214	-26.1266	0.0000	0.0000
0 ZWT22082	0.0000	0.0000	0.0000	0.0000	1.0214	-26.1266	0.0000	0.0000
0 BNS2208	0.0000	0.0000	0.0000	0.0000	1.0080	-27.0249	0.0000	0.0000
0 BUT2208	0.0000	0.0000	0.0000	0.0000	1.0102	-26.6544	0.0000	0.0000
0 BNN2208	0.0000	0.0000	0.0000	0.0000	1.0121	-26.4256	0.0000	0.0000
0 TMM2208	0.0000	0.0000	0.0000	0.0000	1.0187	-27.3166	0.0000	0.0000
0 TBK2208	0.0000	0.0000	0.0000	0.0000	1.0250	-26.7978	0.0000	0.0000
0 DRN2208	0.0000	0.0000	0.0000	0.0000	1.0110	-27.4184	0.0000	0.0000
0 XRD2208	0.0000	0.0000	0.0000	0.0000	0.9988	-28.2092	0.0000	0.0000
0 JAL2208	0.0000	0.0000	0.0000	0.0000	1.0244	-28.0735	0.0000	0.0000
0 FJJ2208	0.0000	0.0000	0.0000	0.0000	1.0150	-35.6772	0.0000	0.0000
0 HMW2208	0.0000	0.0000	0.0000	0.0000	1.0186	-13.6519	0.0000	0.0000
1 TRS1084	65.8700	26.6324	0.0000	0.0000	1.0269	-8.7806	65.8700	26.6324 - 25.0000 60.0000
1 TRW1083	24.7000	5.3487	0.0000	0.0000	1.0211	-8.5296	24.7000	5.3487 - 20.0000 30.0000
0 TAZ1328	0.0000	0.0000	0.0000	0.0000	1.0246	-29.4949	0.0000	0.0000
1 BNN1581	107.0400	38.1731	0.0000	0.0000	1.0267	-24.0684	107.0400	38.1731 -45.0000 120.0000
1 BNN1582	107.0400	38.1731	0.0000	0.0000	1.0267	-24.0684	107.0400	38.1731 -45.0000 120.0000
1 TRS1085	65.8700	31.6980	0.0000	0.0000	1.0238	-9.7098	65.8700	31.6980 - 25.0000 60.0000
1 TRW1084	32.9400	7.1121	0.0000	0.0000	1.0235	-7.7333	32.9400	7.1121 - 20.0000 35.0000
1 BNN1583	107.0400	37.9469	0.0000	0.0000	1.0267	-24.0609	107.0400	37.9469 -45.0000 120.0000
0 BGM1181	0.0000	0.0000	0.0000	0.0000	0.9982	-13.7849	0.0000	0.0000
0 BGM1182	0.0000	0.0000	0.0000	0.0000	0.9993	-13.4228	0.0000	0.0000
0 BNJ1181	0.0000	0.0000	0.0000	0.0000	1.0156	-22.7035	0.0000	0.0000

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0 BNJ1182	0.0000	0.0000	0.0000	0.0000	1.0156	-22.7035	0.0000	0.0000
0 BRE1181	0.0000	0.0000	0.0000	0.0000	1.0159	-26.0801	0.0000	0.0000
0 BRE1182	0.0000	0.0000	0.0000	0.0000	1.0159	-26.0801	0.0000	0.0000
0 TREAUX81	0.0000	0.0000	0.0000	0.0000	1.0071	-13.2593	0.0000	0.0000
0 ZAWAUX81	0.0000	0.0000	0.0000	0.0000	1.0139	-10.2975	0.0000	0.0000
0 FJJ1181	0.0000	0.0000	0.0000	0.0000	1.0253	-35.5621	0.0000	0.0000
0 FJJ1182	0.0000	0.0000	0.0000	0.0000	1.0253	-35.5621	0.0000	0.0000
0 HAD1182	0.0000	0.0000	0.0000	0.0000	0.9750	-17.8110	0.0000	0.0000
1 TRW1085	74.1100	15.1333	0.0000	0.0000	1.0254	-6.7219	74.1100	15.1333 - 30.0000 50.0000
1 TRW1086	74.1100	15.1333	0.0000	0.0000	1.0254	-6.7219	74.1100	15.1333 - 30.0000 50.0000
1 HMPST10	82.3400	63.6188	0.0000	0.0000	1.0575	-11.7554	82.3400	63.6188 - 40.0000 100.0000
1 HMPST181	82.3400	17.9087	0.0000	0.0000	1.0299	-11.4050	82.3400	17.9087 -40.0000 100.0000
1 HMPST182	82.3400	17.9761	0.0000	0.0000	1.0355	-11.6797	82.3400	17.9761 -40.0000 100.0000
1 HMPST183	82.3400	17.9087	0.0000	0.0000	1.0299	-11.4050	82.3400	17.9087 -40.0000 100.0000
0 SJM2208	0.0000	0.0000	0.0000	0.0000	0.9918	-13.7445	0.0000	0.0000
0 ZWT22083	0.0000	0.0000	0.0000	0.0000	1.0214	-26.1266	0.0000	0.0000
0 ZWT22084	0.0000	0.0000	0.0000	0.0000	1.0214	-26.1266	0.0000	0.0000
0 ZWP22081	0.0000	0.0000	0.0000	0.0000	1.0205	-10.4105	0.0000	0.0000
0 ZWP22082	0.0000	0.0000	0.0000	0.0000	1.0227	-9.6767	0.0000	0.0000
0 RLF2208	0.0000	0.0000	0.0000	0.0000	1.0458	-24.8387	0.0000	0.0000
0 DRN6681	0.0000	0.0000	0.0000	0.0000	1.0148	-25.1172	0.0000	0.0000
0 DRN6682	0.0000	0.0000	13.9000	8.6000	1.0032	-25.4501	-13.9000	-8.6000
0 SRT6681	0.0000	0.0000	13.4000	8.3000	1.0066	-24.3515	-13.4000	-8.3000
0 SRT6682	0.0000	0.0000	13.4000	8.3000	1.0066	-24.3515	-13.4000	-8.3000
0 TBK3081	0.0000	0.0000	13.0000	8.0000	1.0167	-25.9534	-13.0000	-8.0000
0 TBK3082	0.0000	0.0000	13.0000	8.0000	1.0123	-27.7891	-13.0000	-8.0000
0 TRH6681	0.0000	0.0000	10.8000	6.7000	0.9985	-14.3430	-10.8000	-6.7000
0 ZMZ6681	0.0000	0.0000	2.0000	1.2000	1.0116	-21.1236	-2.0000	-1.2000
0 ZMZ6682	0.0000	0.0000	2.0000	1.2000	1.0116	-21.1236	-2.0000	-1.2000
1 BNN1584	121.1000	44.8058	0.0000	0.0000	1.0245	-24.5266	121.1000	44.8058 -50.0000 120.0000
0 XRD1183	0.0000	0.0000	0.0000	0.0000	1.0041	-28.9178	0.0000	0.0000
0 RBT1183	0.0000	0.0000	0.0000	0.0000	1.0108	-11.3855	0.0000	0.0000
0 SMN1183	0.0000	0.0000	0.0000	0.0000	1.0185	-32.1618	0.0000	0.0000
0 SBH1183	0.0000	0.0000	0.0000	0.0000	1.0259	-34.1303	0.0000	0.0000

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0 BWD1183	0.0000	0.0000	0.0000	0.0000	1.0115	-20.0315	0.0000	0.0000
0 HON1183	0.0000	0.0000	0.0000	0.0000	1.0164	-26.1113	0.0000	0.0000
0 SRJ1183	0.0000	0.0000	0.0000	0.0000	0.9920	-15.3406	0.0000	0.0000
0 MSE1183	0.0000	0.0000	0.0000	0.0000	1.0007	-19.6126	0.0000	0.0000
0 SRT1183	0.0000	0.0000	0.0000	0.0000	1.0114	-23.9388	0.0000	0.0000
0 SRT1184	0.0000	0.0000	0.0000	0.0000	1.0114	-23.9388	0.0000	0.0000
0 NZR1183	0.0000	0.0000	0.0000	0.0000	0.9867	-16.5735	0.0000	0.0000
0 BUT1183	0.0000	0.0000	0.0000	0.0000	1.0007	-28.8522	0.0000	0.0000
0 DRN1181	0.0000	0.0000	0.0000	0.0000	1.0148	-25.0942	0.0000	0.0000
0 DRN1182	0.0000	0.0000	0.0000	0.0000	1.0032	-25.4303	0.0000	0.0000
0 ZHR1183	0.0000	0.0000	0.0000	0.0000	1.0029	-12.7726	0.0000	0.0000
0 BZZ1183	0.0000	0.0000	0.0000	0.0000	0.9867	-16.3036	0.0000	0.0000
0 NAT1183	0.0000	0.0000	0.0000	0.0000	0.9920	-14.8240	0.0000	0.0000
0 TRH6682	0.0000	0.0000	10.8000	6.7000	0.9969	-14.8565	-10.8000	-6.7000
0 TRH1183	0.0000	0.0000	0.0000	0.0000	1.0054	-14.1243	0.0000	0.0000
0 TRH1184	0.0000	0.0000	0.0000	0.0000	1.0070	-13.6132	0.0000	0.0000
0 ZAWAUX82	0.0000	0.0000	0.0000	0.0000	1.0143	-9.5766	0.0000	0.0000
0 BNS6.18	0.0000	0.0000	0.0000	0.0000	1.0206	-26.6873	0.0000	0.0000
0 HAD6.18	0.0000	0.0000	0.0000	0.0000	1.0040	-13.2736	0.0000	0.0000
0 ZMZ1183	0.0000	0.0000	0.0000	0.0000	1.0123	-21.0562	0.0000	0.0000
0 ZMZ1184	0.0000	0.0000	0.0000	0.0000	1.0123	-21.0562	0.0000	0.0000
0 MSF22081	0.0000	0.0000	0.0000	0.0000	1.0084	-18.0552	0.0000	0.0000
0 MSF22082	0.0000	0.0000	0.0000	0.0000	1.0084	-18.0557	0.0000	0.0000
0 MSF3081	0.0000	0.0000	0.0000	0.0000	0.9824	-25.6628	0.0000	0.0000
0 MSF3082	0.0000	0.0000	0.0000	0.0000	0.9821	-25.6705	0.0000	0.0000
1 MSF3083	0.0000	90.0000	0.0000	0.0000	1.0507	-23.9402	0.0000	90.0000
90.0000	90.0000							
1 MSF3084	0.0000	152.0000	0.0000	0.0000	1.0754	-25.7515	0.0000	152.0000
152.0000	152.0000							
0 MSF30L81	0.0000	0.0000	78.6000	38.0500	0.9807	-25.7089	-78.6000	-38.0500
0 MSF30L82	0.0000	0.0000	42.9000	20.7700	0.9809	-25.7064	-42.9000	-20.7700
0 MSF30L83	0.0000	0.0000	23.0000	11.1400	0.9811	-25.6994	-23.0000	-11.1400
0 MST1081	0.0000	0.0000	0.0000	0.0000	1.0039	-18.8890	0.0000	0.0000
0 MST1082	0.0000	0.0000	0.0000	0.0000	1.0038	-18.8997	0.0000	0.0000
0 MST10L81	0.0000	0.0000	2.4000	1.1600	1.0023	-18.9239	-2.4000	-1.1600
0 MST10L82	0.0000	0.0000	5.0000	2.4200	1.0024	-18.9189	-5.0000	-2.4200
0 MST10L83	0.0000	0.0000	4.0000	1.9400	1.0002	-18.9339	-4.0000	-1.9400
0 MSFF01	0.0000	0.0000	0.0000	0.0000	1.0479	-23.9271	0.0000	0.0000
0 MSFF81	0.0000	0.0000	0.0000	0.0000	1.0735	-25.7469	0.0000	0.0000
1 MSFF02	0.0000	-55.0845	60.0000	29.0600	0.9837	-26.8897	-60.0000	-84.1445
1 MSFF82	0.0000	-58.5736	76.2000	36.9000	1.0031	-29.3401	-76.2000	-95.4736



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0 MSFF83	0.0000	0.0000	0.0000	0.0000	0.9645	-28.0749	0.0000	0.0000
0 MSFF84	0.0000	0.0000	0.0000	0.0000	0.9641	-28.0858	0.0000	0.0000
0 MSFF85	0.0000	0.0000	0.0000	0.0000	1.0497	-25.6646	0.0000	0.0000
0 MSFF86	0.0000	0.0000	0.0000	0.0000	1.0985	-27.7940	0.0000	0.0000
0 DRNCF81	0.0000	0.0000	0.0000	0.0000	0.9896	-26.0758	0.0000	0.0000
0 TMMCF81	0.0000	0.0000	0.0000	0.0000	0.9993	-28.8849	0.0000	0.0000
0 DRNCF82	0.0000	0.0000	6.9000	4.2000	0.9790	-30.6201	-6.9000	-4.2000
0 DRNCF83	0.0000	0.0000	5.1300	3.1800	0.9796	-31.9778	-5.1300	-3.1800
0 LBDCF81	0.0000	0.0000	0.0000	0.0000	0.9915	-16.3592	0.0000	0.0000
0 MRQCF38	0.0000	0.0000	0.0000	0.0000	0.9866	-16.4200	0.0000	0.0000
0 LBDCF82	0.0000	0.0000	7.9400	4.7000	0.9762	-19.3561	-7.9400	-4.7000
0 LBDCF08	0.0000	0.0000	1.8900	1.1800	0.9778	-20.3641	-1.8900	-1.1800
0 MRQCF18	0.0000	0.0000	0.0000	0.0000	0.9850	-19.0001	0.0000	0.0000
0 MRQCF81	0.0000	0.0000	5.1000	3.1000	0.9808	-21.6088	-5.1000	-3.1000
0 MRQCF08	0.0000	0.0000	4.9000	3.0400	0.9799	-22.9058	-4.9000	-3.0400
0 WKMCF38	0.0000	0.0000	0.0000	0.0000	0.9963	-17.1668	0.0000	0.0000
0 SKM308	0.0000	0.0000	0.0000	0.0000	1.0087	-15.2121	0.0000	0.0000
0 SKM68	0.0000	0.0000	9.4000	2.0000	1.0143	-16.9380	-9.4000	-2.0000
0 SKM0.48	0.0000	0.0000	11.5200	7.1300	0.9964	-19.8334	-11.5200	-7.1300
0 ZLTCF81	0.0000	0.0000	0.0000	0.0000	1.0062	-18.5177	0.0000	0.0000
0 ZLTCF82	0.0000	0.0000	13.1000	4.0000	0.9950	-24.2169	-13.1000	-4.0000
0 ZLTCF83	0.0000	0.0000	9.8400	6.1200	0.9929	-26.7188	-9.8400	-6.1200
0 BSCF181	0.0000	0.0000	0.0000	0.0000	1.0012	-28.3661	0.0000	0.0000
0 BSCF182	0.0000	0.0000	3.6000	2.2000	0.9980	-30.4012	-3.6000	-2.2000
0 BSCF183	0.0000	0.0000	4.3900	2.7200	0.9940	-31.5326	-4.3900	-2.7200
0 BSCF281	0.0000	0.0000	0.0000	0.0000	1.0033	-28.3191	0.0000	0.0000
0 BSCF282	0.0000	0.0000	1.8000	1.1000	1.0042	-29.3356	-1.8000	-1.1000
0 BSCF283	0.0000	0.0000	2.1900	1.1900	1.0027	-29.8942	-2.1900	-1.1900
0 MRW6.181	0.0000	0.0000	0.0000	0.0000	1.0130	-27.8529	0.0000	0.0000
0 MRW6.182	0.0000	0.0000	0.0000	0.0000	1.0157	-27.8534	0.0000	0.0000
0 MSE6.18	0.0000	0.0000	0.0000	0.0000	1.0093	-17.8510	0.0000	0.0000
0 TRE6.18	0.0000	0.0000	0.0000	0.0000	1.0071	-13.2593	0.0000	0.0000
0 ZAW6.181	0.0000	0.0000	0.0000	0.0000	1.0139	-10.2975	0.0000	0.0000
0 ZAW6.182	0.0000	0.0000	0.0000	0.0000	1.0143	-9.5766	0.0000	0.0000
0 ABK681	0.0000	0.0000	0.2500	0.1900	1.0015	-7.9050	-0.2500	-0.1900
0 ABK682	0.0000	0.0000	0.2500	0.1900	1.0015	-7.9050	-0.2500	-0.1900
0 ABK683	0.0000	0.0000	0.2500	0.1900	1.0015	-7.9050	-0.2500	-0.1900
0 ABK684	0.0000	0.0000	0.2500	0.1900	1.0006	-8.9012	-0.2500	-0.1900
0 ABK685	0.0000	0.0000	0.2500	0.1900	1.0006	-8.9012	-0.2500	-0.1900
0 ABK686	0.0000	0.0000	0.2500	0.1900	1.0006	-8.9012	-0.2500	-0.1900
0 BNN681	0.0000	0.0000	3.2500	2.4400	1.0104	-25.2652	-3.2500	-2.4400

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0 BNN682	0.0000	0.0000	3.2500	2.4400	1.0104	-25.2652	-3.2500	-2.4400
0 BNN683	0.0000	0.0000	3.2500	2.4400	1.0104	-25.2577	-3.2500	-2.4400
0 BNN684	0.0000	0.0000	3.6200	2.7200	1.0062	-25.8681	-3.6200	-2.7200
0 DRN681	0.0000	0.0000	1.2500	0.9400	1.0044	-22.7470	-1.2500	-0.9400
0 DRN682	0.0000	0.0000	1.2500	0.9400	1.0127	-22.4646	-1.2500	-0.9400
0 HMP601	0.0000	0.0000	3.1200	2.3400	1.0214	-12.8753	-3.1200	-2.3400
0 HMP681	0.0000	0.0000	3.1200	2.3400	1.0153	-12.6118	-3.1200	-2.3400
0 HMP682	0.0000	0.0000	3.1200	2.3400	1.0214	-12.8739	-3.1200	-2.3400
0 HMP683	0.0000	0.0000	3.1200	2.3400	1.0153	-12.6118	-3.1200	-2.3400
0 HMP602	0.0000	0.0000	2.5000	1.8800	0.9354	-19.8272	-2.5000	-1.8800
0 HMP684	0.0000	0.0000	2.5000	1.8800	1.0175	-12.3163	-2.5000	-1.8800
0 HMP685	0.0000	0.0000	2.5000	1.8800	1.0231	-12.5811	-2.5000	-1.8800
0 HMP686	0.0000	0.0000	2.5000	1.8800	1.0175	-12.3163	-2.5000	-1.8800
0 KUF681	0.0000	0.0000	0.3800	0.2800	1.0001	-17.5145	-0.3800	-0.2800
0 KUF682	0.0000	0.0000	0.3800	0.2800	0.9979	-25.1278	-0.3800	-0.2800
0 MST681	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 MST682	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 MST683	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 MST684	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 MST685	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 MST686	0.0000	0.0000	1.5000	1.1200	1.0107	-15.9589	-1.5000	-1.1200
0 SRW681	0.0000	0.0000	0.3000	0.2200	0.9977	-14.8773	-0.3000	-0.2200
0 SRW682	0.0000	0.0000	0.3000	0.2200	0.9977	-14.8773	-0.3000	-0.2200
0 TBK681	0.0000	0.0000	0.7500	0.5600	0.9972	-7.6885	-0.7500	-0.5600
0 TBK682	0.0000	0.0000	1.2500	0.9400	1.0156	-24.1746	-1.2500	-0.9400
0 TBK683	0.0000	0.0000	1.2500	0.9400	1.0156	-24.1746	-1.2500	-0.9400
0 TRS681	0.0000	0.0000	2.0000	1.5000	1.0113	-10.4276	-2.0000	-1.5000
0 TRS682	0.0000	0.0000	2.0000	1.5000	1.0113	-10.4276	-2.0000	-1.5000
0 TRS683	0.0000	0.0000	2.0000	1.5000	1.0113	-10.4276	-2.0000	-1.5000
0 TRS684	0.0000	0.0000	2.0000	1.5000	1.0119	-9.8835	-2.0000	-1.5000
0 TRS685	0.0000	0.0000	2.0000	1.5000	1.0087	-10.8195	-2.0000	-1.5000
0 TRW681	0.0000	0.0000	0.7500	0.5600	1.0085	-9.5146	-0.7500	-0.5600
0 TRW682	0.0000	0.0000	0.8800	0.6600	1.0067	-10.0682	-0.8800	-0.6600
0 TRW683	0.0000	0.0000	0.7500	0.5600	1.0099	-9.3631	-0.7500	-0.5600
0 TRW684	0.0000	0.0000	1.0000	0.7500	1.0084	-8.8436	-1.0000	-0.7500
0 TRW685	0.0000	0.0000	2.2500	1.6900	1.0084	-7.9687	-2.2500	-1.6900
0 TRW686	0.0000	0.0000	2.2500	1.6900	1.0084	-7.9687	-2.2500	-1.6900
0 ZAW683	0.0000	0.0000	3.3800	2.5300	1.0147	-9.9911	-3.3800	-2.5300
0 ZAW684	0.0000	0.0000	3.3800	2.5300	1.0147	-9.9956	-3.3800	-2.5300
0 ZAW685	0.0000	0.0000	3.3800	2.5300	1.0146	-9.2624	-3.3800	-2.5300
0 ZAW686	0.0000	0.0000	3.3800	2.5300	1.0146	-9.2624	-3.3800	-2.5300

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0 ZWT681	0.0000	0.0000	1.0000	0.7500	0.9996	-22.4726	-1.0000	-0.7500
0 ZWT682	0.0000	0.0000	1.0000	0.7500	0.9996	-22.4726	-1.0000	-0.7500
0 ZWT683	0.0000	0.0000	1.0000	0.7500	0.9996	-22.4726	-1.0000	-0.7500
0 ZWT684	0.0000	0.0000	1.0000	0.7500	0.9996	-22.4726	-1.0000	-0.7500
0 HAD3083	0.0000	0.0000	0.0000	0.0000	0.9960	-13.8638	0.0000	0.0000
0 ZAW3083	0.0000	0.0000	0.0000	0.0000	0.9900	-12.3262	0.0000	0.0000
0 ZAW3084	0.0000	0.0000	0.0000	0.0000	0.9904	-11.6034	0.0000	0.0000
0 BNS3083	0.0000	0.0000	0.0000	0.0000	1.0041	-28.2688	0.0000	0.0000
0 MSE3083	0.0000	0.0000	0.0000	0.0000	0.9963	-19.0370	0.0000	0.0000
0 TRE3083	0.0000	0.0000	0.0000	0.0000	0.9944	-14.3559	0.0000	0.0000
0 ABK81	0.0000	0.0000	0.0000	0.0000	0.9981	-10.2930	0.0000	0.0000
0 ABK82	0.0000	0.0000	0.0000	0.0000	0.9951	-11.3733	0.0000	0.0000
0 AGE81	0.0000	0.0000	0.0000	0.0000	0.9919	-14.5263	0.0000	0.0000
0 AGE82	0.0000	0.0000	0.0000	0.0000	0.9929	-14.0495	0.0000	0.0000
0 ARQ81	0.0000	0.0000	0.0000	0.0000	0.9906	-15.9805	0.0000	0.0000
0 ARQ82	0.0000	0.0000	0.0000	0.0000	1.0103	-15.2884	0.0000	0.0000
0 AWN81	0.0000	0.0000	0.0000	0.0000	1.0120	-37.9868	0.0000	0.0000
0 BGM81	0.0000	0.0000	0.0000	0.0000	0.9982	-13.7849	0.0000	0.0000
0 BGM82	0.0000	0.0000	0.0000	0.0000	0.9993	-13.4228	0.0000	0.0000
0 BNJ81	0.0000	0.0000	0.0000	0.0000	1.0156	-22.7035	0.0000	0.0000
0 BNJ82	0.0000	0.0000	0.0000	0.0000	1.0156	-22.7035	0.0000	0.0000
0 BNN81	0.0000	0.0000	0.0000	0.0000	1.0005	-28.1726	0.0000	0.0000
0 BNN82	0.0000	0.0000	0.0000	0.0000	1.0005	-28.1726	0.0000	0.0000
0 BNS81	0.0000	0.0000	0.0000	0.0000	0.9889	-30.7190	0.0000	0.0000
0 BNS82	0.0000	0.0000	0.0000	0.0000	1.0031	-28.3727	0.0000	0.0000
0 BRE81	0.0000	0.0000	0.0000	0.0000	1.0159	-26.0801	0.0000	0.0000
0 BRE82	0.0000	0.0000	0.0000	0.0000	1.0159	-26.0801	0.0000	0.0000
0 BUT81	0.0000	0.0000	0.0000	0.0000	1.0007	-28.8522	0.0000	0.0000
0 BUT82	0.0000	0.0000	0.0000	0.0000	1.0028	-28.8430	0.0000	0.0000
0 BUT83	0.0000	0.0000	0.0000	0.0000	1.0007	-28.8522	0.0000	0.0000
0 BWD81	0.0000	0.0000	0.0000	0.0000	1.0115	-20.0315	0.0000	0.0000
0 BWD82	0.0000	0.0000	0.0000	0.0000	1.0103	-20.5046	0.0000	0.0000
0 BWD83	0.0000	0.0000	0.0000	0.0000	1.0115	-20.0315	0.0000	0.0000
0 BZZ81	0.0000	0.0000	0.0000	0.0000	0.9867	-16.3036	0.0000	0.0000
0 BZZ82	0.0000	0.0000	0.0000	0.0000	0.9899	-16.2832	0.0000	0.0000
0 BZZ83	0.0000	0.0000	0.0000	0.0000	0.9867	-16.3036	0.0000	0.0000
0 COG81	0.0000	0.0000	0.0000	0.0000	0.9964	-29.1147	0.0000	0.0000
0 COG82	0.0000	0.0000	0.0000	0.0000	0.9965	-29.1066	0.0000	0.0000
0 DRN81	0.0000	0.0000	0.0000	0.0000	1.0148	-25.0942	0.0000	0.0000
0 DRN82	0.0000	0.0000	0.0000	0.0000	1.0032	-25.4303	0.0000	0.0000
0 ELH81	0.0000	0.0000	0.0000	0.0000	0.9980	-14.1040	0.0000	0.0000

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0 ELH82	0.0000	0.0000	0.0000	0.0000	1.0005	-13.4746	0.0000	0.0000
0 FJJ81	0.0000	0.0000	0.0000	0.0000	1.0253	-35.5621	0.0000	0.0000
0 FJJ82	0.0000	0.0000	0.0000	0.0000	1.0253	-35.5621	0.0000	0.0000
0 GDB81	0.0000	0.0000	0.0000	0.0000	1.0144	-26.8974	0.0000	0.0000
0 GDB82	0.0000	0.0000	0.0000	0.0000	1.0144	-26.8974	0.0000	0.0000
0 GDB83	0.0000	0.0000	0.0000	0.0000	1.0145	-27.0016	0.0000	0.0000
0 GDB84	0.0000	0.0000	0.0000	0.0000	1.0145	-27.0016	0.0000	0.0000
0 GHR81	0.0000	0.0000	0.0000	0.0000	0.9969	-14.6731	0.0000	0.0000
0 GHR82	0.0000	0.0000	0.0000	0.0000	0.9991	-14.0825	0.0000	0.0000
0 GHR83	0.0000	0.0000	0.0000	0.0000	1.0045	-13.8057	0.0000	0.0000
0 GHR84	0.0000	0.0000	0.0000	0.0000	1.0067	-13.2188	0.0000	0.0000
0 GM181	0.0000	0.0000	0.0000	0.0000	1.0000	-24.6139	0.0000	0.0000
0 GM182	0.0000	0.0000	0.0000	0.0000	1.0000	-24.6139	0.0000	0.0000
0 GM281	0.0000	0.0000	0.0000	0.0000	1.0049	-28.3085	0.0000	0.0000
0 GM282	0.0000	0.0000	0.0000	0.0000	1.0049	-28.3085	0.0000	0.0000
0 GMS81	0.0000	0.0000	0.0000	0.0000	1.0110	-26.9290	0.0000	0.0000
0 GMS82	0.0000	0.0000	0.0000	0.0000	1.0110	-26.9290	0.0000	0.0000
0 GRB81	0.0000	0.0000	0.0000	0.0000	1.0017	-15.2608	0.0000	0.0000
0 GRB82	0.0000	0.0000	0.0000	0.0000	1.0019	-14.9024	0.0000	0.0000
0 GWR81	0.0000	0.0000	0.0000	0.0000	1.0040	-28.4336	0.0000	0.0000
0 GWR82	0.0000	0.0000	0.0000	0.0000	1.0040	-28.4336	0.0000	0.0000
0 GWR83	0.0000	0.0000	0.0000	0.0000	1.0042	-28.6459	0.0000	0.0000
0 GWR84	0.0000	0.0000	0.0000	0.0000	1.0042	-28.6459	0.0000	0.0000
0 HAD81	0.0000	0.0000	0.0000	0.0000	0.9750	-17.8110	0.0000	0.0000
0 HAD82	0.0000	0.0000	0.0000	0.0000	0.9958	-13.8994	0.0000	0.0000
0 HMP81	0.0000	0.0000	0.0000	0.0000	1.0093	-14.7037	0.0000	0.0000
0 HMP82	0.0000	0.0000	0.0000	0.0000	1.0071	-14.4567	0.0000	0.0000
0 HMS81	0.0000	0.0000	0.0000	0.0000	1.0160	-15.2836	0.0000	0.0000
0 HMS82	0.0000	0.0000	0.0000	0.0000	1.0284	-15.0487	0.0000	0.0000
0 HON81	0.0000	0.0000	0.0000	0.0000	1.0164	-26.1113	0.0000	0.0000
0 HON82	0.0000	0.0000	0.0000	0.0000	1.0158	-26.1112	0.0000	0.0000
0 HON83	0.0000	0.0000	0.0000	0.0000	1.0164	-26.1113	0.0000	0.0000
0 JAL81	0.0000	0.0000	0.0000	0.0000	1.0090	-29.2387	0.0000	0.0000
0 JAL82	0.0000	0.0000	0.0000	0.0000	1.0090	-29.2387	0.0000	0.0000
0 KUF81	0.0000	0.0000	0.0000	0.0000	0.9888	-29.7068	0.0000	0.0000
0 KUF82	0.0000	0.0000	0.0000	0.0000	0.9898	-29.7070	0.0000	0.0000
0 MSE81	0.0000	0.0000	0.0000	0.0000	1.0007	-19.6126	0.0000	0.0000
0 MSE82	0.0000	0.0000	0.0000	0.0000	1.0015	-18.6645	0.0000	0.0000
0 MSE83	0.0000	0.0000	0.0000	0.0000	1.0007	-19.6126	0.0000	0.0000
0 MSFHV81	0.0000	0.0000	0.0000	0.0000	0.9645	-28.0749	0.0000	0.0000
0 MSFHV82	0.0000	0.0000	0.0000	0.0000	0.9641	-28.0858	0.0000	0.0000

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0 MSFHV83	0.0000	0.0000	0.0000	0.0000	1.0497	-25.6646	0.0000	0.0000
0 MSFHV84	0.0000	0.0000	0.0000	0.0000	1.0985	-27.7940	0.0000	0.0000
0 MSW81	0.0000	0.0000	0.0000	0.0000	1.0028	-19.7529	0.0000	0.0000
0 MSW82	0.0000	0.0000	0.0000	0.0000	1.0026	-19.7368	0.0000	0.0000
0 NAT81	0.0000	0.0000	0.0000	0.0000	0.9920	-14.8240	0.0000	0.0000
0 NAT82	0.0000	0.0000	0.0000	0.0000	0.9942	-14.8184	0.0000	0.0000
0 NAT83	0.0000	0.0000	0.0000	0.0000	0.9920	-14.8240	0.0000	0.0000
0 NZR81	0.0000	0.0000	0.0000	0.0000	0.9867	-16.5735	0.0000	0.0000
0 NZR82	0.0000	0.0000	0.0000	0.0000	0.9912	-16.3698	0.0000	0.0000
0 NZR83	0.0000	0.0000	0.0000	0.0000	0.9867	-16.5735	0.0000	0.0000
0 RBT81	0.0000	0.0000	0.0000	0.0000	1.0108	-11.3855	0.0000	0.0000
0 RBT82	0.0000	0.0000	0.0000	0.0000	1.0093	-11.4106	0.0000	0.0000
0 RBT83	0.0000	0.0000	0.0000	0.0000	1.0108	-11.3855	0.0000	0.0000
0 RWS81	0.0000	0.0000	0.0000	0.0000	1.0108	-10.2367	0.0000	0.0000
0 RWS82	0.0000	0.0000	0.0000	0.0000	1.0108	-10.2367	0.0000	0.0000
0 SBH81	0.0000	0.0000	0.0000	0.0000	1.0259	-34.1303	0.0000	0.0000
0 SBH82	0.0000	0.0000	0.0000	0.0000	1.0148	-34.3615	0.0000	0.0000
0 SBH83	0.0000	0.0000	0.0000	0.0000	1.0259	-34.1303	0.0000	0.0000
0 SHA81	0.0000	0.0000	0.0000	0.0000	0.9980	-26.4978	0.0000	0.0000
0 SHK81	0.0000	0.0000	0.0000	0.0000	1.0131	-10.6453	0.0000	0.0000
0 SHK82	0.0000	0.0000	0.0000	0.0000	1.0132	-10.6143	0.0000	0.0000
0 SMN81	0.0000	0.0000	0.0000	0.0000	1.0185	-32.1618	0.0000	0.0000
0 SMN82	0.0000	0.0000	0.0000	0.0000	1.0203	-32.1623	0.0000	0.0000
0 SMN83	0.0000	0.0000	0.0000	0.0000	1.0185	-32.1618	0.0000	0.0000
0 SRJ81	0.0000	0.0000	0.0000	0.0000	0.9920	-15.3406	0.0000	0.0000
0 SRJ82	0.0000	0.0000	0.0000	0.0000	0.9989	-14.4566	0.0000	0.0000
0 SRJ83	0.0000	0.0000	0.0000	0.0000	0.9920	-15.3406	0.0000	0.0000
0 SRS81	0.0000	0.0000	0.0000	0.0000	1.0108	-29.0663	0.0000	0.0000
0 SRS82	0.0000	0.0000	0.0000	0.0000	1.0108	-29.0663	0.0000	0.0000
0 SRT81	0.0000	0.0000	0.0000	0.0000	1.0112	-23.9633	0.0000	0.0000
0 SRT82	0.0000	0.0000	0.0000	0.0000	1.0112	-23.9633	0.0000	0.0000
0 SRT83	0.0000	0.0000	0.0000	0.0000	1.0114	-23.9388	0.0000	0.0000
0 SRT84	0.0000	0.0000	0.0000	0.0000	1.0114	-23.9388	0.0000	0.0000
0 SRW81	0.0000	0.0000	0.0000	0.0000	1.0148	-28.4310	0.0000	0.0000
0 SRW82	0.0000	0.0000	0.0000	0.0000	1.0148	-28.4310	0.0000	0.0000
0 TBK81	0.0000	0.0000	0.0000	0.0000	1.0101	-27.7559	0.0000	0.0000
0 TBK82	0.0000	0.0000	0.0000	0.0000	1.0101	-27.7559	0.0000	0.0000
0 TMM81	0.0000	0.0000	0.0000	0.0000	1.0203	-27.8951	0.0000	0.0000
0 TMM82	0.0000	0.0000	0.0000	0.0000	1.0107	-27.6823	0.0000	0.0000
0 TRE81	0.0000	0.0000	0.0000	0.0000	0.9896	-15.9483	0.0000	0.0000
0 TRE82	0.0000	0.0000	0.0000	0.0000	0.9930	-14.4811	0.0000	0.0000

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0 TRG81	0.0000	0.0000	0.0000	0.0000	1.0155	-36.4055	0.0000	0.0000
0 TRG82	0.0000	0.0000	0.0000	0.0000	1.0155	-36.4055	0.0000	0.0000
0 TRH81	0.0000	0.0000	0.0000	0.0000	0.9991	-14.8377	0.0000	0.0000
0 TRH82	0.0000	0.0000	0.0000	0.0000	1.0009	-14.3241	0.0000	0.0000
0 TRH83	0.0000	0.0000	0.0000	0.0000	1.0054	-14.1243	0.0000	0.0000
0 TRH84	0.0000	0.0000	0.0000	0.0000	1.0070	-13.6132	0.0000	0.0000
0 TRS81	0.0000	0.0000	0.0000	0.0000	0.9973	-14.8884	0.0000	0.0000
0 TRS82	0.0000	0.0000	0.0000	0.0000	0.9990	-14.3298	0.0000	0.0000
0 TRW81	0.0000	0.0000	0.0000	0.0000	0.9973	-13.3990	0.0000	0.0000
0 TRW82	0.0000	0.0000	0.0000	0.0000	0.9998	-12.4199	0.0000	0.0000
0 TZR81	0.0000	0.0000	0.0000	0.0000	1.0121	-29.6813	0.0000	0.0000
0 TZR82	0.0000	0.0000	0.0000	0.0000	1.0121	-29.6813	0.0000	0.0000
0 UBR81	0.0000	0.0000	0.0000	0.0000	1.0221	-36.8906	0.0000	0.0000
0 UBR82	0.0000	0.0000	0.0000	0.0000	1.0221	-36.8906	0.0000	0.0000
0 WKM81	0.0000	0.0000	0.0000	0.0000	1.0148	-16.2137	0.0000	0.0000
0 WKM82	0.0000	0.0000	0.0000	0.0000	1.0265	-16.1522	0.0000	0.0000
0 WRL81	0.0000	0.0000	0.0000	0.0000	1.0172	-28.6983	0.0000	0.0000
0 WRL82	0.0000	0.0000	0.0000	0.0000	1.0172	-28.6983	0.0000	0.0000
0 XRD81	0.0000	0.0000	0.0000	0.0000	1.0041	-28.9178	0.0000	0.0000
0 XRD82	0.0000	0.0000	0.0000	0.0000	1.0069	-28.9138	0.0000	0.0000
0 XRD83	0.0000	0.0000	0.0000	0.0000	1.0041	-28.9178	0.0000	0.0000
0 ZHR81	0.0000	0.0000	0.0000	0.0000	1.0029	-12.7726	0.0000	0.0000
0 ZHR82	0.0000	0.0000	0.0000	0.0000	1.0061	-11.9506	0.0000	0.0000
0 ZHR83	0.0000	0.0000	0.0000	0.0000	1.0029	-12.7726	0.0000	0.0000
0 ZLT81	0.0000	0.0000	0.0000	0.0000	1.0175	-17.8796	0.0000	0.0000
0 ZLT82	0.0000	0.0000	0.0000	0.0000	0.9978	-17.9135	0.0000	0.0000
0 ZMZ81	0.0000	0.0000	0.0000	0.0000	1.0120	-21.1241	0.0000	0.0000
0 ZMZ82	0.0000	0.0000	0.0000	0.0000	1.0120	-21.1241	0.0000	0.0000
0 ZMZ83	0.0000	0.0000	0.0000	0.0000	1.0123	-21.0562	0.0000	0.0000
0 ZMZ84	0.0000	0.0000	0.0000	0.0000	1.0123	-21.0562	0.0000	0.0000
0 ZUR81	0.0000	0.0000	0.0000	0.0000	0.9958	-13.9591	0.0000	0.0000
0 ZUR82	0.0000	0.0000	0.0000	0.0000	0.9962	-13.7432	0.0000	0.0000
0 EGYPT	0.0000	0.0000	0.0000	0.0000	1.0329	-26.8603	0.0000	0.0000
0 TUNISIA	0.0000	0.0000	0.0000	0.0000	1.0259	-10.3145	0.0000	0.0000

























## I.II.III Protection Systems for Libya System

Generation Unit Protection	Threshold (Hz)	Time ( Second )
Under Frequency	47.6	0.2
Over Frequency	54.0	0.1
Under Voltage	0.7	1.0
	0.85	3.0
Loss of Excitation	0.85	2.0

Table I-3 Protection of generation units

Interconnection	Line Code	Under Voltage		Over Voltage		Under Frequency	
		PU	S	PU	S	PU	S
Libya-Egypt	Line 1	0.82	0.6	1.2	5	49.5	0.2
	Line 2	0.82	0.6	1.2	5	49.5	0.2
Libya-Tunisia	Line 1	0.75	0.45	1.2	1	48.0	0.2
	Line 2	0.75	0.45	1.2	1	48.0	0.2
	Line 3	0.75	0.45	1.2	1	48.0	0.2
West-East	Line 1	0.82	0.6	1.2	1	48.0	0.2
	Line 2	0.82	0.6	1.2	1	48.0	0.2
	Line 3	0.82	0.6	1.2	1	48.0	0.2
	Line 4	0.82	0.6	1.2	1	48.0	0.2

Table I-4 Protection of interconnection lines



## I.III Contingencies of Assessment

### I.III.I Load Shedding Contingencies

CL1	Three phase fault in ZAW with protection system failure	Area1
CL2	Three phase fault in TRW with protection system failure	Area2
CL3	Three phase fault in MST with protection system failure	Area3
CL4	Three phase fault in SBH with protection system failure	Area4
CL5	Three phase fault in BNN with protection system failure	Area5
CL6	Three phase fault in DRN with protection system failure	Area6
CL7	Three phase fault in TZP with protection system failure	Area7

Table I-5 Assessing load shedding contingencies

### I.III.II Islanding Contingencies

CI1	Tripping two extra generation units	Area1
CI2	Tripping two extra generation units	Area2
CI3	Tripping two extra generation units	Area3
CI4	Tripping two extra generation units	Area5
CI5	Tripping two extra generation units	Area6

Table I-6 Assessing islanding contingencies

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## Publication

- El-werfelli, M.H.; Dunn, R.; Brooks, J., "Design of a transient stability scheme to prevent cascading blackouts," Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International , vol., no., pp.443-448, 4-6 Sept. 2007
- El-werfelli, M.; Brooks, J.; Dunn, R., "Controlled islanding scheme for power systems", Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International, vol., no., pp.1-6, 1-4 Sept. 2008
- Mahmud El-werfelli, H. Haddud , Rod Dunn “ Design of an optimized defence plan for a power system” This paper will appear in: 2008 CIGRE SESSION, Paris ( code number C2-209)
- El-werfelli, M.; Brooks, J.; Dunn, R., "An optimized defence plan for a power system," Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International , vol., no., pp.1-6, 1-4 Sept. 2008
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# Design of a transient stability scheme to prevent cascading blackouts

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## ABSTRACT

This paper presents a novel optimization technique of the settings for various emergency controls in an electrical power system. The goal of this technique is to prevent a cascading blackout and retrieve a new equilibrium operation point following a severe contingency. The main stabilizing actions are tripping generators together with load shedding. This problem is a complex mixed integer programming problem and it is very difficult to solve by ordinary optimization methods such as mathematical approaches. Genetic Algorithms are search algorithms based on the mechanics of natural selection and natural genetics, and are subject to survival of the fittest among string structures. Since the Genetic Algorithm approach is very successful at solving combinatorial optimization problems, it has been applied to solving the problem of cascading blackouts. A Genetic algorithm approach is used to find the optimal combination of generators and loads to be tripped in order to regain a new state of equilibrium in operation, and hence, to prevent the system from failing in this cascading manner. These solutions are evaluated by using the hybrid transient energy function, and the GA optimization technique is able to select the best solution. The two cases tested in order to assess the feasibility of this technique were the 14-bus IEEE network and the 20-machine, dynamically-reduced England Network. The results presented in this paper show that global or near-global optimum solutions can be ascertained within reasonable amounts of time by this new method.

**Keywords:** Cascading blackout, Genetic Algorithm, Power system stability.

## 1. INTRODUCTION

A major blackout is when a large area or a complete area of a power system collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units. A partial blackout may start with a severe fault which can cause a large variation in power flow and busbar voltage which, in turn, can cause the outage of generation units or transmission lines. This certainly causes imbalance in the demand for and generation of power. This sort of disturbance can be the beginning of a cascading blackout when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for stability. This makes the likelihood of converting a local blackout to a major blackout very high. This gives rise to the necessity of having an appropriate scheme to prevent a cascading blackout from becoming a major blackout. [1] A variety of emergency controls are used to prevent cascading blackouts. These emergency controls are generator tripping, fast-valving, load shedding and excitation controls. According to Machowski [2], however, generators and load tripping are the most effective control. Due to this fact, generators and load tripping were considered as the main emergency controls in this technique.

Mathematical optimization methods have been used over the years for power system control problems. However, the solution for large-scale power systems is not easy to obtain by way of ordinary mathematical optimization methods. This is due to the fact that there are many uncertainties in power system problems such as complexity, size and geographical distribution. It is also very much preferred that the solution for power system be a global optimum solution. However; this can not be reached by mathematical methods. All of these factors therefore make it necessary to use a global search technique such as a genetic algorithm. [3]

## 2. GENETIC ALGORITHM

Genetic algorithm is sort of global search technique used in optimization problems by imitating the mechanisms of natural selection and genetics. An increasingly better approximation of the desired solution can be produced by applying the principal of survival of the fittest. In each generation, a new set of approximations of the solution are chosen according to fitness evaluation. The more 'fit' the approximation is, the higher likelihood it has to be selected to reproduce the next generation by using operators borrowed from natural genetics. Thus, the population of solutions is improved from one generation to the next with respect to their fitness evaluation. So, the least fit individuals

are replaced with new offspring, which come from a previous generation, and which are better suited to the evolution of the environment.

Fig (1) shows the Genetic Algorithm Flowchart. In the first step, a set of possible random solutions is created. Every solution in the population (which can also be called an individual or a chromosome) is represented by a string of numbers that in turn represent the number of variables in the problem. Every variable is encoded in a suitable coding format (binary, integer, etc.).

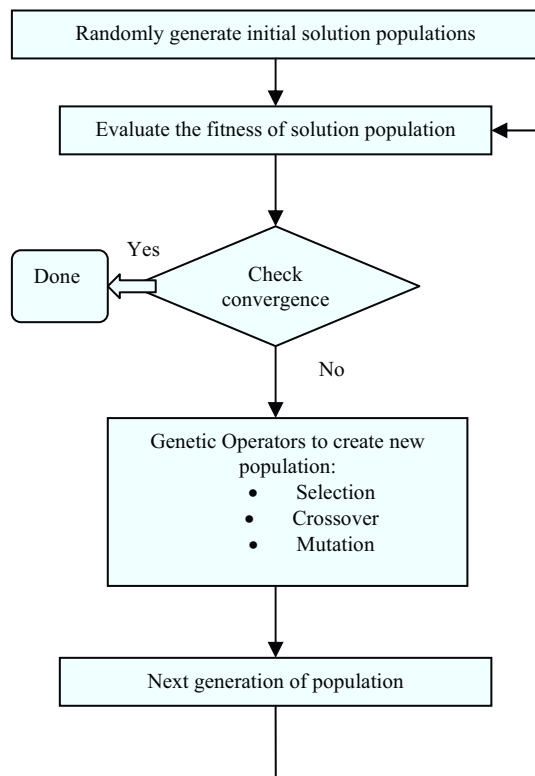


Fig (1) GA Flowchart

In the second step, every chromosome is applied to the fitness function (also called the objective function) to produce an output of fitness values. In accordance with their fitness values a probabilistic technique, such as the Roulette Wheel [4], is used to select the chromosomes that will contribute to the production of the next generation. The reason for this selection process is to keep the best and most fit chromosomes and increase the number of their offspring in the next generation, eliminating the least fit chromosome.

Having selected the parents, the crossover process then takes place by the exchange of genetic information between the selected chromosomes in order to form two

new chromosomes (also referred to as children or offspring). This helps to avoid sticking in local optima. In order to ensure that GA will search different zones of the search space, a mutation is applied by randomly selecting and changing the structure of a limited number of chromosomes. This process is repeated until all solutions converge into one optimum solution. [3]

### 3. STABILITY EVALUATION

For the simulation and stability evaluation, PSSENG (a power system simulator) [6] [7] was used to decide whether the system is stable or not since it is able to give clear assessments of the stability or instability of a system. The stability evaluation algorithm on PSSENG, which is based on time domain simulation output, can classify the simulation cases into the following categories:

1. Transiently unstable class
2. Oscillatory unstable class
3. Poorly damped stable class
4. Well damped stable class

For the two unstable classes the stability index is expressed by the severity index. Unstable cases with a detection of pole-slipping are classified in the transiently unstable class. The time taken for the system to pole-slip is used as the severity index in this class. Other unstable cases, without a detection of pole-slipping, are classified as being in the oscillatory unstable class. In this class, the calculation of the severity index is more complicated than in the previous one. The maximum magnitude of the rotor swing among all other generators is used as the main indicator of the severity index. Moreover, the frequency deviation and generator's active power are also used as auxiliary measurements in addition to the maximum rotor swing of the machine in order to give an accurate severity index. For the stable classes, the examination of the machine's rotor swings can give a decent indication of how stable the system is. The swing amplitudes can help to identify the extraction of the envelopes of the rotor swing curve for all machines. The swing of the envelopes can be approximately defined as an exponential function

$$S(t) = A e^{bt} \quad (1)$$

The value of b is the system time decay which is used as an index for the degree of stability. If b is less than 12s the case is classified as being in the well damped stable class, or, if more than 12s, as being in the poorly damped stable class. [5]

#### 4. PROBLEM FORMULATION

A severe fault may lead to blackouts in some local areas. Under certain circumstances, some small blackouts can lead to a major blackout. However, having a prepared scheme to resolve this problem can help to prevent such a transition. In order to produce this sort of scheme or solution, the production of the scheme should be treated as a constrained optimization problem. This will make the produced scheme meet the following requirements:

- As less power as possible will be tripped
- The system stability will be maintained

#### 5. GENETIC ALGORITHM IMPLEMENTATION

##### 5.1. Encoding

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions of the problem into symbol strings (chromosomes).

Since the aim of our optimization problem is to minimize the amount of tripped power and tripped generations that can stabilize a power system network, the power of the generator will be considered in the structure of the chromosomes. Therefore every generator and load will be numbered from 0 to K, where K = number of generators + number of loads, and each chromosome is composed of S unique integers (S < K) with each integer corresponding to a certain generator or load. For instance, chromosome with a value of 5214309 means that the elements number 5, 2, 1, 4, 3 and 9 are the ones that might trip.

##### 5.2. Selection

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes.

##### 5.3. Crossover

In this Algorithm the Midpoint for exchanging information was applied.

##### 5.4. Fitness Function

The fitness function provides an evaluation of the chromosomes' performance in the problem domain. In this particular problem, the objective of the fitness function is to grade each chromosome with respect to the following aspects:

- Stability class: The stability evaluation algorithm will rank the chromosome according to its stability class, as mentioned in section III
- Amount of generated and load power: The chromosomes are evaluated in terms of the amount of tripped power they possess. The higher the amount of tripped power, the lower the rank of the chromosome.
- System decay rate: This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- Severity Index: This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index the lower the rank of the chromosome.

The corresponding fitness function can be written as

$$FF = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} & \text{Stable case} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} & \text{Unstable case} \end{cases} \quad (2)$$

Where: SC represents the stability class and is equal to 30 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, ΣMVI is the summation of the amount of load reductions, TDR is the time decay ratio and SI is the severity index.

#### 6. NUMERICAL EXAMPLES

Two cases are presented in this paper. The first is that of the IEEE 14-bus network and the second case is that of the 20-machine dynamically-reduced England network. For both cases the applied faults were artificially chosen in order to drive the system into the region of instability.

##### 6.1. IEEE 14-Bus Network

Following the experience of many previous experiments, the GA operators were selected as follows:

Number of generations = 50

Size of chromosomes = 8

Number of chromosomes = 50

Mutation rate = 5%

The 14-bus system is shown in Fig (2) below. The network consists of 11 loads, 2 generators and 3 synchronous condensers.

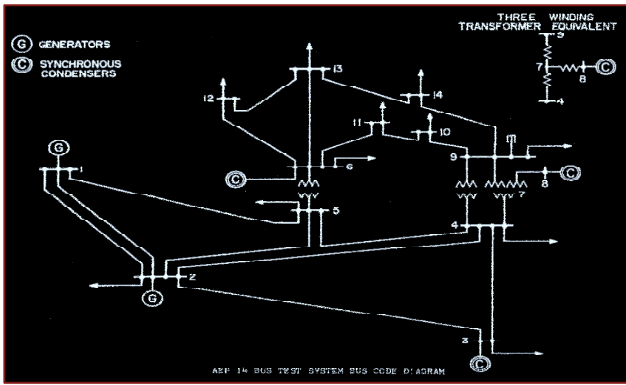


Fig (2) IEEE 14-bus Network

Two three-phase faults were applied on bus 2 and bus 5 at 0.2s while the system was fully loaded. Consequently, the line 2-5 switched out. The faults on bus 2 and bus 5 were cleared at 0.09s and 0.12s, respectively, after the contingency. This severe contingency succeeded at destabilizing the system as shown in Fig (3).

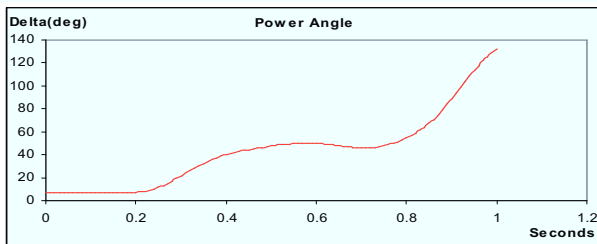


Fig (3) Rotor angle of G1 without any

Due to the simplicity of the IEEE 14-bus network, the stability control scheme can be achieved on the 5th generation as shown in Fig (4), which shows the convergence characteristics of the Genetic Algorithm.

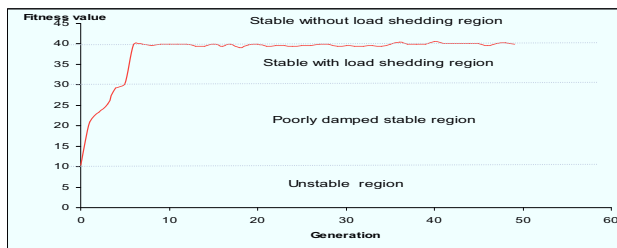


Fig (4a) GA average of solutions

As a result, the network can be stabilized, as shown in Fig (5), simply by tripping two synchronous condensers which are connected to bus 6 and 8 at 0.24s after the contingency.

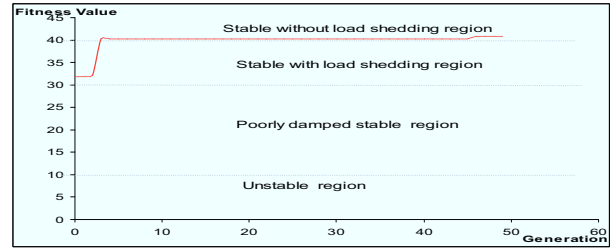


Fig (4b) GA highest Solutions

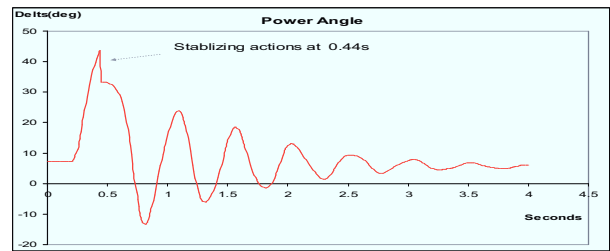


Fig (5) Rotor angle of G1 with control

Obviously, the algorithm proves its robustness by ascertaining a solution without any disruption to consumers, i.e., zero load shedding. The simulation results, shown in Fig (3) and Fig (5), illustrate the rotor angle of the main generator (the generator connected to bus 1).

## 6.2. 20-machine dynamically-reduced England Network

The GA operators were selected as follows:  
 Number of generations = 75  
 Size of chromosomes = 10  
 Number of chromosomes = 150  
 Mutation rate = 5%

In the second numerical example, the algorithm was applied to the practical 20-machine, 100 bus dynamically-reduced England Network. The test system data are listed in [8] and are available from the authors. The model covers the main 400KV system and extends to cover some of the Scottish system.

This network is sufficiently complex, therefore making it more than suitable model with which to prove the validity of the algorithm on a realistic power system network.

Two three-phase faults were applied on bus DIN04 and bus PENT4 at 0.2s while the system was fully loaded. Consequently, the line DIN04 - PENT4 switched out. The fault on bus DIN04 and bus PENT4 were cleared at 0.09s and 0.12s, respectively, after the contingency. This severe contingency did indeed manage to destabilize the system, as shown in Fig (6).

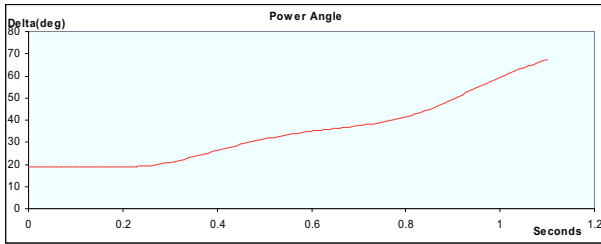


Fig (6) Rotor angle of Wylfa Generator without any control actions

It is noticeable from the convergence characteristics in Fig (7) that before the 9<sup>th</sup> generation, all solutions evolved toward the ultimate solution by means of load shedding. Due to the high capability of Genetic Algorithm to discover the solution space, however, the solutions evolved toward a better solution after the 9<sup>th</sup> generation, without any load shedding action, i.e., global minima.

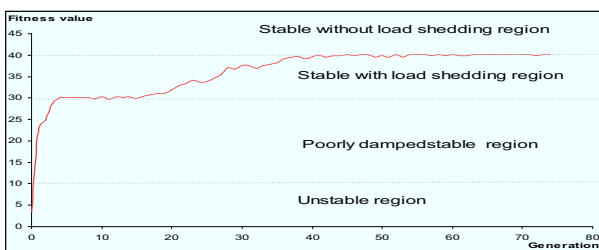


Fig (7a) GA average of solutions

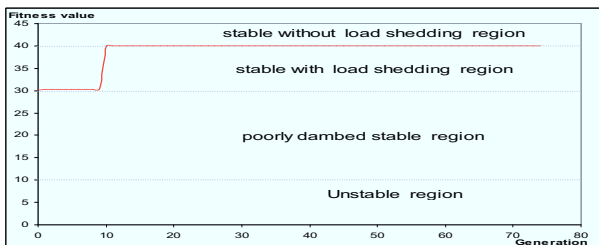


Fig (7b) GA highest Solutions

The global solution was to trip the following generators: DINORWIG, TRAWS and FIDDLWRS at 0.29s after the contingency. Fig (8) shows the rotor angle of the Wylfa generator, which is one of the most affected generators and can; consequently, give a good indication about the whole network.

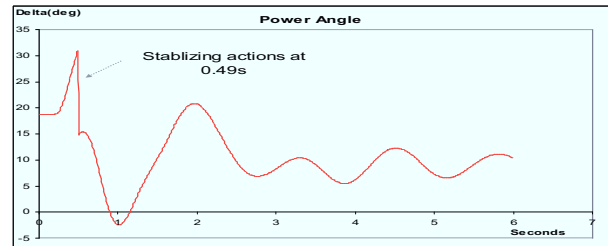


Fig (8) Rotor angle of Wylfa Generator with control actions

## 7. CONCLUSIONS

The objective of the optimization technique is to derive combinations of various controls to stabilize unstable transient events that could cause cascading blackouts. Using the new technique described here, Global or near global optimum solutions were obtained for both the case of the 14-bus network and the 20-machine dynamically-reduced England Network. Power systems can maintain their stability by a scheme of load and generator tripping.

In order to guarantee the robustness of the algorithm, the size of the population should be sufficiently large in order to allow discovery of the whole solution space. This scheme can be enhanced to include more stabilizing actions, such as system islanding and fast valving, in order to convert this stabilizing scheme into a comprehensive defence plane.

Further work will focus on enhancing the scheme in terms of its speed so that the scheme can be used in an on-line environment.

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# Controlled Islanding Scheme for Power Systems

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**Abstract-** System islanding is often considered as the final stage of power system defense plans. The goal is to preserve stable areas of the faulted power systems. The islanding scheme plays an important role in the power system restoration phase as it can make the power system restoration less complex and reduce the overall restoration time. The basis for islanding is not standard but rather depends upon the nature of the utility. Even though the formation of islands is dominated by geographical proximity of the synchronous generators to maintain generation-load balance, there are some factors which can assist in designing a better islanding scheme. These factors are the type and location of the fault and the dynamic performance of every island on the system against the fault. This paper presents an optimization technique to obtain the optimal formation of islands taking into consideration the geographical distribution of the synchronous generators and the dynamic performance of every island in the system against the extreme and credible faults that lead to full system breakdown. In order to show the validity of this algorithm, the Algorithm is applied to IEEE 118 Bus System and a comparison between the proposed islanding scheme and an islanding scheme based on the geographical distribution of the synchronous generators is presented. The results presented in this paper show that taking into the account the type and location of the extreme and credible faults helps to preserve more stable area than that of the traditional islanding scheme.

## I. INTRODUCTION

A major blackout happens when a large area or a complete area of a power system collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units. A partial blackout may start with a severe fault which can cause a large variation in power flow and busbar voltage, which in turn can cause the outage of generation units or transmission lines. This causes imbalance in the demand and generation of power. This sort of disturbance can be the beginning of a cascading blackout when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for stability. This makes the likelihood of converting a local blackout to a major blackout very high. This gives rise to the necessity of having an appropriate scheme to prevent a cascading blackout from becoming a major blackout[1].A variety of emergency controls are used to prevent cascading blackouts. These emergency controls are generator tripping, fast valving, load shedding, excitation controls and system islanding [2].

However, system islanding is usually considered as the ultimate control action to preserve as many stable areas as possible. It is well known that many blackouts, including the series of 2003 blackouts, could have been avoided if appropriate defensive islanding operation were taken following the disturbances. Defensive islanding implies intentional separation of the network in controllable islands. It is not like the passive islanding where the system can be unintentionally split in uncontrollable islands.

In literature, reasonable amount of work has been undertaken in the area of islanding. This work can be divided in two categories. The first category is about grouping the generators according to slow coherency and then trying to find the minimum cutting set from interface network between the generator groups using some searching techniques [3-8]. Due to the fact that they were using slow coherency as the main algorithm, their solutions are not only maintaining load generation balances but also providing good dynamic transient performance during islanding operation. The second group presented completely deferent method for system splitting [9-10]. Unlike the first group, their studies are based on steady state stability. The ordered binary decision diagrams are used after simplifying the original power network by graph theory. This helps in narrowing the solution space. As presented in [11], the balanced islands problem is an NP-problem and it is very difficult to find the optimal solution for large power system using searching algorithm. This is due to the fact that these algorithms are not efficient in searching NP-hard searching space. So far, most of the islanding algorithms are optimized in the way that the solution space is reduced by simplifying the power network. This simplification can be achieved either using simplified version of the power network or a part of it. These kinds of simplification could make it possible to lose one of the better solutions that may exist for the original power system. It is desirable to use the original power system data configuration directly. However, this would prolong the computational time. In this paper, the algorithm used is based on dynamic performance and slow coherency of the islands. The islanding problem is treated as an optimization problem where every solution is evaluated according to its dynamic behavior. Also taking into account the types and the locations of more probable extreme faults, which cause inter-area oscillation problems, and the stability of every possible island have enhanced the scheme design. As mentioned before, in the previous work [3-8], before running the algorithm the generators are grouped according to slow coherency. However, in the proposed algorithm, the solution with slow coherency would be avoided so the ultimate solution should

not have slow coherency. In general, this paper raises an argument that designing an islanding scheme against most probable contingencies can be better than designing an islanding scheme with contingencies uncertainty.

It is also very much preferred that the solution for power system be a global optimum solution. However; this can not be reached by mathematical methods. All of these factors therefore make it necessary to use a global search technique such as a Genetic Algorithm [12].

## II. SIMULATION TOOLS

### A. Genetic Algorithm (GA)

Genetic algorithm is a global search technique used in optimization problems by imitating the mechanisms of natural selection and genetics. Full description of Genetic Algorithm can be found in [12].

### B. Stability evaluation

For the simulation and stability evaluation, PSS-ENGINE (a power system simulator) [13] was used to decide whether the system is stable or not since it is able to give clear assessments of the stability or instability of a system. The stability evaluation algorithm on PSS-ENGINE, which is based on time domain simulation output, can classify the simulation cases into the following categories:

- Transiently unstable class
- Oscillatory unstable class ( including inter-area oscillations cases)
- Poorly damped stable class
- Well damped stable class

For the two unstable classes, the stability index is expressed by the severity index. Unstable cases with a detection of pole-slipping are classified in the transiently unstable class. The time taken for the system to pole-slip is used as the severity index in this class. Other unstable cases, including inter-area oscillations cases, without a detection of pole-slipping, are classified as being in the oscillatory unstable class. In this class, the calculation of the severity index is more complicated than in the previous one. The maximum magnitude of the rotor swing among all other generators is used as the main indicator of the severity index. Moreover, the frequency deviation and generator's active power are also used as auxiliary measurements in addition to the maximum rotor swing of the machine in order to give an accurate severity index. For the stable classes, the examination of the machine's rotor swings can give a decent indication of the stability of the system. The swing amplitudes can help to identify the extraction of the envelopes of the rotor swing curve for all machines. The swing of the envelopes can be approximately defined as an exponential function

$$S(t) = A e^{bt} \quad (1)$$

The value of  $b$  is the system time decay which is used as an index for the degree of stability. If  $b$  is less than  $1/12$  the case

is classified as being in the well damped stable class. If it is more than  $1/12$ , the case is classified as being in the poorly damped stable class [14].

## III. PROBLEM FORMULATION

A severe fault may lead to blackouts in some local areas. Under certain circumstances, unexpected faults can lead to a major blackout. However, having a prepared scheme to resolve this problem can help to prevent such a transition. In order to produce this sort of scheme or solution, the production of the scheme should be treated as a constrained optimization problem. This will make the produced scheme meet the following requirements:

- Minimum possible power will be tripped in every island to maintain generation load balance
- As many stable islands as possible will be preserved.
- Line flows will not exceed loading limits
- System bus voltage will remain within limits

## IV. METHODOLOGY

### A. Algorithm overview

The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible. This scheme is optimized and assessed against some critical contingencies which are carefully chosen to cause system decent. Figure 2 shows the Algorithm flowchart. Before running the original power system, a list of more likely contingencies is artificially chosen to cause slow system coherency. The solutions produced by GA are tested and evaluated against each contingency in that list. After testing all solutions against all the contingencies, the best solutions are chosen, to contribute in the production of next generation of solutions, according to probabilistic technique. Following that the GA operators are applied to produce a better generation of the solutions.

### B. GA Implementation

#### Encoding

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions of the problem into symbol strings (chromosomes). Since the aim of our optimization problem is to obtain the optimal island formation with minimum amount of load shedding, every possible tie line that may aid to form island and loads are considered in the structure of the possible solutions (chromosomes). Therefore, every possible line and loads is numbered from 0 to  $K$ , where  $K = \text{Number of Lines} + \text{number of Loads}$ . Each chromosome is composed of  $S$  unique integers ( $S < K$ ) with each integer corresponding to a line or load. For instance, chromosome with a value of 5214309 means that the elements number 5, 2, 1, 4, 3 and 9 are the ones that might trip.

**Selection:** The Rolette Wheel technique is used as the probabilistic technique to select the chromosomes [12].

**Crossover:** In this Algorithm the Midpoint technique for exchanging information was applied [12].

**Fitness Function:** The fitness function provides an evaluation of the chromosomes' performance in the problem domain. In this particular problem, the objective of the fitness function is to grade every possible island with respect to the following aspects:

- **Stability class of the island:** The stability evaluation algorithm will evaluate the island according to its stability class.
- **Amount of load shedding that survives the island:** The islands are evaluated in terms of the amount of tripped load they might need to survive. The higher the amount of tripped power, the lower the rank of the chromosome.
- **System decay rate:** This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- **Severity Index:** This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index the lower the rank of the chromosome.

The corresponding fitness function for every island can be written as

$$F = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} & \text{Stable} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} & \text{Unstable} \end{cases} \quad (2)$$

Where: SC represents the stability class and is equal to 20 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, MVI is the summation of the amount of load reductions, TDR is the time decay ratio and SI is the severity index.

The overall fitness function for each chromosome is

$$FF = F_1 + F_2 + \dots + F_N \quad (3)$$

Where N is the number of islands in one chromosome.

## V. 118 IEEE BUS SYSTEM

### A. Overview

In order to show the validity of the algorithm, the algorithm is applied to IEEE 118 bus system [15]. The network is fully loaded and every generator is equipped with AVR and governor. The dynamic data can be requested from the main author.

### B. Assessing contingencies

Due to the large size of 118 networks, there are many type of contingencies which are able to cause generators slow coherency. Out of these, three contingencies are carefully chosen to help find the optimal islands formation. These four

contingencies are assumed to be most probable and severe contingencies.

**Contingency 1:** At 1.00 second permanent three phase fault on the transformer between bus SproneE and SproneW with failure of bus bar protection. The fault was cleared on the second zone.

**Contingency 2:** At 1.0 S permanent three phase fault on the transformer between MusknngumN and MusknngumS with failure of bus bar protection. The fault was cleared on the second zone.

**Contingency 3:** At 1.0 S permanent three phase fault on ClinchRV bus with protection failure. The fault was cleared on the second zone.

**Contingency 4:** At 1.0 S permanent three phase fault on the transformer between TannrsCKN and TannrsCKS with failure of bus bar protection. The fault was cleared on the second zone.

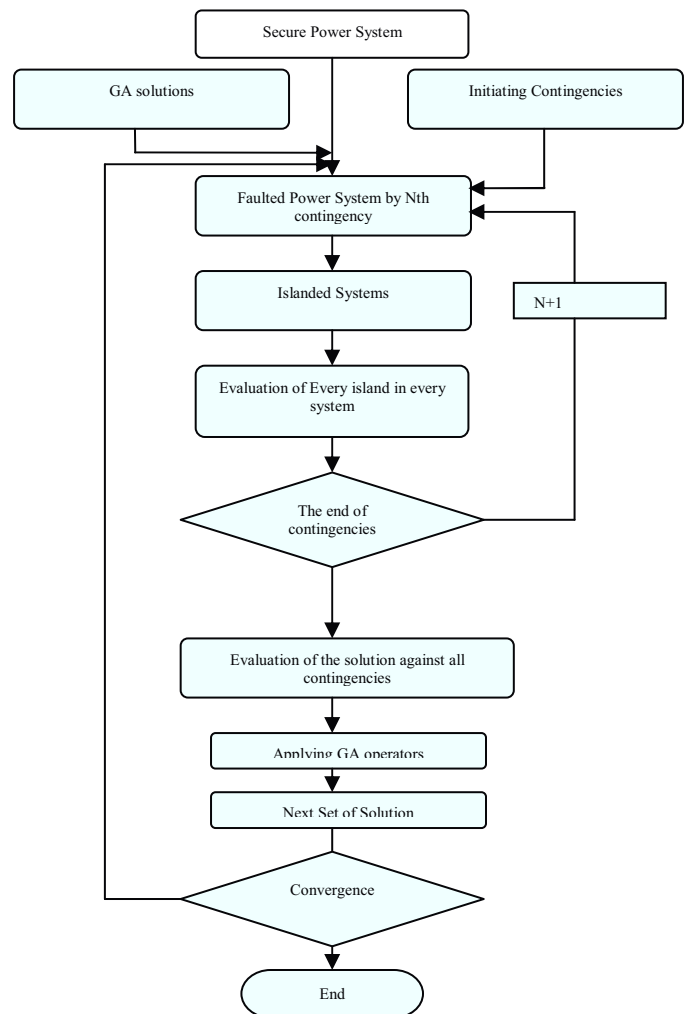


Figure 1 Algorithm Flowchart

## VI. RESULT AND ANALYSIS

### A. Traditional scheme

Based on the geographical distribution of the synchronous generators, the obvious boundaries of the islands and load

/generation balance requirement, the system can be islanded into six viable islands which can be seen in figure 3. Table 1 shows the amount of load shedding, required to maintain load / generation balance, in every island. At the stage of choosing the island boundaries, the issue of uncertainty appears. This is due to the fact that many combinations of the six mentioned islands can fulfill the requirement of the load /generation balance [16]. Practically, the islanding scheme designers analyze every island combination against some critical contingencies. However, this makes the best combination very difficult to reach in large power systems.

### B. Optimized Islanding Scheme

#### GA criteria

Following the experience of many previous experiments, the GA operators were selected as follows: Number of generations = 150, Size of chromosomes = 35, Number of chromosomes =150 and Mutation rate =5%. It can be noticed from GA convergence on figure 2 that the best solution was found just before generation number 80 and after that all solution converged to the best one.

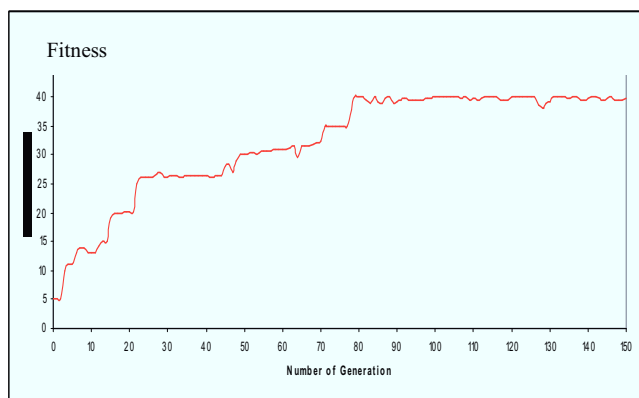


Figure 2 Genetic Algorithm Convergence

Table 1 The performance of the islands using Traditional method

	CO	Island	SC	TDR	LC
Traditional Islanding Scheme	1	1	Stable	8.5	%42.7
		2	Unstable	-	
		3	Stable	6.6	
		4	Stable	4.6	
		5	Stable	3.9	
		6	Stable	7.2	
	2	1	Stable	7.15	%34.8
		2	Stable	4.9	
		3	Stable	8.5	
		4	Unstable	-	
		5	Stable	4.7	
		6	Stable	8.4	
	3	1	Stable	8.91	%42.7
		2	Unstable	-	
		3	Stable	6.4	
		4	Stable	4.1	
		5	Stable	3.6	
		6	Stable	7.34	
	4	1	Stable	6.2	%22.4
		2	Stable	4.65	
		3	Stable	6.2	
		4	Stable	4.9	
		5	Unstable	-	
		6	Unstable	-	

#### GA outcome

Based on the islanding Algorithm result the optimized islanding formation can be shown in Figure 4. The algorithm was able to find five islands without any need of load shedding to maintain the generation/load balance equilibrium. Also the islands formation found by the algorithm can preserve more stable areas than that of the traditional one. It is interesting to notice that the solution obtained by the GA algorithm combined island 3 to island 4 and island 6 to 5. This is due to the fact that island 6 and island 3 can not survive following contingency 4 and contingency 2 respectively, as it can be seen on Table 2. Also, another reason for island number 3 to disappear is the large amount of load shedding required to maintain load/generation balance. Island number 2 has been divided into two islands. This happened in order to minimize the amount of the load collapse following contingency number one and number three. The boundaries of island number two have been adjusted to drop some loads to strengthen the island from the stability point of view. Based on the traditional scheme and the optimized scheme, Table 2 and Table 3 present the stability class (SC) and the time decay rate of every stable case (TDR) of every island against the assessing contingencies (CO). Also percentage of total load collapse (LC) after each contingency is presented on the tables. It can be noticed that, following the application of assessing the contingencies, the optimized scheme can maintain more serviced loads than that of traditional one. For instance, the optimized islanding scheme decreased the percentage of total load collapsed from 42.7 of the total load to 11.8 of the total load. This reduction in the collapsed area can be noticed as well following contingency number 3. It is worth noting that the optimized islanding scheme performs as good as the traditional scheme following the application of contingency 2 and 4. However it was perfectly able to preserve more areas following the application of contingency number 1 and 3. Also by observing the Time decay Rates and the amount of collapsed loads in both schemes in Table 2 and Table 3, it can be noticed that the algorithm made a decent compromise between stability and the amount of collapsed loads. In other words, the algorithm forms big island in order to avoid small islands that can not survive after some contingencies or require big amount of load shedding to survive, such as island number 6 and 3 in the traditional scheme. On the other hand, it goes towards the choice of small islands in order to preserve more stable area.



**Table 2 The performance of the islands using Optimized method**

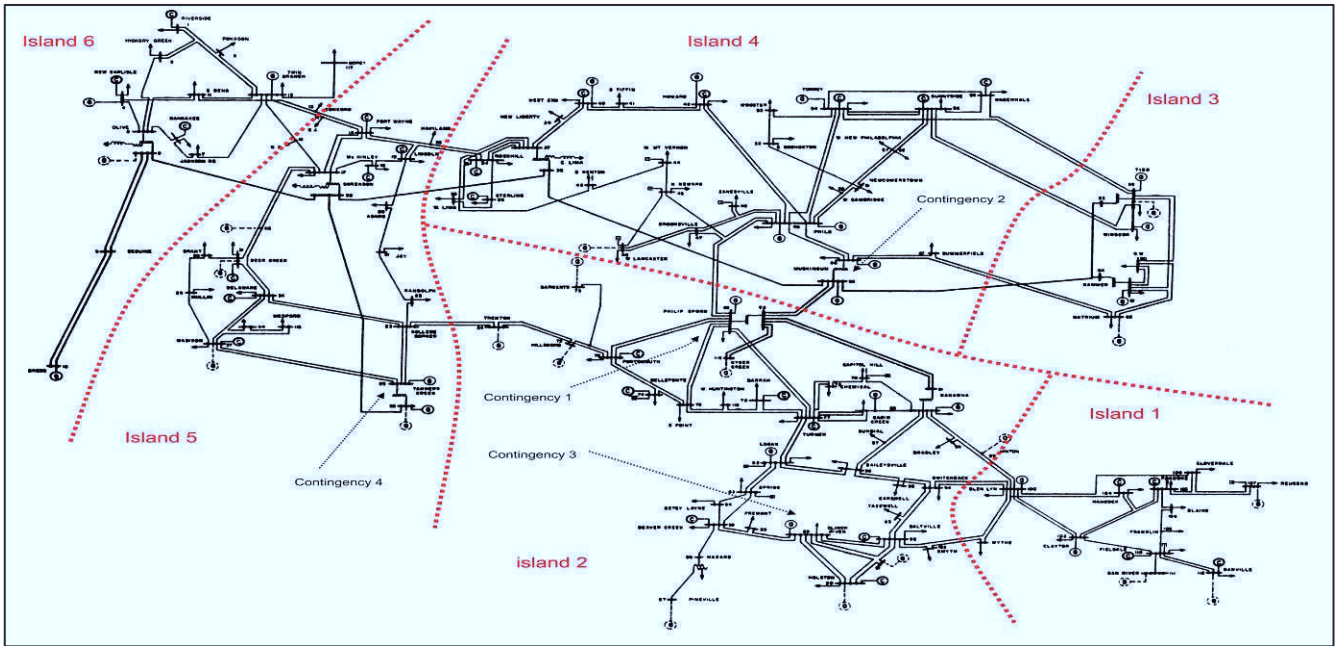
	CO	Island			LC
		Island	SC	TDR	
Optimized Islanding Scheme	1	1	Stable	8.5	%11.8
		2	Stable	6.3	
		3	Unstable	-	
		4	Stable	3.9	
		5	Stable	4.9	
	2	1	Stable	7.15	%34.8
		2	Stable	6.1	
		3	Stable	5.4	
		4	Unstable	-	
		5	Stable	3.1	
	3	1	Stable	8.91	%22.8
		2	Unstable	-	
		3	Stable	9.89	
		4	Stable	4.0	
		5	Stable	3.4	
	4	1	Stable	6.2	%22.4
		2	Stable	4.9	
		3	Stable	5.2	
		4	Stable	4.0	
		5	Unstable	-	

## VII. CONCLUSION

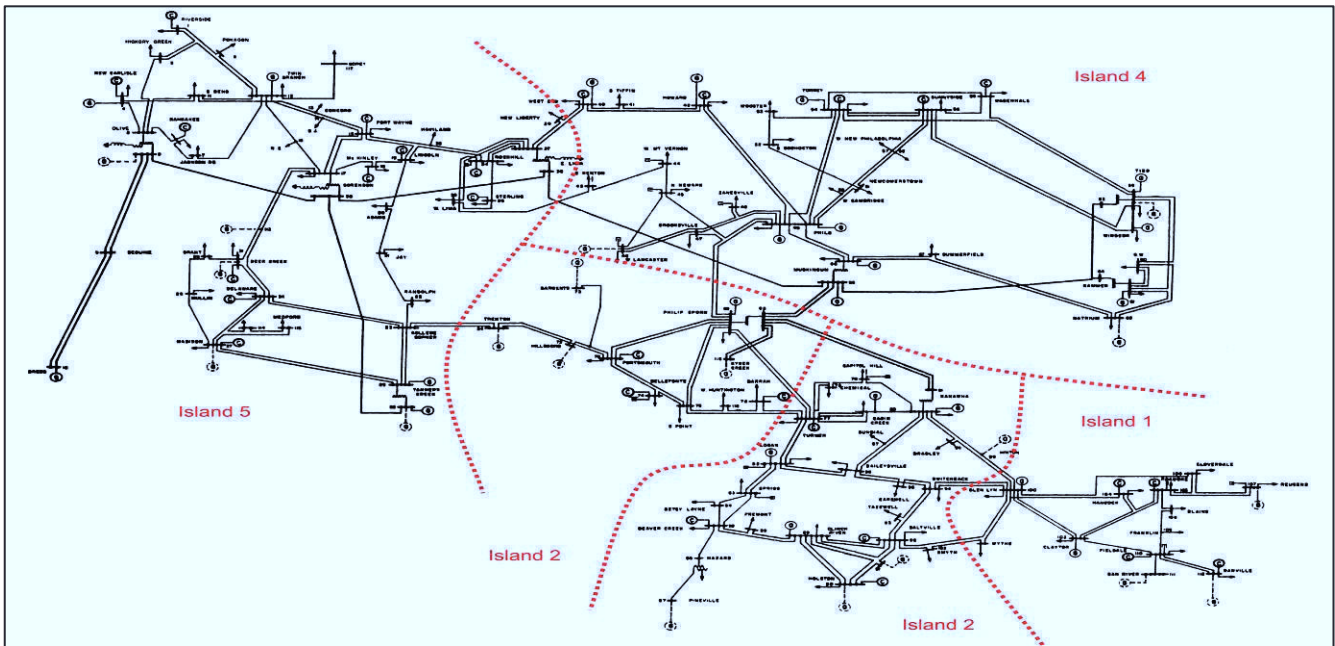
By minimizing the amount of disrupted loads, the algorithm can play an important role to obtain the optimal islanding boundaries. Also, the Algorithm shows its robustness by obtaining islanding formation, which preserves more stable areas, with optimal amount of load shedding required to maintain load/generation balance. The comparison between the traditional and the optimized scheme shows that the optimized scheme performs as good as the traditional one in some contingencies and performs better in other contingencies. By using a list of assessing contingencies, the optimal islanding scheme becomes skewed towards these contingences. This makes the islanding scheme perform much better than the one designed for an open list of contingencies. Of course, the list of contingencies can be easily extended and is not in any way restricted to any particular limits. The algorithm makes good compromise between stability and the amount of collapsed loads. Finally, this algorithm will be more helpful in the case of complicated power systems where the natural boundaries of the islands are not obvious. This method will be applied to find an optimal islanding scheme for the Libyan Power System.

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**Figure 3 the performance of the islands using Traditional method**



**Figure 4 the performance of the islands using Optimized method**



## **System Operation and Control**

New applications in system operation and control for detection and mitigation of system conditions

### **Design of an optimized defence plan for a power system**

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### **SUMMARY**

This paper presents a novel optimization technique for determining the setting of various emergency power system controls. This will allow for the production of a comprehensive defence plan, against events such as cascading blackouts. The goal of this technique is to retrieve a new equilibrium operation point following a severe contingency. In general, the emergency controls used to prevent cascading blackouts are generator tripping, fast-valving, load shedding, excitation controls and system islanding. However, generator tripping, load shedding and system islanding are the most effective control actions. As such, these are considered as the main emergency control actions in the proposed optimization technique described in this paper. This problem is a complex nonlinear problem and it is very difficult to solve using ordinary numerical optimization method such as mixed integer linear programming. Since Genetic Algorithm approaches are very successful at solving nonlinear combinatorial optimization problems, these have been applied in this work to produce an optimized defence plan. Genetic Algorithms are search algorithms based on the mechanism of natural selection and natural genetics subject to survival of the fittest among string structures that identify possible solutions to a problem. A Genetic Algorithm approach is used to find the optimal combination of generators and loads to be tripped as the best solution for the network to regain a new state of equilibrium that is operationally stable, whilst maintaining supply to as many consumers as possible. System islanding may also be applied if a satisfactory state of equilibrium can not otherwise be obtained. The optimization technique uses transient stability evaluation algorithms, based on time-domain simulation, to assess the fitness of the potential solutions. The test case, presented in this paper, for the optimization technique was the Libyan power system network. In order to show the validity of the optimized defence plan, a comparison between the existing Libyan power system defence plan and the optimized defence plan is presented for the case of a major blackout in the western part of the Libyan power system that took place on 8<sup>th</sup> November 2003. The results presented in this paper show that a robust defence plan with a satisfactory amount of load shedding and system islands can be obtained by the new technique. The paper also demonstrates that the new defence plan outperforms the existing Libyan power system defence plan.

### **KEYWORDS**

Stability-Genetic Algorithm-Defence Plan- System islands- Load shedding.

## 1 INTRODUCTION

The main goal of power system security measures taken during planning and operation are to minimize the number of interrupted customers following likely incidents. This goal can be reached by implementing planning and operation rules to ensure that power systems remain viable following any credible contingency. However, abiding by these security rules does not guarantee that the network will be fully protected against all types of severe faults. This is due to the fact that major disturbances are the consequence of complex situations associated with control or protection failures. This kind of situation is rare but does occur. Instances include France in 1978 and 1987 and the Western United States in July 1996 [1]. Practically, special defensive measures called a “defence plan” are used. By limiting the geographical extent, duration and effects of the disturbances, defence plans can play an important role in minimizing the number of interrupted customers [2]. Owing to the complexity of modern power systems, the design of defence plans can be very difficult. Human experience and observation are used as the main keys in designing the necessary measures. Although using the experience of power systems engineers can be of assistance in the design a good defence plan, the optimality of the defence plan, in terms of loss of loads, can not be guaranteed [3]. This heightens the necessity of using optimization methods to obtain more optimal defence plans. Mathematical optimization methods have been used over the years for power system control problems. However, the solution for large-scale power systems is not easy to obtain by way of ordinary mathematical optimization methods. This is due to the fact that there are many uncertainties in power system problems due to their complexity, size and geographical distribution. It is also much preferred that the solution for the power system be close to the global optimum solution. However, this can not easily be reached by mathematical methods due to the multi-objective, discontinuous nature of the problem space [4]. All of these factors therefore make it necessary to use a robust global search technique such as a Genetic Algorithm [5]. In this paper, a Genetic Algorithm is applied to find the minimum amount of load shedding, following severe faults, at various frequency thresholds that are able to secure the network, or even enhance the dynamic performance. Also, another Genetic Algorithm is applied to obtain an optimal islanding scheme to geographically restrict the extent of the fault. Practically, defence plans are designed to act against incidents which are not covered at the system planning stage. There are many methods that can be used to prevent system collapse immediately following an incident. These include generator tripping, fast valving, load shedding excitation controls and system islanding. Of these, load shedding, generator tripping and system islanding are considered to be the most effective control actions [6]. However, generator tripping is often associated with conservative networks. These defence schemes are based on the fact that, in extreme situations, it is better to shed some loads, or parts of the network, rather than to lose the whole network.

## 2 HOW TO DESIGN A DEFENCE PLAN

Numerous specific dynamic simulations are taken into consideration in the process of defence plan design [2, 3]. Unlike conventional operational security studies, the contingencies that are investigated for defence plan design are much more complicated than N-1 contingencies. The goal of these dynamic simulations is to assess system security and to determine the behaviour and the limits of the adopted defence measures, and to examine the impact of a new strategy [7].

### *2.1 Necessity to represent an accurate model for the network*

As in any other study, the relevance of the study and the usefulness of the results depend on the accuracy of the system modelling. With regard to the dynamic simulation, a good representation of the dynamic components such as generators, AVR, governors, and the fast-valving system, SVC and FACTS, should be ensured. It is necessary to model the behaviour of the protection system, including unit protection such as generation unit protection, lines protection, and protection schemes that include the defence plan itself [8].

### *2.2 Incident Scenarios*

Building incident Scenarios that represent different types of transient phenomena which lead to full system collapse, is one of the important steps in defence plan designing. Under secure operation conditions, power systems can withstand most likely incidents. Therefore, chosen incidents scenarios



should be sufficiently complex and severe to break the system. Most of the time, the network is built to be of sufficient strength to withstand major disturbances. For this reason, the network must be weakened in order to simulate the situation that is very different from the normal operation conditions. Taking into account different weakening operation conditions such as unhealthy voltage profile, an unbalance generation plan, an exceptional load demand, special import/export conditions and losing an important high voltage line, can be of assistance in representing severe transient phenomena that might lead to full system breakdown. Hence, this leads to a feasible defence plan. Incident scenario can be also built by using a probabilistic technique [9].

### **2.3 Simulation Tools**

System collapses involve complex transients, which are a combination of slow transient and fast transient phenomena. Therefore, it necessary to have simulation tools to study the ability of the power system to remain in synchronism for just a few seconds following the occurrence of the incident and to represent voltage, frequency and power flow variations[10].

## **3 LIBYA'S POWER SYSTEM**

The power system in Libya consists of four geographically well-dispersed, totally interconnected major island systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and steam units with some diesel generators located in rural areas of the Libyan Desert. The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length 442 km, a high voltage transmission level of 220 kV, and a total circuit length 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV; with a total circuit length of 6,237 km. geographically, the Libyan Network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation, in the south. For purpose of study the Libyan Power System is geographically divided into seven electrical areas [11].

## **4 CURRENT DEFENCE PLAN**

### **4.1 Overview**

Since the current situation of the Libyan power system is characterized by weak connections in extended areas, the main goal of Libyan power system engineers was to produce a defence plan which is able to avoid propagation of severe phenomena, like loss of synchronism and voltage collapse.

### **4.2 Current Defence plan design**

The Libyan defence plan design is based on the following steps [12]:

#### ***STEP 1 Operation conditions definitions.***

In order to be able to represent severe transient phenomena that could lead to full system collapse, the 2003 Libyan network with interconnection with Egypt and the peak load situation has been considered along with some severe conditions. The conditions are attached with this paper in appendix 1.

#### ***STEP 2 selections of assessment contingencies.***

As mentioned in Section 2.2, building comprehensive incident scenarios assists in the design of an efficient defence plan. In the Libyan defence plan, the assessing contingencies are attached in appendix 1.

#### ***STEP 3 Contingency simulations***

The current Libyan defence plan including load shedding scheme, lines trip under frequency criterion and islanding scheme has been performed on a SICRE simulator environment [13].

#### ***STEP 4 Local protection design and setting***

In order to achieve an accurate system, the following protection relays were implemented: out of step relays, under-voltage protection, power flow protections and power swing blocking.

### **STEP 5 Load shedding scheme design**

Based on the Libyan power system topology, the Libyan network was considered as six areas. Each area has its own load shedding scheme as can be seen in Table 1. For coordination reasons, General Electricity Company of Libya recommended 49.4, 49.2, 49.0, 48.8, 48.6 Hz as frequency thresholds for load shedding. However, the choice of the first and last threshold is based on the following points. The first threshold should be fixed so as to avoid load shedding for electromechanical oscillations, even of large amplitude, in case of interconnected system still integrated. With the amount of spinning reserve being fixed, it is a good rule to choose the first threshold that is low enough to allow the regulating energy to recover frequency drops with no load shedding. Therefore, in order to get the reasonable threshold values, the following values should be determined: maximum frequency deviation recovered by spinning reserve, maximum frequency deviation due to electromechanical oscillations and minimum frequency value. The minimum frequency threshold has to be fixed with reference to the under-frequency protection of units. In addition to the load shedding scheme, further load is shed by line trips for under-frequency protection intervention. Table 1 reports the amount of load shed and figure 1 shows the areas that were shed by line trips protection.

**Table I The current load shedding scheme**

AREA	LOAD SHEDDING FOR EACH THRESHOLD					Total
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	
Area 1	3.30%	3.3%	0.00%	0.4%	0.0%	6.9%
Area 2	2.4%	1.8%	4.7%	3.9%	1.3%	14.1%
Area 3	1.60%	1.20%	1.2%	2.30%	1.9%	8.2%
Area 4	0.4%	0.0%	2.8%	1.7%	6.60%	11.6%
Area 5	2.9%	1.5%	2.4%	0.5%	2.1%	9.4%
Area 6	0.00%	0.9%	0.00%	1.6%	1.30%	3.8%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	10.6%	5.6%	11.1%	10.7%	13.2%	54.3%

### **STEP 6 Under-frequency islanding design**

The adopted technique of splitting the system into islands for a frequency below the last load shedding stage presents pros and cons. One advantage is to increase the probability of survival of some islanded power plants, with the possibility of accelerating the restoration procedure. One drawback is the diminution of the probabilities of survival of the small areas, along with instability of the units in small areas and a greater difficulty in balancing load and generation. Based on the experience of electrical Engineers from GECOL and the criteria of the designed islanding scheme, the Libyan Power system was islanded into six islands as shown in figure 1.

## **5 OPTIMIZED DEFENCE PLAN**

### **5.1 Overview**

Generally, in this study, the same defence plan designing procedures are followed. Unlike the current defence plan, optimization techniques are applied in some critical stages as follows. The first optimization technique is used to obtain a load shedding scheme. At this stage, the optimization technique is used to find the minimum amount of loads that should be tripped in every frequency level. At the second stage, the optimization is applied while obtaining the islanding scheme. Therefore, the optimization technique would be of assistance in finding the optimal islanding scheme.

### **5.2 Optimization tools (Genetic Algorithm)**

A Genetic Algorithm (GA) is a global search technique used in optimization problems. It imitates the mechanisms of natural selection and genetics. [14]

### **5.3 Optimized defence plan design**

The optimized defence plan design follows the same logic of the current defence plan. Therefore the optimized defence plane is based on the following:

#### **STEP 1 Operation conditions definitions.**

Unlike the current defence plan, the optimized defence plan is based on a one operation situation. This is due to the fact that it is believed that if the defence plan is designed based upon the worst operation conditions, it can act properly in better conditions. In this case, the weakest operation conditions for the Libyan power system is the 2003 Libyan network with interconnection with Egypt and the peak load situation with 120 MW exchange from Egypt and 64 MW from the West to the East .

**STEP 2 Assessing contingencies selections.**

The assessing contingencies reported in appendix 1 are recommended by the General Electricity Company of Libya. This is due to the fact that these contingencies are carefully chosen to represent different types of severe transient phenomena on the Libyan System.

**STEP 3 Contingency simulations.**

For the simulation and stability evaluation, a stability-assessment-optimized simulator, (PSS-ENG) [15, 16, 17] is used to decide whether the system is stable or not, due to its ability to give clear assessments of the system stability. The stability evaluation algorithm on PSS-ENG is based on a time domain simulation output.

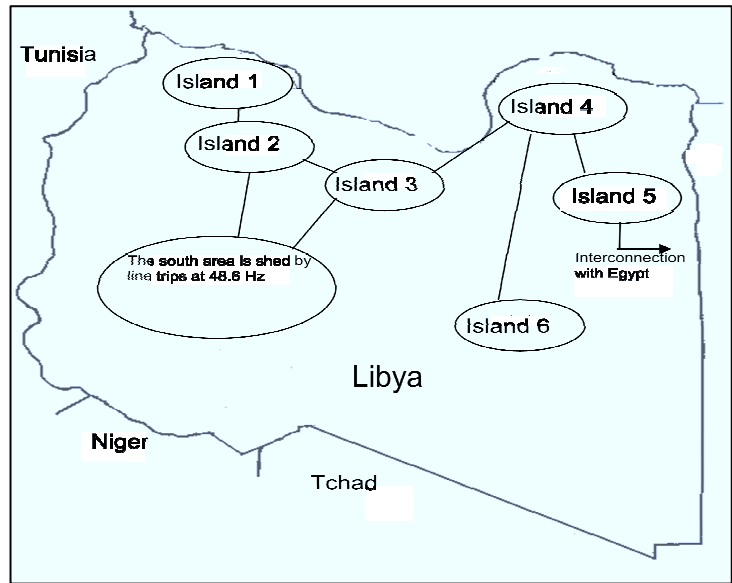


Figure 1 The Current islanding Scheme

**STEP 4 Local protection design and setting.**

PSS-ENG is not implemented with any type of protection system. Undoubtedly, the protection systems play a vital role in defence plan design. However, using GA helps to simplify the application of the protection system. By using GA, the solutions violating the protection elements are avoided. In other words, the power system protection is added to the assessment of the GA. So, if a certain solution causes some protection relays to be actuated, this solution will be lowly ranked.

**STEP 5 Under-frequency load shedding design.**

Unlike the current defence plan, an optimization technique is used to find the minimum amount of load shedding that is able to stabilize the network in every frequency stage. GA is used as an optimization tool.

**STEP 6 Islanding scheme design.**

As mentioned before the GA is applied to obtain an optimal islanding scheme. The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible

**5.4 Genetic algorithm Implementation for load shedding**

**• Encoding**

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions to the problem into symbol strings (chromosomes). Since the aim of the optimization technique in this stage is to minimize the amount of load shedding in different frequency stages ( frequency threshold ), the amount of power in every load is considered in the structure of every chromosome. Also, every chromosome is divided into five parts (5 frequency thresholds). Every part corresponds to a certain frequency stage, and is hence applied in that frequency stage. The following is an example of the chromosome structure:

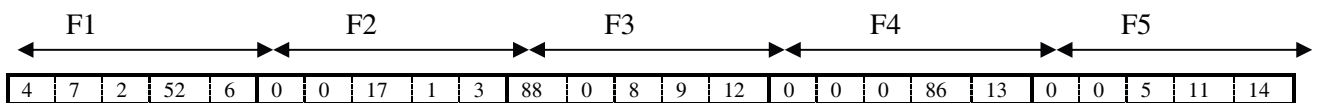


Figure 2 chromosome structure

- **Selection**

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes [5].

- **Crossover**

In this Algorithm the Midpoint for exchanging information was applied [5].

- **Fitness Function**

The fitness function provides an evaluation of the chromosomes' performance in the problem domain. In this particular problem, the objective of the fitness function is to grade each chromosome with respect to the following aspects:

- Stability class: The stability evaluation algorithm will rank the chromosome according to its stability class.
- Amount of generated and load power: The chromosomes are evaluated in terms of the amount of tripped power they possess. The higher the amount of tripped power, the lower the rank of the chromosome.
- System decay rate: This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- Severity Index: This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index, the lower the rank of the chromosome.

The corresponding fitness function can be written as

$$FF = \begin{cases} SC + \frac{10}{1 + \sum_{l=1}^{NL} MVI_{Li}} + \frac{1}{TDR} + PS & \text{Stable case} \\ SC + \frac{10}{1 + \sum_{l=1}^{NL} MVI_{Li}} + \frac{1}{SI} + PS & \text{Unstable case} \end{cases} \quad (1)$$

Where: SC represents the stability class and is equal to 30 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, MVI is the summation of the amount of load reductions, TDR is the time decay ratio, SI is the severity index and PS is the protection system evaluation.

### 5.5 Results of the GA for Load shedding

The GA operators were selected as follows: number of Generations is 500, size of chromosomes is 60 and mutation Rate is 5%

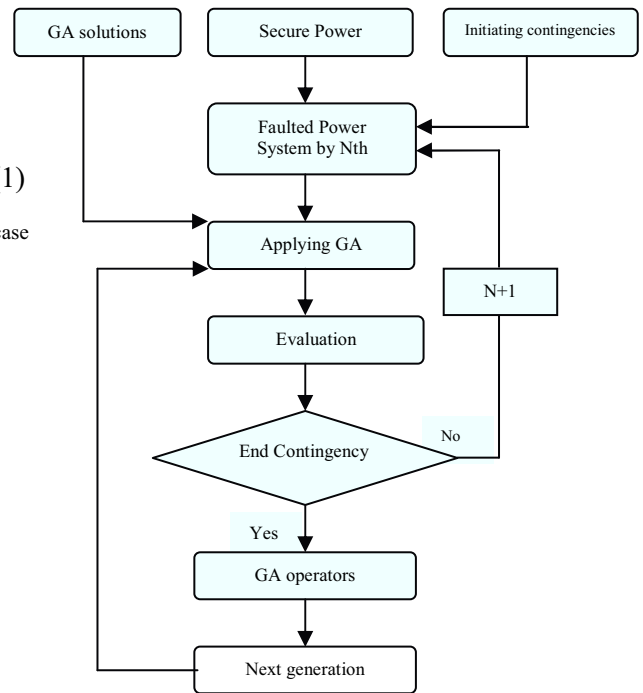


Figure 3 Load shedding algorithm flowchart

The GA obtains the best solution after generation 260. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. The ultimate solution is reported in Table 2. It is interesting to note that the load shedding scheme obtained by GA is similar to the current one in some senses. However, some extra load shedding is required in the new scheme in areas 1, 2 and 4. This makes the total load shedding in the network 63.32%, which is higher than that of the current scheme. It is worthy of note that the optimized solution shares with the current scheme the necessity of tripping the majority of area 4 by line trips load shedding at 48.6Hz . Also, it can be noted from Table 2 that an additional amount of load shedding is introduced in the last stage of load shedding. This additional amount of load shedding will play important role in saving the system in some critical situations, since it is vital in preparing the network for islanding.

### 5.6 GA Implementation for islanding

- **Encoding**

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions of the problem into symbol strings (chromosomes). Since the aim of our optimization problem is to obtain the optimal island formation with minimum amount of load shedding, every possible tie line that may aid in the formation of islands and loads are considered in the structure of the possible solutions (chromosomes). Therefore, every possible line and load is numbered from 0 to K, where K = Number of Lines + number of Loads. Each chromosome is composed of S unique integers (S < K) with each integer corresponding to a line or load. For instance, a chromosome with a value of 5214309 means that the elements number 5, 2, 1, 4, 3 and 9 are the ones that might trip.

- **Selection**

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes.

- **Crossover**

In this Algorithm the Midpoint technique for exchanging information was applied.

- **Fitness Function**

The fitness function provides an evaluation of the chromosomes' performance in the problem domain. In this particular problem, the objective of the fitness function is to grade every possible island with respect to the following aspects:

- **Stability class of the island:** The stability evaluation algorithm will evaluate the island according to its stability class.
- **Amount of load shedding that survives the island:** The islands are evaluated in terms of the amount of tripped load they might need to survive. The higher the amount of tripped power, the lower the rank of the chromosome.

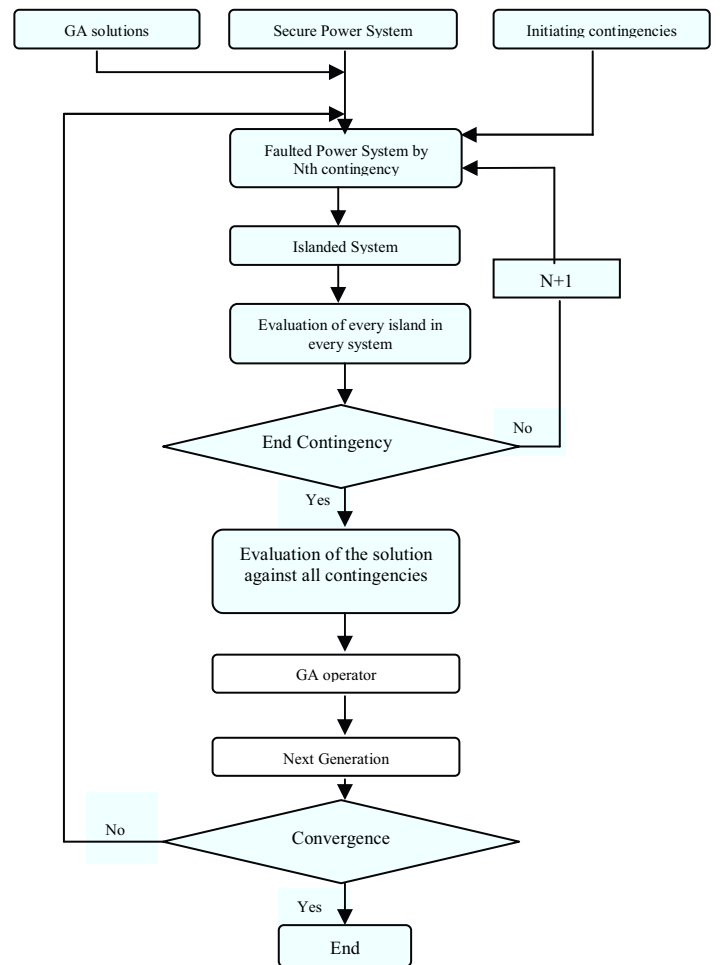
- **System decay rate:** This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- **Severity Index:** This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index the lower the rank of the chromosome.

The corresponding fitness function for every island can be written as

$$F = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} & \text{Stable} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} & \text{Unstable} \end{cases} \quad (2)$$

**Table II The optimized load shedding scheme**

AREA	LOAD SHEDDING FOR EACH THRESHOLD					
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	Total
Area 1	4.20%	4.10%	0.00%	2.00%	1.0%	11.30%
Area 2	2.00%	2.60%	4.10%	5.00%	3.10%	16.80%
Area 3	1.30%	1.00%	0.90%	2.50%	3.10%	8.80%
Area 4	0.32%	0.8	2.40%	2.10%	6.60%	11.6%
Area 5	2.00%	1.00%	2.10%	0.00%	3.10%	8.20%
Area 6	0.00%	1.00%	0.00%	1.00%	2.30%	4.30%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	9.82%	10.60%	9.50%	12.80%	20.20%	63.32%



**Figure 4 The islanding Algorithm flowchart**

Where: SC represents the stability class and is equal to 20 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, MVI is the summation of the amount of load reductions, TDR is the time decay ratio and SI is the severity index.

The overall fitness function for each chromosome is

$$FF = F_1 + F_2 + \dots + F_N \quad (3)$$

Where N is the number of islands in one chromosome.

### 5.7 Results of the GA for islanding scheme

The GA operators were selected as follows: number of Generations is 500, size of chromosomes is 60 and mutation Rate is 5%. The GA obtains the best solution after generation 394. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. Referring to figure 2, in spite of the fact that the GA had completely free hand to choose the cutting point to form the islands, the GA obtained the same island formation of the current defence plan. The only change is in combining island 2 and island 3.

## 6 OPTIMIZED DEFENSE PLAN VS CURRENT DEFENSE PLAN

### 6.1 Overview

In order to show the validity of the optimized defence plan, it is compared with the current defence plan for the case of the major blackout in the western part of the Libyan Power System took place on 8<sup>th</sup> November 2003.

### 6.2 November 2003 Blackout

Four years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 kV transformer on a power production plant on the West side of the Libyan Power System, Tripoli West Plant (on island 1). This occurred while the Libyan power system was connected to the Egyptian power system with Zero power exchange and the power transfer from the West to the East was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The fault was cleared on the second zone.

#### 6.2.1 Dynamic evolution vs. the current defence plan

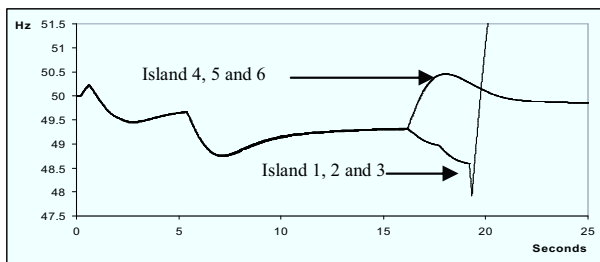


Figure 5 The dynamic evolution of the current defence plan

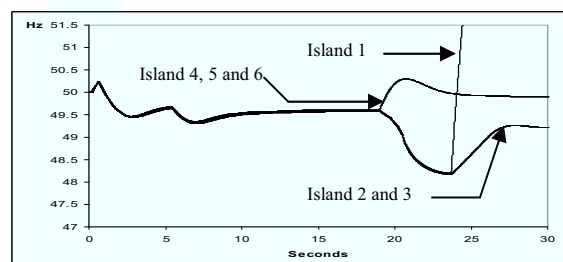


Figure 6 The dynamic evolution of the optimized defence plan

Figure 5 presents the evolution of the frequencies in the Libyan power system with the current defence plan. The dynamic evolution following the occurrence of the fault can be divided based on time into three periods. The first period, which is from 0-10s, starts with the fault occurrence which caused an immediate loss of four units in the west of Tripoli, which caused a loss of generation equal to 120 MW. At 0.8 s following the fault, three units were lost in the south of Tripoli, which caused a loss of generation equal to 237 MW. Two generation units were lost in the Zawia Plant at 5.5s. One second later another unit in the same plant lost. This period can be distinguished by a loss of generation amount equal to 848 MW. The second Period 2 (7-12s) is characterized by a slow dynamic instability between the East and the West side of the Libya. The third Period (12s- end) started with a fast drop in voltage in the interconnected line between East the West. This is due to a loss of synchronism between the East and the West. Therefore, the interconnection lines between the East and the West were tripped due to under voltage protection at 16.33s at the same time, the Libyan

Network was disconnected from the Egyptian Network. It is noticeable from Figure 5 that the East part of Libya survived while the West part of Libya fell in a cascading manner by losing four units in Homs plant until it reached the islanding stage at 48 Hz. Here, the islanding scheme played a decisive role at 19.34s where the network was spitted into three unstable islands. This led to a complete shutdown of the west.

#### 6.2.2 *Dynamic evolution vs. the optimized defence plan*

Figure 6 presents the evolution of the frequencies in the Libyan power system with the optimized defence plan. Similarly, the dynamic evolution in this case went in the same sequence as in the previous one. However, the extra load shedding introduced in the beginning of the optimized load shedding scheme was able to survive two generation units in the Zawaia Plant which helped to reduce the fast drop in the voltage in the interconnection lines between the East and the West of the country. Hence, the disconnection was postponed to 19.1 s. In general, the period of 10-18s is also characterized by long and slow instability due to loss of synchronism between the East and the West, leading to disconnection. Following the disconnection between the East and the West part of the country, the additional amount of load shedding introduced in the last frequency dependent of the load shedding step has properly prepared the west part of the network for islanding phase. At 23.5 s the network reaches the islanding stage where island 2 (island 2 and 3 in the current defence plan) was able to survive while island number 1 (island of Tripoli) lost its stability just following the islanding action. Comparing the optimized defence plan and the current defence plan in terms of survival load, the current defence plan was able to survive the eastern part of Libyan power system which is equal to 26.0 % of the total load and the optimized defence plan was able to preserve the east part of the Libyan power system and considerable part of the western part of the network. The whole preserved amount of loads is equal to 41.4% of the total loads. Besides this substantial increase in the amount of served load, this difference plays a vital role in reducing the restoration time.

## 7 CONCLUSION

The new defence plan algorithm that has been described in this paper can play an important role in obtaining the optimal islanding boundaries and the minimum amount of load shedding required to stabilize the power system after severe faults. The paper has shown that the algorithm is robust and has produced a superior defence plan when compared to the present Libyan defence plan. In particular, it recommends the amalgamation of two islands and in doing so it is able to preserve the supply to more loads. This was tested using the data from the Libyan blackout of 2003. The use of the optimization method has shown the necessity of having an additional amount of load shedding in the last frequency dependent load shedding step, not only to stabilize the network but also to prepare the system for the islanding phase.

A limitation of the method is that by using a specific list of assessing contingencies, the optimized defence plan becomes skewed toward these contingencies. This makes the defence plan perform much better than one designed for an open list of contingencies. Of course, the list of contingencies can be easily extended and is not in any way restricted.

Finally, this algorithm will be more helpful than relying on operator experience in the case of complicated power systems where the natural boundaries of the islands are not obvious. Having a proper defence plan not only helps to prevent cascading blackouts but also helps to rapidly restore the network.



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## APPENDIX

### *Operation conditions definitions.*

- Zero exchange with Egypt and Tunisia and 66MW from the West to the East.
- Max import from Tunisia (-150 MW), Egypt (-120 MW) and 63 MW from the West to the East.
- Zero exchange with Egypt and Tunisia and 130 MW form the west to the East.
- Zero exchange with Tunisia and 120 MW form Egypt and 64 MW from the West to the East.
- Zero exchange with Egypt and 150 MW from Tunisia and 65 MW from the West to the East.

### *Assessing contingencies selections.*

- Bus-bar fault with failure of bus-bar protection in Homs Switch.
- Bus-bar fault with failure of bus-bar protection in Zawia.
- Bus-bar fault with failure of bus-bar protection in Bengazi.
- Bus-bar fault with failure of bus-bar protection in Misurata switch bus-bar and Bengazi bus-bar.



# An Optimized Defence Plan for a Power System

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*Abstract*- This paper presents a novel optimization technique for determining the setting of various emergency power system controls. This will allow for the production of a comprehensive defence plan, against events such as cascading blackouts. The goal of this technique is to retrieve a new equilibrium operation point following a severe contingency. In the proposed optimization technique described in this paper the generator tripping, load shedding and islanding are considered as the main emergency control actions. Genetic Algorithm approaches are very successful at solving nonlinear combinatorial optimization problems; these have been applied in this work to produce an optimized defence plan. A Genetic Algorithm approach is used to find the optimal combination of generators and loads to be tripped as the best solution for the network to regain a new state of equilibrium that is operationally stable, whilst maintaining supply to as many consumers as possible. System islanding may also be applied if a satisfactory state of equilibrium can not otherwise be obtained. The optimization technique uses transient stability evaluation algorithms, based on time-domain simulation, to assess the fitness of the potential solutions. The test case, presented in this paper, for the optimization technique was the Libyan power system network. In order to show the validity of the optimized defence plan, a comparison between the existing Libyan power system defence plan and the optimized defence plan is presented for the case of a major blackout in the western part of the Libyan power system that took place on 8<sup>th</sup> November 2003. The results presented in this paper show that a robust defence plan with a satisfactory amount of load shedding and system islands can be obtained by the new technique. The paper also demonstrates that the new defence plan outperforms the existing Libyan power system defence plan.

## I. INTRODUCTION

The main goal of power system security measures taken during planning and operation is to minimize the number of interrupted customers following likely incidents. This goal can be reached by implementing planning and operation rules to ensure that power systems remain viable following any credible contingency. However, abiding by these security rules does not guarantee that the network will be fully protected against all types of severe faults. This is due to the fact that major disturbances are the consequence of complex situations associated with control or protection failures. This kind of situation is rare but does occur. Instances include France in 1978 and 1987 and the Western United States in July 1996 [1]. Practically, special defensive measures called a “defence plan” are used. By limiting the geographical extent, duration and effects of the disturbances, defence plans can play an important role in minimizing the number of interrupted customers [2]. Owing to the complexity of modern power systems, the design of defence plans can be very difficult. Human experience and observation are used as the main keys in designing the necessary measures. Although using the experience of power systems engineers can be of assistance in the design of a good defence plan, the optimality of the defence plan, in terms of loss of loads, can not be

guaranteed [3]. This heightens the necessity of using optimization methods to obtain more optimal defence plans. Mathematical optimization methods have been used over the years for power system control problems. However, the solution for large-scale power systems is not easy to obtain by way of ordinary mathematical optimization methods. This is due to the fact that there are many uncertainties in power system problems due to their complexity, size and geographical distribution. It is also much preferred that the solution for the power system be close to the global optimum solution. However, this can not easily be reached by mathematical methods due to the multi-objective, discontinuous nature of the problem space [4]. All of these factors therefore make it necessary to use a robust global search technique such as a Genetic Algorithm [5]. In this paper, a Genetic Algorithm is applied to find the minimum amount of load shedding, following severe faults, at various frequency thresholds that are able to secure the network, or even enhance the dynamic performance. Also, another Genetic Algorithm is applied to obtain an optimal islanding scheme to geographically restrict the extent of the fault. Practically, defence plans are designed to act against incidents which are not covered at the system planning stage. There are many methods that can be used to prevent system collapse immediately following an incident. These include generator tripping, fast valving, load shedding excitation controls and system islanding. Of these, load shedding, generator tripping and system islanding are considered to be the most effective control actions [6]. However, generator tripping is often associated with conservative networks. These defence schemes are based on the fact that, in extreme situations, it is better to shed some loads, or parts of the network, rather than to lose the whole network.

## II. HOW TO DESIGN A DEFENCE PLAN

Numerous specific dynamic simulations are taken into consideration in the process of defence plan design [2, 3]. Unlike conventional operational security studies, the contingencies that are investigated for defence plan design are much more complicated than N-1 contingencies. The goal of these dynamic simulations is to assess system security and to determine the behaviour and the limits of the adopted defence measures, and to examine the impact of a new strategy [7].

### A. Necessity to represent an accurate model for the network

As in any other study, the relevance of the study and the usefulness of the results depend on the accuracy of the system modelling. With regard to the dynamic simulation, a good representation of the dynamic components such as generators, AVR, governors, and the fast-valving system, SVC and FACTS, should be ensured. It is necessary to model the

behaviour of the protection system, including unit protection such as generation unit protection, lines protection, and protection schemes that include the defence plan itself [8].

### B. Incident Scenarios

Building incident Scenarios that represent different types of transient phenomena which lead to full system collapse, is one of the important steps in defence plan designing. Under secure operation conditions, power systems can withstand most likely incidents. Therefore, chosen incidents scenarios should be sufficiently complex and severe to break the system. Most of the time, the network is built to be of sufficient strength to withstand major disturbances. For this reason, the network must be weakened in order to simulate the situation that is very different from the normal operation conditions. Taking into account different weakening operation conditions such as unhealthy voltage profile, an unbalanced generation plan, an exceptional load demand, special import/export conditions and losing an important high voltage line, can be of assistance in representing severe transient phenomena that might lead to full system breakdown. Hence, this leads to a feasible defence plan. Incident scenario can be also built by using a probabilistic technique [9].

### C. Simulation Tools

System collapses involve complex transients, which are a combination of slow transient and fast transient phenomena. Therefore, it is necessary to have simulation tools to study the ability of the power system to remain in synchronization for just a few seconds following the occurrence of the incident and to represent voltage, frequency and power flow variations[10].

## III. LIBYA'S POWER SYSTEM

The power system in Libya consists of four geographically well-dispersed, totally interconnected major island systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and steam units with some diesel generators located in rural areas of the Libyan Desert. The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length 442 km, a high voltage transmission level of 220 kV, and a total circuit length 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV; with a total circuit length of 6,237 km. geographically, the Libyan Network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation, in the south. For purpose of study the Libyan Power System is geographically divided into seven electrical areas [11].

## IV. CURRENT DEFENCE PLAN

### A. Overview

Since the current situation of the Libyan power system is characterized by weak connections in extended areas, the main goal of Libyan power system engineers was to produce

a defence plan which is able to avoid propagation of severe phenomena, like loss of synchronism and voltage collapse.

### B. Current Defence plan design

The Libyan defence plan design is based on the following steps [12]:

#### *STEP 1 Operation conditions definitions.*

In order to be able to represent severe transient phenomena that could lead to full system collapse, the 2003 Libyan network with interconnection with Egypt and the peak load situation has been considered along with some severe conditions. The conditions are attached with this paper in appendix 1.

#### *STEP 2 selections of assessment contingencies.*

As mentioned in Section 2.2, building comprehensive incident scenarios assists in the design of an efficient defence plan. In the Libyan defence plan, the assessing contingencies are attached in appendix 1.

#### *STEP 3 Contingency simulations*

The current Libyan defence plan including load shedding schemes, lines trip under frequency criterion and islanding scheme has been performed on a SICRE simulator environment [13].

#### *STEP 4 Local protection design and setting*

In order to achieve an accurate system, the following protection relays were implemented: out of step relays, under-voltage protection, power flow protections and power swing blocking.

#### *STEP 5 Load shedding scheme design*

Based on the Libyan power system topology, the Libyan network was considered as six areas. Each area has its own load shedding scheme as can be seen in Table 1. For coordination reasons, General Electricity Company of Libya recommended 49.4, 49.2, 49.0, 48.8, 48.6 Hz as frequency thresholds for load shedding. However, the choice of the first and last threshold is based on the following points. The first threshold should be fixed so as to avoid load shedding for electromechanical oscillations, even of large amplitude, in case of interconnected systems still integrated. With the amount of spinning reserve being fixed, it is a good rule to choose the first threshold that is low enough to allow the regulating energy to recover frequency drops with no load shedding. Therefore, in order to get the reasonable threshold values, the following values should be determined: maximum frequency deviation recovered by spinning reserve, maximum frequency deviation due to electromechanical oscillations and minimum frequency value. The minimum frequency threshold has to be fixed with reference to the under-frequency protection of units. In addition to the load shedding scheme, further load is shed by line trips for under-frequency protections intervention. Table 1 represents the amount of load shed and figure 1 shows the areas that were shed by line trips protection.

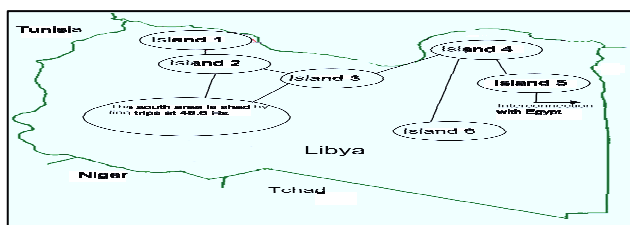
#### *STEP 6 Under-frequency islanding design*

The adopted technique of splitting the system into islands for a frequency below the last load shedding stage has both pros as well as cons. One advantage is the increase in probability of survival of some islanded power plants, with the possibility of accelerating the restoration procedure. One

drawback is the diminution of the probabilities of survival of the small areas, along with instability of the units in small areas and a greater difficulty in balancing load and generation. Based on the experience of electrical Engineers from GECOL and the criteria of the designed islanding scheme, the Libyan Power system was islanded into six islands as shown in figure 1.

**Table I The current load shedding scheme**

AREA	LOAD SHEDDING FOR EACH THRESHOLD					Total
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	
Area 1	3.30%	3.3%	0.00%	0.4%	0.0%	6.9%
Area 2	2.4%	1.8%	4.7%	3.9%	1.3%	14.1%
Area 3	1.60%	1.20%	1.2%	2.30%	1.9%	8.2%
Area 4	0.4%	0.0%	2.8%	1.7%	6.60%	11.6%
Area 5	2.9%	1.5%	2.4%	0.5%	2.1%	9.4%
Area 6	0.00%	0.9%	0.00%	1.6%	1.30%	3.8%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
<b>Total</b>	<b>10.6%</b>	<b>5.6%</b>	<b>11.1%</b>	<b>10.7%</b>	<b>13.2%</b>	<b>54.3%</b>



**Figure 1 The Current islanding Scheme**

V. OPTIMIZED DEFENCE PLAN

A. Overview

Generally, in this study, the same defence plan designing procedures are followed. Unlike the current defence plan, optimization techniques are applied in some critical stages. The first optimization technique is used to obtain a load shedding scheme. At this stage, the optimization technique is used to find the minimum amount of loads that should be tripped in every frequency level. At the second stage, the optimization is applied while obtaining the islanding scheme. Therefore, the optimization technique would be of assistance in finding the optimal islanding scheme.

B. Optimization tools (Genetic Algorithm)

A Genetic Algorithm (GA) is a global search technique used in optimization problems. It imitates the mechanisms of natural selection and genetics. [14]

C. Optimized defence plan design

The optimized defence plan design follows the same logic as the current defence plan. Therefore the optimized defence plane is based on the following:

**STEP 1 Operation conditions definitions.**

Unlike the current defence plan, the optimized defence plan is based on one operation situation. This is due to the fact that it is believed that if the defence plan design is based upon the worst operation conditions, it can act properly in better

conditions. In this case, the weakest operation conditions for the Libyan power system is the 2003 Libyan network with interconnection with Egypt and the peak load situation with 120 MW exchange from Egypt and 64 MW from the West to the East.

**STEP 2 Assessing contingencies selections.**

The assessing contingencies reported in appendix 1 are recommended by the General Electricity Company of Libya. This is due to the fact that these contingencies are carefully chosen to represents different types of severe transient phenomena on the Libyan System.

**STEP 3 Contingency simulations.**

For the simulation and stability evaluation, a stability-assessment-optimized simulator, (PSS-EM) [15, 16, 17] is used to decide whether the system is stable or not, due to its ability to give clear assessments of the system stability. The stability evaluation algorithm on PSS-EM is based on a time domain simulation output.

**STEP 4 Local protection design and setting.**

PSS-EM is not implemented with any type of protection system. Undoubtedly, the protection systems play a vital role in defence plan design. However, using GA helps to simplify the application of the protection system. By using GA, the solutions violating the protection elements are avoided. In other words, the power system protection is added to the assessment of the GA. So, if a certain solution causes some protection relays to be actuated, this solution will be lowly ranked.

**STEP 5 Under-frequency load shedding design.**

Unlike the current defence plan, an optimization technique is used to find the minimum amount of load shedding that is able to stabilize the network in every frequency stage. GA is used as an optimization tool.

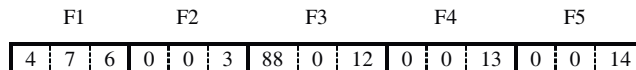
**STEP 6 Islanding scheme design.**

As mentioned before the GA is applied to obtain an optimal islanding scheme. The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible

D. Genetic algorithm Implementation for load shedding

• **Encoding**

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions to the problem into symbol strings (chromosomes). Since the aim of the optimization technique in this stage is to minimize the amount of load shedding in different frequency stages ( frequency threshold ) , the amount of power in every load is considered in the structure of every chromosome. Also, every chromosome is divided into five parts (5 frequency thresholds). Every part corresponds to a certain frequency stage, and is hence applied in that frequency stage. The following is an example of the chromosome structure:



**Figure 2 chromosome structure**

• **Selection**

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes [5].

- **Crossover**

In this Algorithm the Midpoint for exchanging information was applied [5].

- **Fitness Function**

The fitness function provides an evaluation of the chromosomes' performance in the problem domain.

In this particular problem, the objective of the fitness function is to grade each chromosome with respect to the following aspects:

- **Stability class:** The stability evaluation algorithm will rank the chromosome according to its stability class.
- **Amount of generated and load power:** The chromosomes are evaluated in terms of the amount of tripped power they possess. The higher the amount of tripped power, the lower the rank of the chromosome.
- **System decay rate:** This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- **Severity Index:** This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index, the lower the rank of the chromosome.

The corresponding fitness function can be written as

$$FF = \begin{cases} SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{SI} + PS & \text{Stable case} \\ SC + \frac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \frac{1}{TDR} + PS & \text{Unstable case} \end{cases} \quad (1)$$

Where: SC represents the stability class and is equal to

30 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, MVI is the summation of the amount of load reductions, TDR is the time decay ratio, SI is the severity index and PS is the protection system evaluation.

### E. Results of the GA for Load shedding

The GA operators were selected as follows: number of generations is 500, size of chromosomes is 60 and mutation Rate is 5%. The GA obtains the best solution after generation 260. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. The ultimate solution is reported in Table 2. It is interesting to note that the load shedding scheme obtained by GA is similar to the current one in some senses. However, some extra load shedding is required in the new scheme in areas 1, 2 and 4. This makes the total load shedding in the network 63.32%, which is higher than that of the current scheme. It is worthy of note that the optimized solution shares with the current scheme the necessity of tripping the majority of area 4 by line trips load shedding at 48.6Hz. Also, it can be noted from Table 2 that an additional amount of load shedding is introduced in the last stage of load shedding.

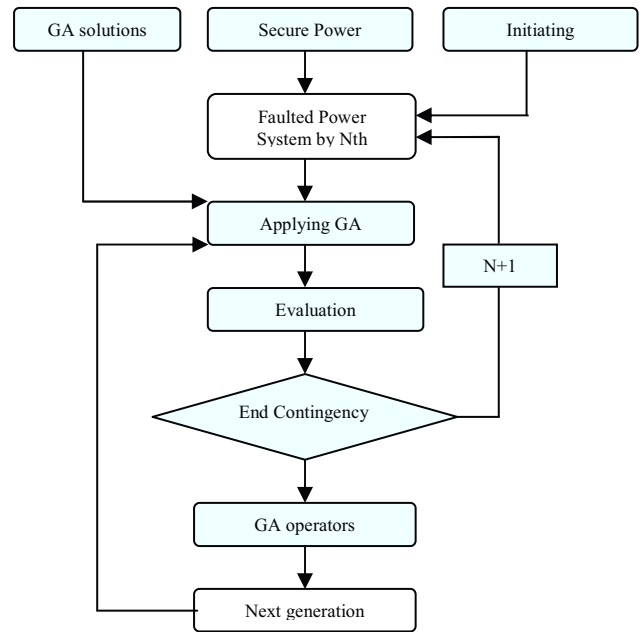


Figure 3 Load shedding algorithm flowchart

This additional amount of load shedding will play important role in saving the system in some critical situations, since it is vital in preparing the network for islanding.

Table II The optimized load shedding scheme

AREA	LOAD SHEDDING FOR EACH THRESHOLD					Total
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	
Area 1	4.20%	4.10%	0.00%	2.00%	1.0%	11.30%
Area 2	2.00%	2.60%	4.10%	5.00%	3.10%	16.80%
Area 3	1.30%	1.00%	0.90%	2.50%	3.10%	8.80%
Area 4	0.32%	0.8	2.40%	2.10%	6.60%	11.6%
Area 5	2.00%	1.00%	2.10%	0.00%	3.10%	8.20%
Area 6	0.00%	1.00%	0.00%	1.00%	2.30%	4.30%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	9.82%	10.60%	9.50%	12.80%	20.20%	63.32%

### F. GA Implementation for islanding

The implementation of the islanding algorithm is fully explained in the accompanying paper [18] and [19].

### G. Results of the GA for islanding scheme

The GA operators were selected as follows: number of Generations is 500, size of chromosomes is 60 and mutation Rate is 5%. The GA obtains the best solution after generation 394. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. Referring to figure 2, in spite of the fact that the GA had completely free hand to choose the cutting point to form the islands, the GA obtained the same island formation of the current defence plan. The only change is in combining island 2 and island 3.

## VI. OPTIMIZED DEFENCE PLAN VS CURRENT DEFENSE PLAN

### A. Overview

In order to show the validity of the optimized defence plan, it is compared with the current defence plan for the case of the



major blackout in the western part of the Libyan Power System took place on 8<sup>th</sup> November 2003.

### B. November 2003 Blackout

Four years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 kV transformer on a power production plant on the West side of the Libyan Power System, Tripoli West Plant (on island 1). This occurred while the Libyan power system was connected to the Egyptian power system with Zero power exchange and the power transfer from the West to the East was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The fault was cleared on the second zone.

#### *Dynamic evolution vs. the current defence plan*

Figure 4 presents the evolution of the frequencies in the Libyan power system with the current defence plan. The dynamic evolution following the occurrence of the fault can be divided based on time into three periods. The first period, which is from 0-10s, starts with the fault occurrence which caused an immediate loss of four units in the west of Tripoli, which caused a loss of generation equal to 120 MW. At 0.8 s following the fault, three units were lost in the south of Tripoli, which caused a loss of generation equal to 237 MW. Two-generation units were lost in the Zawia Plant at 5.5s. One second later another unit in the same plant lost. This period can be distinguished by a loss of generation amount equal to 848 MW. The second Period 2 (7-12s) is characterized by a slow dynamic instability between the East and the West side of the Libya. The third Period (12s- end) started with a fast drop in voltage in the interconnected line between East the West. This is due to a loss of synchronism between the East and the West. Therefore, the interconnection lines between the East and the West were tripped due to under voltage protection at 16.33s at the same time, the Libyan Network was disconnected from the Egyptian Network. It is noticeable from Figure 5 that the East part of Libya survived while the West part of Libya fell in a cascading manner by losing four units in Homs plant until it reached the islanding stage at 48 Hz. Here, the islanding scheme played a decisive role at 19.34s where the network was splitted into three unstable islands. This led to a complete shutdown of the west.

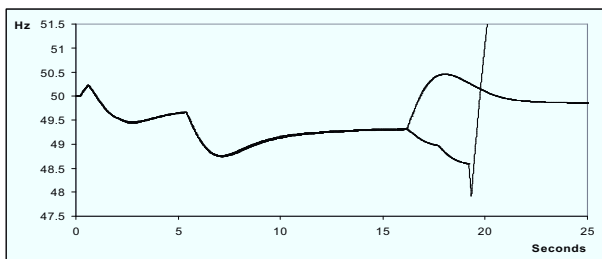


Figure 4 The dynamic evolution of the current defence plan

#### *Dynamic evolution vs. the optimized defence plan*

Figure 5 presents the evolution of the frequencies in the Libyan power system with the optimized defence plan. Similarly, the dynamic evolution in this case went in the same sequence as in the previous one. However, the extra load shedding introduced in the beginning of the optimized load shedding scheme was able to survive two generation units in the Zawiaia Plant which helped to reduce the fast drop in the voltage in the interconnection lines between the East and the West of the country. Hence, the disconnection was postponed to 19.1 s. In general, the period of 10-18s is also characterized by long and slow instability due to loss of synchronism between the East and the West, leading to disconnection. Following the disconnection between the East and the West part of the country, the additional amount of load shedding introduced in the last frequency dependent on the load shedding step has properly prepared the west part of the network for islanding phase. At 23.5 s the network reaches the islanding stage where island 2 (island 2 and 3 in the current defence plan) was able to survive while island number 1 (island of Tripoli) lost its stability just following the islanding action. Comparing the optimized defence plan and the current defence plan in terms of survival load, the current defence plan was able to survive the eastern part of Libyan power system which is equal to 26.0 % of the total load and the optimized defence plan was able to preserve the east part of the Libyan power system and considerable part of the western part of the network. The whole preserved amount of loads is equal to 41.4% of the total loads. Besides this substantial increase in the amount of served load, this difference plays a vital role in reducing the restoration time.

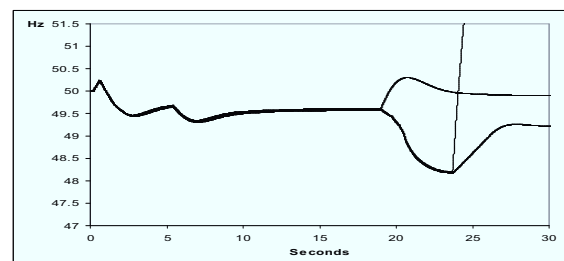


Figure 5 The dynamic evolution of the optimized defence plan

## VII. CONCLUSION

The new defence plan algorithm that has been described in this paper can play an important role in obtaining the optimal islanding boundaries and the minimum amount of load shedding required stabilizing the power system after severe faults. The paper has shown that the algorithm is robust and has produced a superior defence plan when compared to the present Libyan defence plan. In particular, it recommends the amalgamation of two islands and in doing so it is able to preserve the supply to more loads. This was tested using the data from the Libyan blackout of 2003. The use of the optimization method has shown the necessity of having an additional amount of load shedding in the last frequency

dependent load shedding step, not only to stabilize the network but also to prepare the system for the islanding phase.

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# Analysis of the National 8th November 2003 Libyan Blackout

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**Abstract**--During last few years many blackouts have been experienced throughout the world. It seems that modern power systems are more exposed to major blackouts. Studying and analyzing real-world blackouts can play a very important role in the avoidance of such events. In this paper, the experience of 8th November Libyan blackout is presented. The blackout is studied and analyzed from a dynamic point of view. A comparison between the Libyan blackout and some international blackout is also introduced. Some suggestions and solutions are given to improve the security of the system during future major disturbances.

## I. INTRODUCTION

During the last few years, many different major blackouts have been experienced around the world. Apparently, the modern power systems are more exposed to major disturbances. The capability of power systems to respond promptly and properly to major disturbances has been decreasing. This might be due to the fact that the modern power systems are suffering from lack of investment or due to the degree of complicity and power system deregulation with its related non-mature rules.

Blackouts are consequences of various complicated phenomena and abnormal events. These complicated phenomena have to be studied carefully in order to gain sufficient knowledge of the blackout evolution. Lack of careful and detailed studies of power system transient events and protection practices during the disturbances can lead to reoccurrences of system collapse.

The main objective of a detailed study of blackouts is to clarify the reason causing the collapse by verifying the behavior and performance of the system components and identifying the phenomena affecting the system during the transient evolution. Another objective is to find some improvements in system performance on the basis of the dynamic response. In order to be able to do this, a well dynamic reconstruction should be performed [1].

In this paper, the 2003 Libyan blackout is fully reconstructed and analyzed. Performance of various power system protective schemes is analyzed. Power system stability, out-of-step protection, real power deficit, frequency relaying, and load shedding are among the aspects which are studied. Some suggestions and solutions are also recommended to decrease the chance of collapse reoccurrences. Improving the current protection scheme and revision of system relay settings are

among the solutions considered to improve the system performance during abnormal events.

## II. LIBYAN BLACKOUT

### A. Libyan Power System

The power system in Libya consists of four geographically well-dispersed, totally interconnected major island systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and steam units with some diesel generators located in rural areas of the Libyan Desert. The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length of 442 km, a high voltage transmission level of 220 kV, and a total circuit length of 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV with a total circuit length of 6,237 km. Geographically; the Libyan Network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation in the south [2].

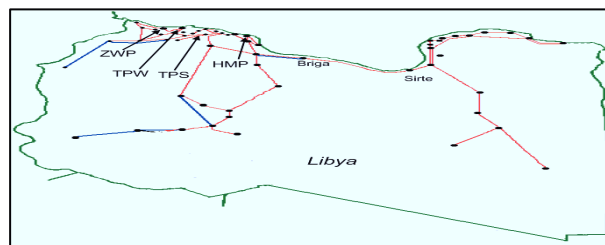


Figure 1 Libyan Power System

### B. Incident

Four years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 KV transformer at the power production plant on the west side of the Libyan Power System (Tripoli West Plant). The Libyan power system was connected to the Egyptian power system with zero power exchange, and the power transfer from the West to the East was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The fault was cleared on the second zone.[3]

## III. LIBYAN BLACKOUT VS INTRNATIONAL BLACKOUTS

In this section the Libyan blackout will be compared to some international blackouts, in terms of blackout severity, pre-

fault conditions and Causes of the blackout. This comparison is based on ten well known blackouts including the Libyan blackout

**A. Severity**

To give general idea, Table (1) presents some facts and figures ten well known blackout.[4,5,6,7,8,9,10]

**Table 1 Blackout information**

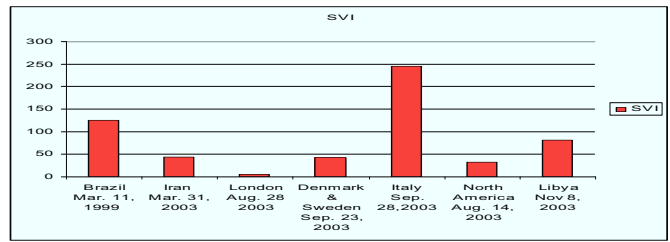
Blackout	Customers without service	Lost load	Time duration	Affected populations
Brazil Mar. 11,1999	75.000.000	24.731	Up to 4 hours	%44.65
Iran Mar.31,2003	22.000.000	7.063	8 hours	%32.22
London Aug. 28 2003	410.000	724	0.62 hours	%5.43
Denmark & Sweden	4.000.000	6.550	5 hours	%27.86
Italy Sept. 28,2003	57.000.000	24.000	5 to 9 hours	%100.00
North America August 14,2003	50.000.000	61.800	16 to 192 hours	%15.51
Libya Nov 8,2003	4.000.000	1.876	0.5 to 6 hours	%70.0

In order to classify the severity of the Libyan Blackout among other blackouts, a new blackout Severity Index (SVI) was produced to give a sensible indication of system blackout severity.

A good severity index should include the effect of blackout on domestic and industrial demand. The first term (AP) on the severity index equation represents the percentage of the affected population within the domestic demand. The second term (UL/GC) is a ratio of unserved energy during the blackout period to the generation capacity of the whole network. So, the size of the unserved load and the duration of the blackout are included. Assuming the effect of blackout on the industry and the domesticity is equal; the severity index can be presented as following:

$$SVI = \sqrt{(AP)^2 + (UL / GC)^2}$$

Where AP is the percentage of affected population and the UL is amount of the unserved load in MWh and GC is the Base of the power. Based on the SVI, figure (2) presents the ten blackouts in severity order.



**Figure 2 The Severity of Blackouts**

**B. Pre fault conditions & Causes of Blackouts**

Table (2) summarizes the operation condition prior to the incident.

**Table 2 blackouts Pre Fault conditions**

Blackout	Pre fault conditions
Brazil Mar. 11,1999	Normal loading operation
Iran Mar.31,2003	High load level and some lines and power plant were out of services
London Aug. 28 2003	Two lines were out of services
Denmark & Sweden	Five transmission lines and four generation units were out of service
Italy Sept. 28,2003	High power transfer toward the country
North America August 14,2003	High temperature , High load level and some generation units and five capacitor bank were out of service
Libya Nov 8 ,2003	Normal loading operation

**Table 3 Blackouts causes**

Blackout	Initial cause	Supporting cause
Brazil Mar. 11,1999	Phase to ground fault as a result of lightning	Unexpected heavy loaded line tripped causing a stability problem
Iran Mar.31,2003	Unknown	Unknown
London Aug. 28 2003	Transformer Fault combined with Human Error of setting power	-----
Denmark & Sweden	Internal valve fault in nuclear power plant	Double busbar fault lead to loss of two nuclear power plants
Italy Sept. 28,2003	Tree fault indirectly cause interconnection lines to trip	Heavy import of power
North America August	Significant reactive power deficiency combined with Tree	Software Problem at control centre causes the corrective action not to
Libya Nov 8 ,2003	Transformer fault	inadequate defense plan



Considering the fact presented on table 2 and 3, the incorrect protection elements was not only the initial cause in some blackouts but also a factor that accelerated the system outages in some others. Inadequate vegetation trimming which causes the contact of lines with trees was also one of the main causes that initiate the system outages. Although, the deficiencies in voltage stability and the supplying of reaction power were amongst the causes of one blackout, it played the main role in spreading the system outages in some others. The inadequate defense plan and lack of maintenance was reported in some cases. It is worthy of note that the absence of the sense of urgency before the situation degraded and inadequate training, information technology problem were reported in some cases.

#### IV. PRE FAULT CONDITONS OF THE BLACKOUT

It is vital in this stage to produce an accurate steady state operating condition prior to the incident. This will help to produce an accurate dynamic model. The grid structure consists of two main areas, which are the western part of Libya (West) and the Eastern part of Libya (East). These two areas are connected through a long double line connection called the Sirte-Briga connection. The East is connected to the Egyptian network through a long, double circuit connection called the Tobruk-Salume connection. The operation condition prior to the incident can be summarized in the following numbers:

Available Power = 2536 MW

Load at the time of incident = 2345Mw

Spinning reserve= 190 Mw

Sirte-Briga connection transient = 30 Mw through the East

Tobruk-Salume connection transient = 0 Mw

The situation prior to the incident presents two weak connections with risk of instability in case of severe contingencies.[3]

#### V. RECONSTRUCTED DYNAMIC PERFORMANCE

##### A. Overview

At 18.30 a severe disturbance occurred on 220Kv consisting of a three phase to ground fault on the 220/30 kV transformer at TPW power plant. The differential protection operated and gave a trip command but the circuit breaker on 220kV side did not respond due to control trip circuit failure. Therefore, distance protections at the second end of all the line connected to the busbar of TPW (busbar with the faulted transformer) operated in second zone and isolated the fault in about 380 ms leading to outage of main generation groups and 220Kv lines in Tripoli region.

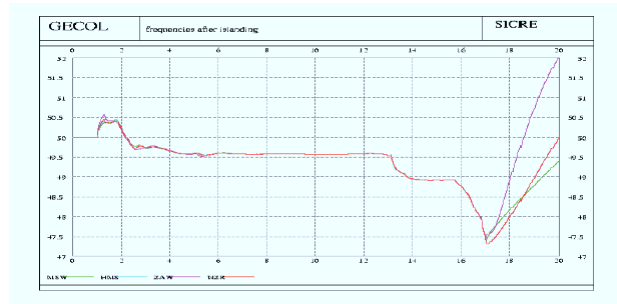


Figure 3 System frequencies during the blackout

##### B. Dynamic evolution

Generally, the dynamic performance of the network is presented in Figure 3. Figure 3 shows the frequencies of various bus bars following the occurrence of the fault. The dynamic evolution following the occurrence of the fault can be divided based on time into three periods.

##### 1. First period (0-10s)

The first period, which is presented in Figure 4, starts with the fault occurrence which caused an immediate loss of four units in the west of Tripoli. This caused a loss of generation equal to 120 MW. At 0.8 s following the fault, three units were lost in the south of Tripoli, which caused a loss of generation equal to 237 MW. Two generation units were lost in the Zawia Plant at 5.5s. One second later, another unit in the same plant was lost. This period can be distinguished by a loss of generation amount equal to 848 MW. It is worthy of note at this stage that this type of fault is considered as extreme contingency, and it has very low probability of occurrence. It is noticeable that the frequency varies up to 49.6 Hz in this period for all the areas; such value is above the first stage of load shedding. It is also worthy of note that all units tripped in this period were due to auxiliary failures.

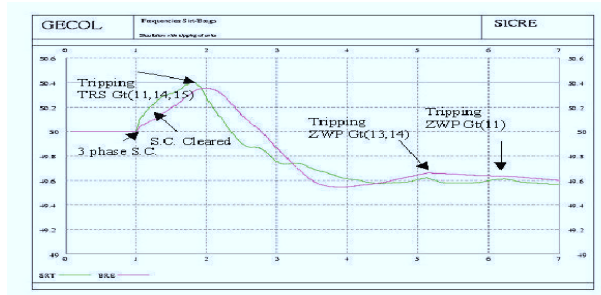


Figure 4 Sequence of events during the first stage

##### 2. Second Period (7-12 s)

The second, which is presented in Figure 5, is characterized by a slow dynamic instability between the East and the West side of Libya. This kind of instability is due to a slow oscillation between the eastern and western generators with a slow increase of transfer power along a large distance.

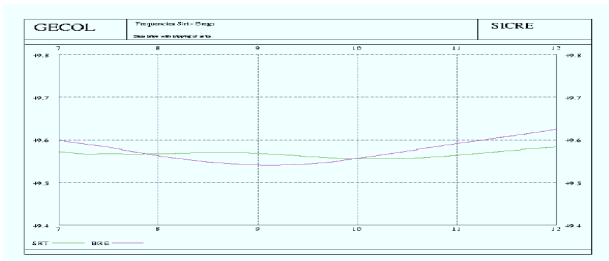


Figure 5 Sequence of events during the second stage

### 3. Third Period (12s- end)

It started with a fast drop in voltage in the interconnected line between the East and the West. This is due to a loss of synchronism between the East and the West. Therefore, the interconnection lines between the East and the West were tripped due to under voltage protection at 16.33s. At the same time, the Libyan Network was disconnected from the Egyptian Network. It is noticeable from Figure 6 that the eastern part of Libya survived; while the western part of Libya fell in a cascading manner by losing four units in the Homs plant. Two seconds following the separation of the East and the West of the network, the system dynamic, in terms of voltage and current related to Khoms machine, led to the under voltage and Over current generators protection near to the intervention settings. During this stage, two units in the Khoms plant were lost for reasons not completely clear. On the basis of event log, the most probable motivation is a “flame failure” for one and an unjustified intervention of the loss of excitation protection for the other. After these events, it is justified both for values and duration of the operation of the loss of excitation protections for the remaining two units.

Following the cascade tripping of Khoms generation units, the frequency drop was very fast with load shedding and system islanding. Such a stage is difficult to analyze because very small differences in the sequence of tripping and also defense plan activation can cause remaining generation units tripping for under frequency relay intervention. It reached the islanding stage at 48 Hz. Here, the islanding scheme played a decisive role at 19.34s where the network was split into three unstable islands. This led to a complete shutdown of the west.

As a general remark, in the case of rapid frequency decline, the proximity of the settings of under frequency relay for the units and islanding relay were not sufficiently able to assure good selectivity.

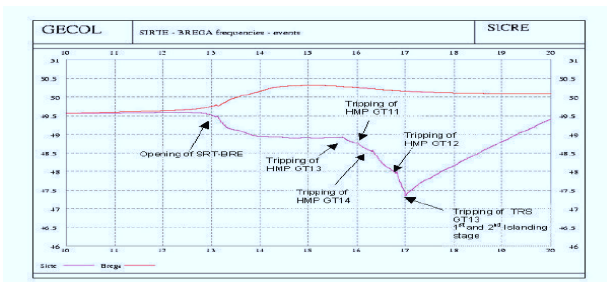


Figure 6 Sequence of events during the third stage

## VI. CONCLUSION

The Libyan power system has been considerably developed during last years. Considerable number of high voltage transmission lines and substation are built. New power plants are added in order to match the increase in electrical power consumptions rate. However, due to the economical development, the increase electrical power consumption rate (ECR) is significantly high. This has emerged some difficulties in maintaining a balance between matching ECR and system security.

In this particular case, it is worthy of notice that the occurred transient stability problem was not due to electromechanical oscillation damping or fast transient stability due to short circuit of system fast variation in acceleration immediately after the consequence of units tripping. It was found that the instability is due to an angle opening between the West and the East where the maximum angle difference (about 90) was reached. The slow variation up to instability is largely dependent on the continuous operation of the frequency primary control trying to support the system until saturation of regulating energy in the most affected areas is reached. It is worth noting that the stability conditions for the Libyan system, characterized by a very long longitudinal structure, are influenced by many factors. These factors are frequency, primary control characteristics, the load typology, and power system stabilizer.

It is clear that the protection system of the generation units have played a vital role to collapse the system. It seems that protection of the generation units have acted as apparatus protection rather than system protection. Proper protection system should be designed in a way to maintain the safe and operation of the power system as whole. They are not strictly related to protecting a specific apparatus being in danger due to its internal fault. In this sense the protection of generation units should be adjustment in away to keep the generation units connected to the grid as long as possible. It is worthy of note that the defense plan is useless if the generation units can not operate in islanding situations

## VII. RECOMMENDATIONS

Based on the above dynamic reconstruction and analysis the recommendations can be summarized in the following points:

1. The system should be monitored in terms of electromechanical phenomena.
2. The system should be reviewed in terms logic and setting for electrical supply of the auxiliaries of the gas turbine.
3. Co-ordination between grid and generation unit protections should be assured.
4. PSS gains and analysis of factors influencing the system stability should be reviewed.

5. The defense plan should be co-ordinated with the protective scheme and should be reviewed.
6. Tests on the thermal unit performance, to check their ability to face grid emergency conditions, should be conducted periodically.

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