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A New Expert System for Load Shedding in Oil & Gas Plants – A Practical Case Study

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1. Introduction

Electrical Power source of gas turbine driven generators is widely used in oil & gas industries.
It is the most adequate means due to availability of natural gas as a fuel to prime movers.
This type of power generation is in most cases used in isolation from the utility source as an island generation pool.
In critical operation conditions at which the generation drops severely , a case of insufficiency between generation and loading is established. In such a critical case a compromise between maintaining the process production and whole area power outage is made by shedding the non essential loads. Shedding of these loads is made till power is restored by the operators.
This chapter presents an integrated knowledge base system for generation dropping monitoring in oil& gas plants. The knowledge-based designed system monitors clearly and continuously the performance of power generation and distribution during operation. Effects of different generation insufficiency probabilities resulting from one or more of power turbine sudden shutdown are investigated. The developed system checks the stability of the system after generation dropping disturbance with power flow prior& after the disturbance and at each load shedding step to insure safe and stable operation of the industrial power system.
It indicates the system frequency and its deviation, voltage levels on established buses, generator machines operating point, real and reactive power flow.
The developed system discusses the overload capability of the generator as well. It indicates the recommended loads to be shed at discrete time events. It generates also system parameters and operating points curves.
The Main novelty of this approach is utilizing a built-in knowledge base to automatically remember the system configuration, operation conditions as load is added **or removed**. Thus predicting the system response to different disturbances. So it makes fast, correct and reliable decisions on load shedding priority. Obviously it is more suitable to industrial applications.
Whilst the modern utility load shedding applications use more monitoring and mining network data streams is crucial for managing and operating data networks. Such systems must cope with the effects of overload situations due to large volumes , high data rates and bursty nature of the network traffic. Some Intelligent trials use adaptive load shedding

strategy by executing the artificial neural network (ANN) and transient stability analysis for an Industrial cogeneration facility. To prepare the training data set for ANN, the transient stability analysis has been performed to solve the minimum load shedding for various operation scenarios without causing tripping problem of cogeneration units.

2. The developed system

Large industrial plants usually feed large electric loads at different voltage levels.
Severe losses are foreseen in case of loss of power supply. Accordingly, the load shedding scheme to control the process of generation drop to counterpoise the most needed loads so as to maintain production till the power supply problem clearance, is a real serious vital job.
Most commercial load shedding schemes are using independent system under-frequency relays that detect the frequency drop limit and start to trip loads in stages according to a predefined truth table. Other alternatives are using the SCADA software on power management system to detect the number of operating power generators to decide the start of load shedding.
Power system stability is the property of a power system that insures that the system remains in electromechanical equilibrium throughout any normal and abnormal conditions (i.e. generator operating point remains in the limits indicated on manufacturer power chart).
One of major causes of industrial power system instability problems is generation drop (unbalance between generation and load demand). The consequences of instability problems are very severe and may cause permanent damage on equipment, moreover the whole area power outage. Stability studies are dynamic simulations of the particular groups of machines in the system that are known to have important influence on the system operation, in order to study system frequency variations , power output,…etc. One of tools for power system enhancement is adding load shedding scheme.
A stability study is performed to investigate dynamic conditions on the power system during generation. The study shall begin with steady state load flow conditions for the purpose of establishing power flows (watt & Var) in the system at time intervals immediately prior to the system disturbances under investigation. The dynamic studies shall determine the following: machine operating point, real & reactive power flows for selected machines, system frequency & frequency deviation, voltage levels on established buses at disturbance initiation, discrete times during and following its removal from the system. The conditions for each time interval shall be printed out and the values for each time interval shall be used as the initial condition for the subsequent interval during the entire period studied to obtain a definite stability conclusion.
In this chapter a new method for load shedding is presented using the transient stability studies to analyze this problem. It is deemed necessary to make dynamic simulations of the particular group of machines in the system that have major influence on system operation.
A combined system for monitoring of generation and load demand to load shedding in case of unbalance between them has been developed. An integrated software has been designed to perform this vital task.
The developed system is composed of three different modules; input and general studies modules are constructed and carried out supported by the Electrical Transient Analyzer Program (ETAP). Outputs of these modules are automatically collected and indexed within the knowledge base module. The knowledge base module contains mainly the generator power chart constraints, generator thermal limitations and load shedding design rules. Also

it contains switching events rules as well as a list of load categories recommended by process engineers. The knowledge base and output modules are developed using Matlab Simulink. As well a graphic module has been developed to visualize the system and record generator frequency, generator exciter voltage, generator output power and generator current. The developed system is designed in a modular form and consists mainly of three modules as described in the following sections.

2.1 Input module

This module constructs the data base which represents the plant. The input module specifies the plant description, edits the single line diagram and defines the operation of different loads using colour code. Using this module, the power plant will be fully described and the following data is transferred to the knowledge base module automatically:

a. Plant bus-bars connection.
b. Location of each load in the plant map.
c. Feeders and cables data. A special library is used for cable description.
d. Load description, specification, category and duty.

The load Category is classified to serve the load shedding priority as category (0) stands for important loads that can not be shed, category (1) stands for second priority loads to be shed with minimum impact on process for load shedding duration, category (2) stands for first priority loads to be shed with no process impact for load shedding duration.

The system also accepts different definitions of power consumption for each load as follows:

a. Design active power is defined as the active power for a driven machine or load in its normal mode of operation,
b. Design particular power is defined as the active power for a driven machine or load in a load in a special loading conditions,
c. Nameplate power is a rated active power as stated in the nameplate of a driven machine or load.

2.2 General studies module

This module is responsible for carrying out all plant calculations such as load flow study and transient stability study.

2.2.1 Load flow study

The load flow calculation tool specifies the plant operating conditions. It generates branch current loading, branch losses, bus loading and transformer loading. It generates also alarms for critical equipment and critical buses. For monitoring of motors operation in large plants, the load flow runs are made based on possible load and their results are considered as initial operating conditions. These runs are then repeated for load shedding steps to check the power system operating conditions at these circumstances.

2.2.2 Transient stability study

This is performed to investigate dynamic conditions on power system during generation drop. The dynamic simulations of a particular group of machines in the system that are known to have important influence on the system operation is performed. The aim of this study is to calculate system frequency variations, power output…etc. Fig.(1) indicates the AVR/exciter model applied for the case study presented in this chapter.

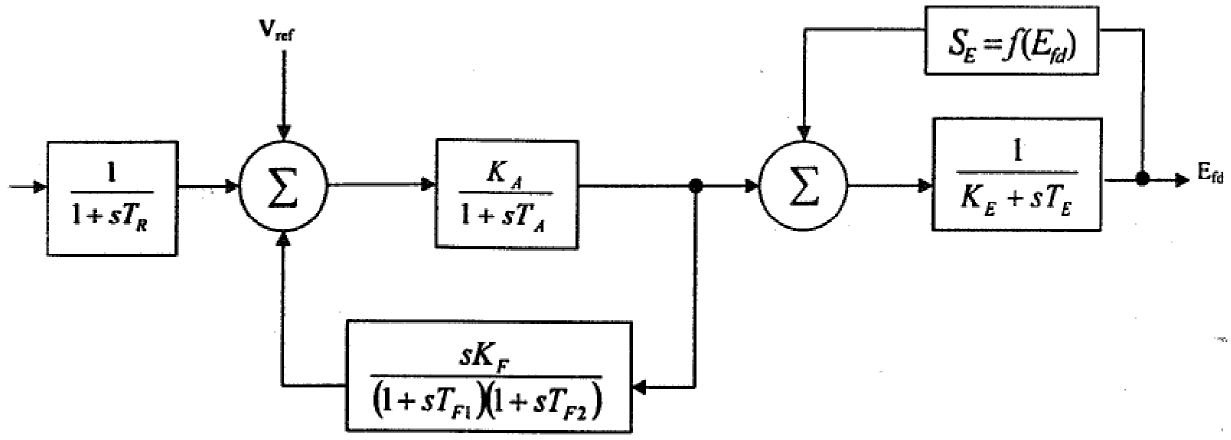


Fig. 1. AVR/Exciter model

2.3 Knowledge base module

This module is the heart of the system. It consists of two types of the rule base that manipulates the load shedding steps. Type (I) is a time event of generation dropping and load shedding actions in the plant. Type(II) is concerned with generator stability check.

This expert knowledge is normally stored separately from the procedural part of the program. It is a form of data base containing both facts which describe fixed properties or characteristics of generation & loads and information on how to do load shedding.

As an example the statement:

"A3 is a circuit breaker" is a fact.

If it is desired to shed network by opening a circuit breaker, a rule could be formed expressing such knowledge in the form of IF (X) THEN (Y), where X is the premise or antecedent and Y is the conclusion or consequent, which is either True or false.

2.3.1 Type I

The rule base specifies the process constraints and the events expected in each plant. This part of the rule base has a storage capacity of time events from (t1 to t15). Each time event allows 10 actions to be defined. Fig.(2) shows a time event page.

2.3.2 Type II

This type of rule base identifies the level of control and monitoring for generation and load demand as well as recommended settings. It may include up to 300 rules for a similar number of motors. It classifies the motors based on motor type, motor ratings and operation criteria as well. The following constraints are some rules in the rule base:

a. The generator thermal withstand monitoring unit: This part covers many items such as generator manufacturers thermal withstand characteristics as related to the fault current and duration that the machine can withstand. This unit is of prime importance to check continuously the generator loading to decide the instant of load shedding initiation.
   The load category unit: This unit is for the load category as classified to serve the load shedding priority category (0,1,2).
b. Generator power limiter unit: This unit supervises the generators power capability with respect to many limits such as rated stator current, rotor current limit, practical stability limit, minimum excitation, power factor, lead & lag domains…etc.
c. Generator power angle check unit: This unit provides the check for power angle as a stability index for operating generator.
d. Load shedding control unit: This unit determines the number of loads, the steps, and the duration of each step to apply a proper load shedding scheme.

The execution is based on the knowledge base contains six rules of the following form:

IF (A) THEN (B)

Where:
A: is the condition part of the rule.
B: is the action part of the rule.
Each Rule corresponds to a path in the decision tree in Fig(3) that provides an established technique for solving classification problems, which have a small number of categories stable versus unstable.
The set of rules are as follows:
Rule 1: IF the power angle of each generator in the system with respect to fixed reference in the system increases to a maximum value and then decreases THEN the system is considered as synchronously stable no load shedding.
Rule 2: IF the system is synchronously stable,
AND the final voltage profile of the system is acceptable.
AND the final loading of every branch in the system is acceptable.
THEN the final system condition is considered as acceptable.
AND the run can be terminated.
Rule 3: IF the system is synchronously stable,
AND the final voltage profile of the system is unacceptable due to violation of the voltage limit in one more of the system bus THEN load shedding is needed to correct the final voltage profile.
Rule 4: IF the system is synchronously stable,
AND the final loading profile of the system is unacceptable due to violation of the loading limit in one or more of the system branches THEN load shedding is needed to correct the final loading profile.
Rule 5: IF the power angle of one or more generators in the system with respect to fixed reference in the system increases indefinitely THEN the system is considered as synchronously unstable.

Rule 6: IF the loading is higher than generation.
AND the system is synchronously unstable.
AND the power angle of certain generator (i) increases indefinitely.
THEN load shedding is performed as a control action.

The rules from (1) to (6) have to be repeated till a stable position is reached.

The interpreter tool that links between ETAP and Matlab Simulink is the UDM control blocks. The UDM control blocks are created using Matlab Simulink interface tool.

The components of the new expert system are shown in Fig.(4). The four major components of this system are the user interface , the simulation program , the rules for transient stability evaluation & for suggesting load shedding control actions and the interface between them. The operation logic is described in the flow chart Fig.(5).

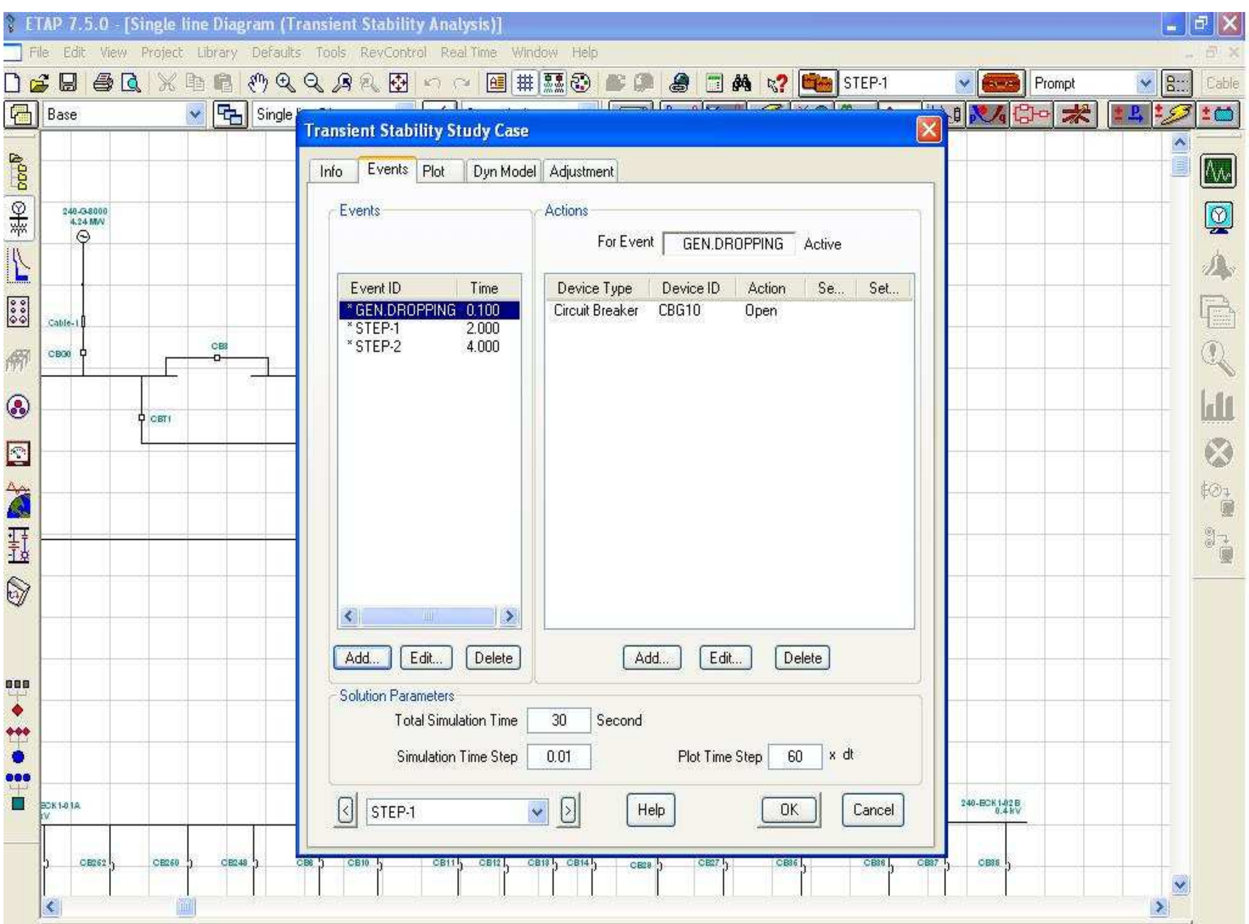


Fig. 2. Recommended Time Event unit for generator dropping and load shedding actions.

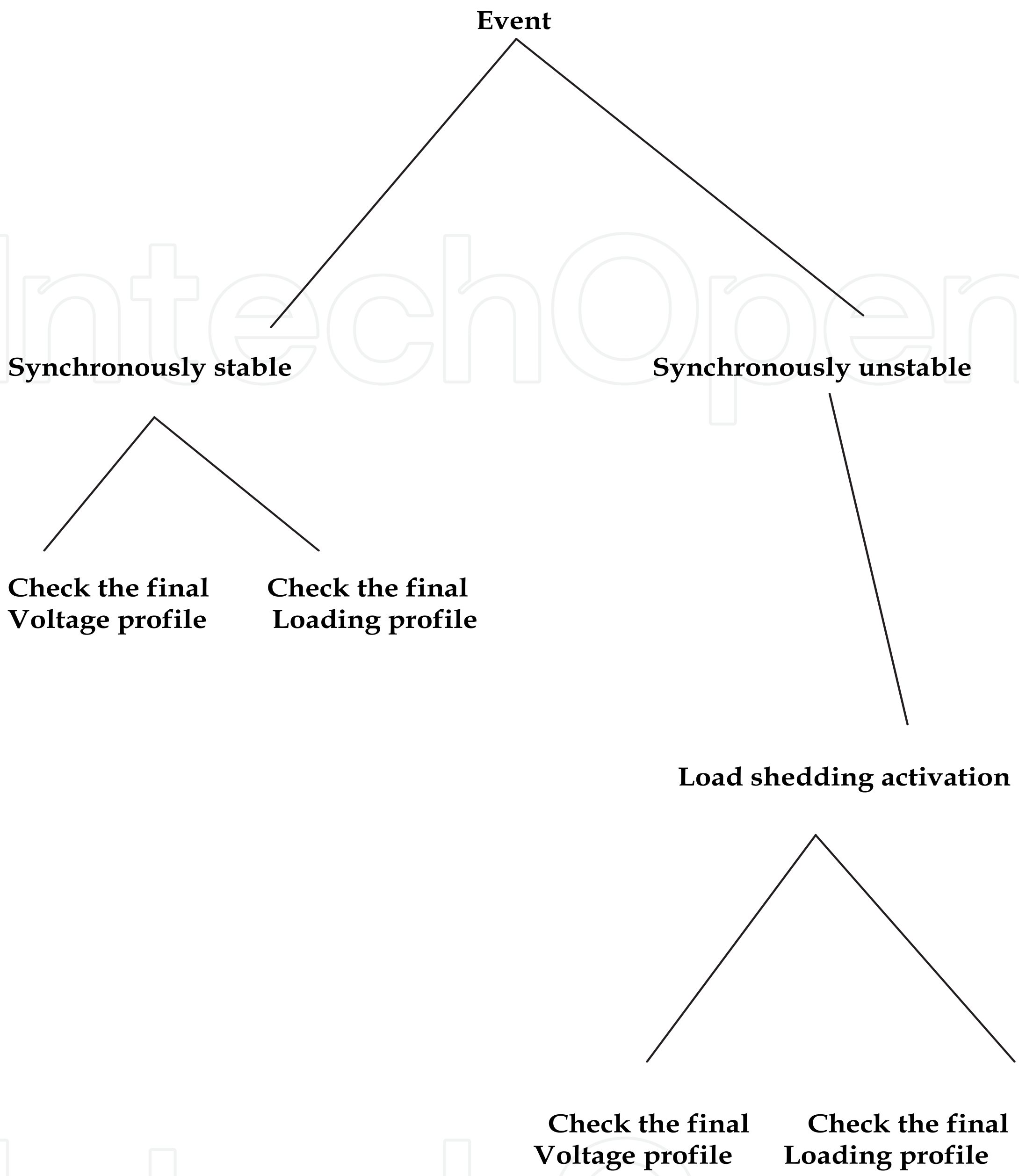


Fig. 3. Decision tree for knowledge base.

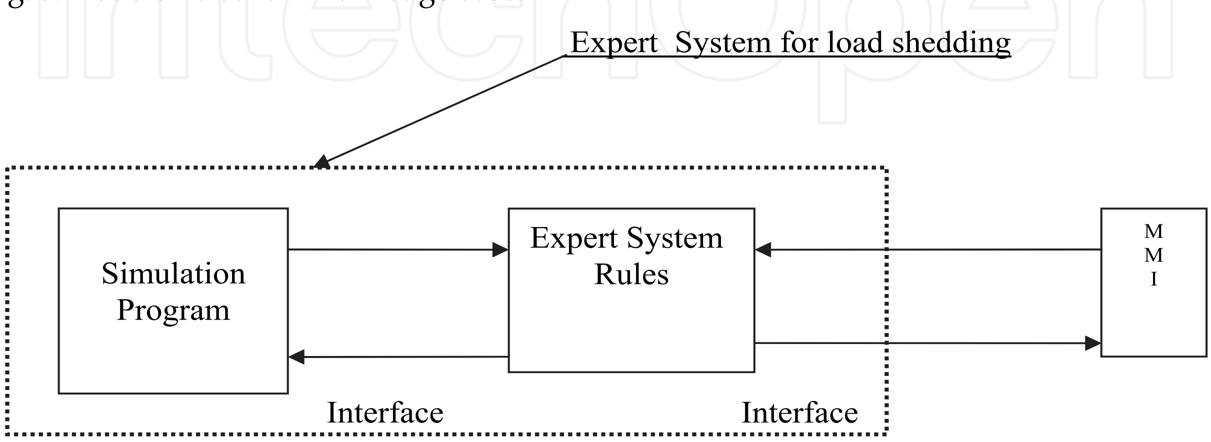


Fig. 4. Components of the new expert system.

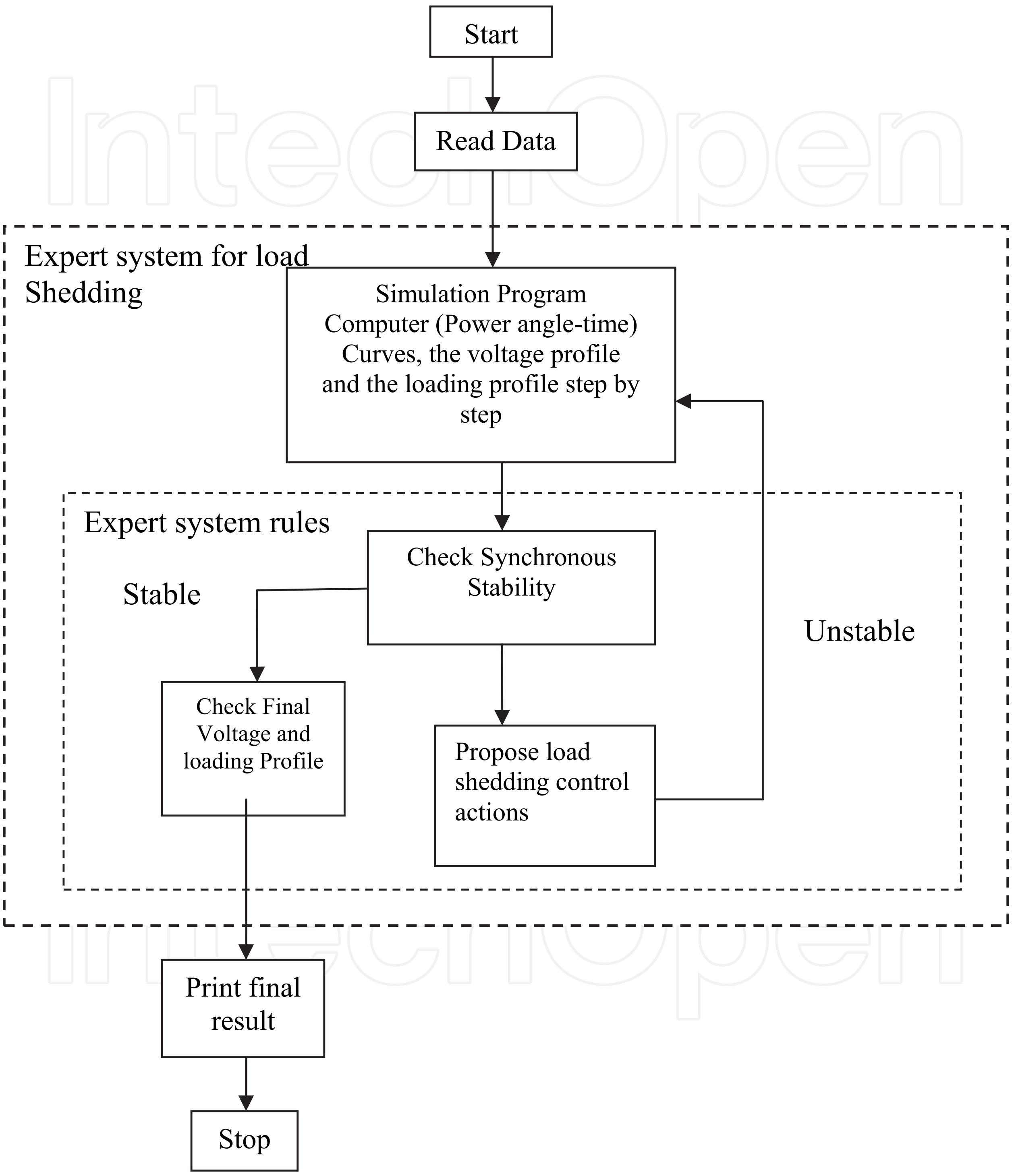


Fig. 5. The operation logic flow chart of the new expert system.

3. The case study

The industrial power system investigated here is a typical natural gas processing plant onshore facility. The loads of the plant are supplied at two voltage levels. The ratings range from 1MVA motors down to fractions of horsepower rating loads. The power supply to the plant consists of three gas turbine driven generators each rated 4.24MW at 0.8 power factor.
Two gas turbines are continuously feeding the demand loads and the third one is in standby mode.
For clarification, the simplified single line diagram is shown in Fig.(6).
During severe conditions of the power generation system one turbine is carrying the total plant load which results in insufficient generation to meet loads , especially in Summer time where the turbine rating is de-rated due to high ambient temperature.
The condition in this abnormal operation , the second turbine will be able to share the load with the running turbine within one hour. After the duration is elapsed the plant must be shutdown in case the second turbine is failed to start. Automatic load shedding program preset to drop specific loads to steer the power system operation into safe margins.
The load shedding system shall be implemented in the substation switchgear by having initiation signal from turbine emergency system (voltage free contacts from each turbine to indicate turbine shutdown) to the substation supervisory system. The speed of communication is a dominating factor to achieve a rapid load shedding system within the overload capacity of the generator.
These hardwired signals are processed in the substation supervisory system which would operate the load shedding scheme the instant it detects that 2 of the 3 turbines are stopped (off) and the third is supplying the whole load. The status of the generator circuit breakers are used as a confirmation signal. The consumed power measurements on each generator circuit breaker monitored by the substation supervisory system shall be used to determine that the only running generator loading above 3.7MW.
The loads in switchgear panel tag item 240-ESI1-02 would be tripped through the already wired stop signals (inhibit to start for the load shedding duration) and a signal would be transmitted via fibre optic cable to trip the loads (inhibit to start for the load shedding duration) in panel 240-ESI1-02.

3.1 Input and general studies output

A load flow study had been done for the system under consideration. Table (1) shows the results of this study for normal operation of the system in which two turbines carry the demand loads.
As generation drop of one generator causes the system to no longer operate in safe margins and therefore loads have to be shed to remove the overload on the still operating turbine-generator.
The system parameters are shown in the following curves are depicted versus time
Fig.(7) speed response at generation drop.
Fig.(8) Generator electrical power demand.
Fig.(9) Generator terminal current.
Fig.(10) Generator exciter voltage.
Fig.(11) Generator exciter current.
In critical operating conditions the load shedding steps are used to remove the only running turbine overload. Item 3.2 indicates the results of applying load shedding steps. The

generator thermal withstand curve indicates that the machine can sustain 3 times nameplate current for 10 seconds and overload capability is 120% for 5 seconds. Accordingly the amount of load shed at every stage should keep the generator overload less than 120%. After application as described in item 3.2, the system parameters after load shedding are shown in the following curves are depicted versus time:

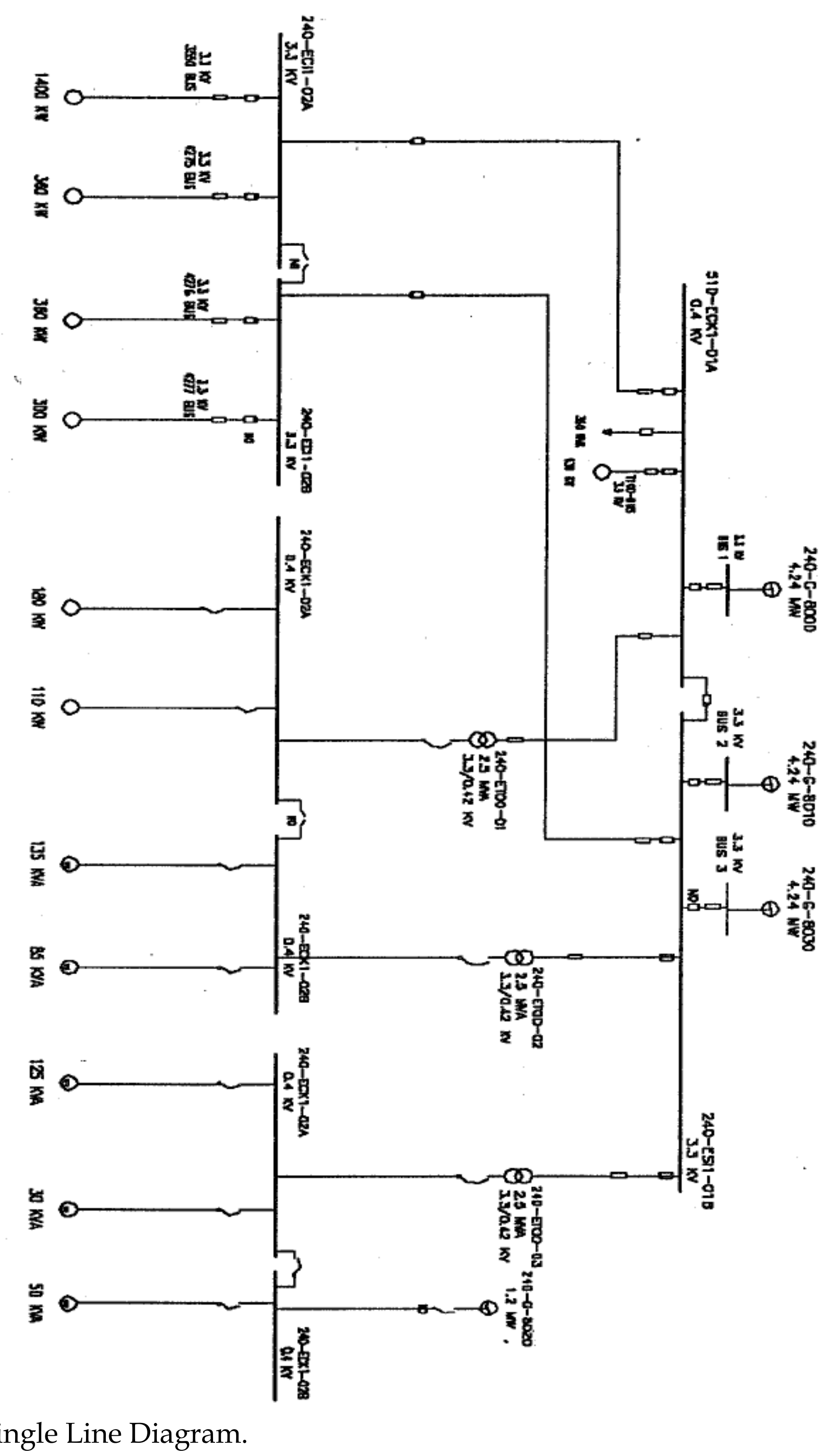


Fig. 6. Global Single Line Diagram.

Bus		Voltage		Generation		Motor load		Static load		Load flow					
ID	KV	%MAG	ANG	MW	MVAR	MW	MVAR	MW	MVAR	ID	MW	MVAR	AMP	%PF	%TAP
240-ECK1-01A	0.4	102.714	-1.4	0	0	0.33	0.23	0.38	0.29	ECK1-01A	-0.71	-0.52	123.5	91.7	
240-ECK1-01B	0.4	103.314	-1	0	0	0.12	0.09	0.39	0.29	ECK1-01B	-0.51	-0.39	897.2	80	
240-ECK1-02A	0.4	100.279	-2.7	0	0	0.09	0.07	0.43	0.47	ECK1-02A	-1.17	-0.98	210.3	80	
										240-ECK1-02B	0.45	0.34	803.7	80	
240-ECK1-02B	0.4	100.279	-2.7	0	0	0.01	0.01	0.44	0.33	240-ECK1-02A	-0.45	-0.34	803.7	80	
240-EC11-01A	3.3	99.978	0	0	0	0	0	0.28	0.21	BUS 1	-2.88	-1.72	587.6	85.8	
										7100 - BUS	0.07	0.06	16.8	73.9	
										ECK1-01A	0.71	0.55	157.1	79.3	
										ES11-02A	2.64	0.95	492	94.1	
										240-ES11-01B	-0.83	-0.05	144.8	99.8	
240-ES11-01B	3.3	99.978	0	0	0	0	0	0	0	BUS2	-3.31	-1.98	674.3	85.8	
										ECK1-0-1B	0.52	0.4	114.2	79	
										ECK1-02A	1.18	0.97	267.7	77.1	
										ES11-02B	0.79	0.55	168.1	81.9	
										240-ES11-01A	0.83	0.05	144.8	99.8	
7100-BUS	3.3	99.954	0	0	0	0.07	0.06	0	0	240-ES1-01A	-0.07	-0.06	168	73.9	
BUS 1	3.3	100	0	2.98	1.72	0	0	0	0	240-ES11-01A	2.88	1.72	587.5	85.8	
BUS 2	3.3	100	0	3.31	1.98	0	0	0	0	240-ES11-01B	3.31	1.98	674.2	85.8	
BUS 7	15	103.524	-1.6	0	0	0	0	0	0	240-ES12-01	0	0	0	0	
BUS 9	3.3	98.914	-0.1	0	0	1.37	0.9	0	0	3550BUS	-1.37	-0.9	291.1	83.5	
ECK1-01A	3.3	98.961	0	0	0	0	0	0	0	240- ES11-01A	-0.71	-0.55	157.1	79.3	
										240-ECK1-1A	0.71	0.55	157.1	79.3	
ECK1-01B	3.3	99.963	0	0	0	0	0	0	0	240-ES11-01B	-0.52	-0.4	114.2	79	
										240-ECK1-01B	0.52	0.4	267.7	79	
ECK1-02A	3.3	99.883	0	0	0	0	0	0	0	240-ES11-01B	-1.18	-0.97	2667.7	77.1	
										240-ECK1-02A	1.18	0.97	367.7	77.1	
ES11-02A	3.3	99.498	-0.1	0	0	0	0	0	0	240-ES11-01A	-2.63	-0.95	492.3	94.1	
										240-ES11-02A	2.63	0.95	492.3	94.1	
ES11-02B	3.3	99.801	0	0	0	0	0	0	0	240-ES11-01B	-0.79	-0.56	168.6	81.6	
										240-ES11-02B	0.79	0.56	168.6	81.6	

Table 1. Global load flow report for system normal operation

Fig.(12) speed response at generation drop after load shedding.
Fig.(13) Generator electrical power demand after load shedding.
Fig.(14) Generator terminal current after load shedding.
Fig.(15) Generator exciter voltage after load shedding.
Fig.(16) Generator exciter current after load shedding
Fig.(7) shows that the generator speed drops 1465 rpm, then it rises and keeps steady at 1475 rpm (approximately keeps fixed at -1.6% drop from rated speed).

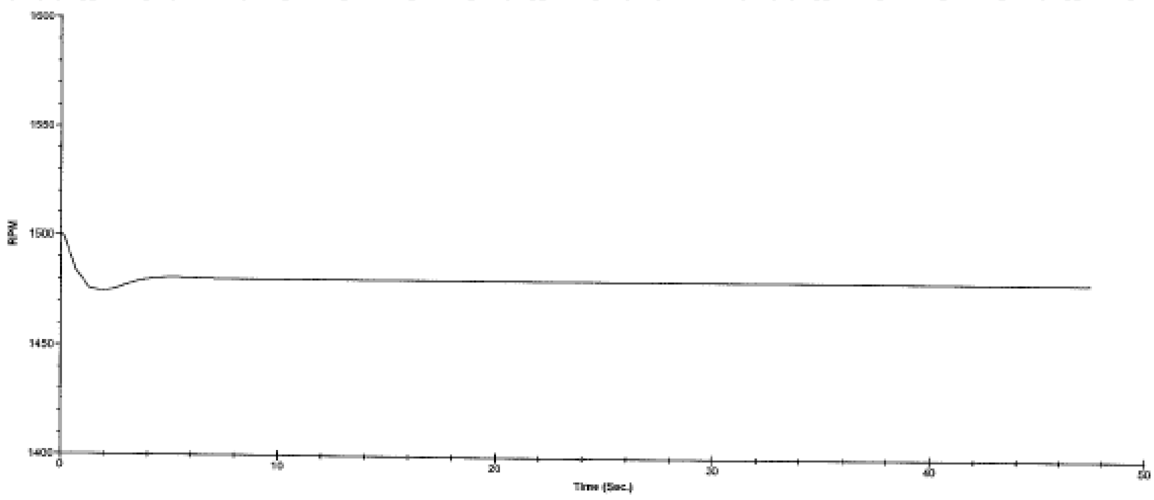


Fig. 7. Speed response at generation drop.

Fig.(8) shows that the generator electrical power demand rises to 4.5 MW to reflect generator overload capability to supply the system requirements after generation drop.

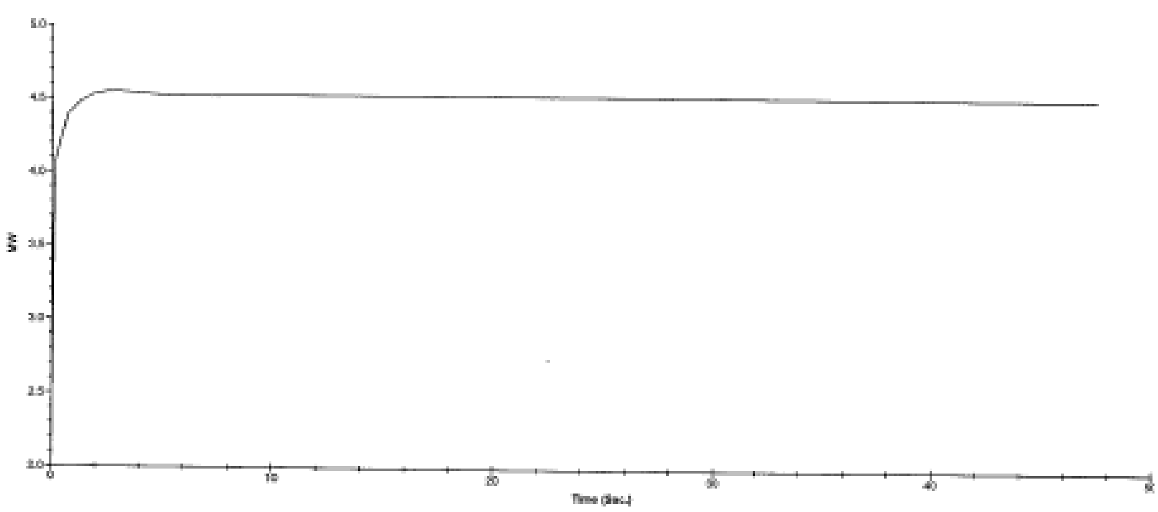


Fig. 8. Generator electrical power demand.

Fig.(9) shows that the generator terminal current rises to 950A to reflect generator overload capability to supply the system requirements after generation drop.
Fig.(10) shows that the generator exciter voltage rises to 3.25 p.u. representing the behaviour of the regulated exciter to accommodate the overload demand.
Fig.(11) shows that the generator exciter current rises to 3.25 p.u. representing the behaviour of the regulated exciter to accommodate the overload demand.

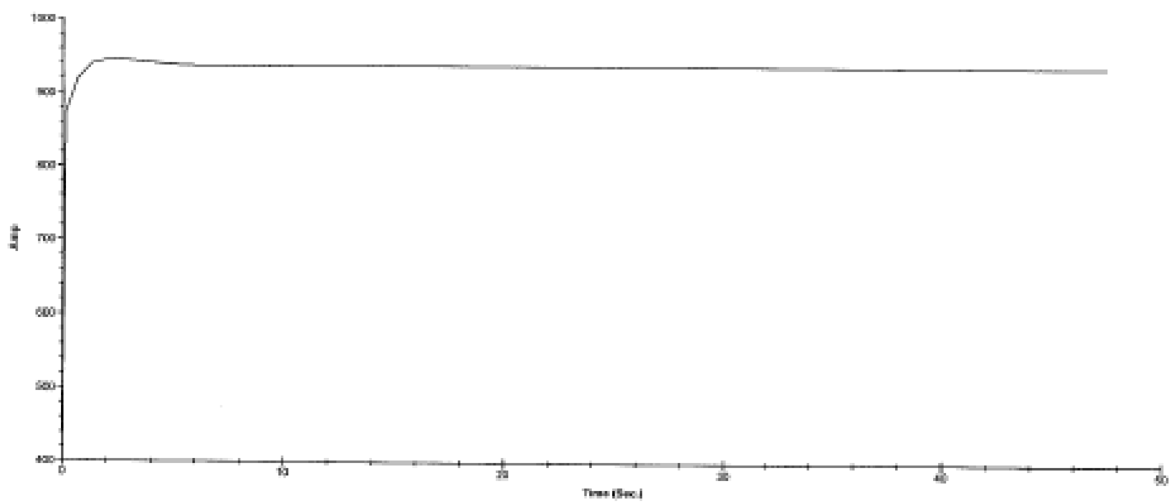


Fig. 9. Generator terminal current.

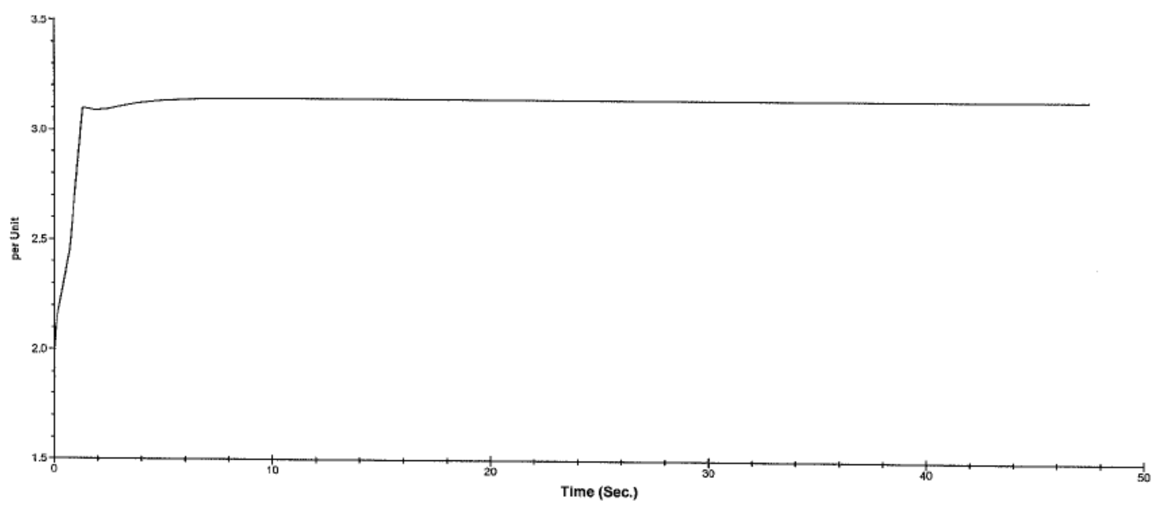


Fig. 10. Generator exciter voltage.

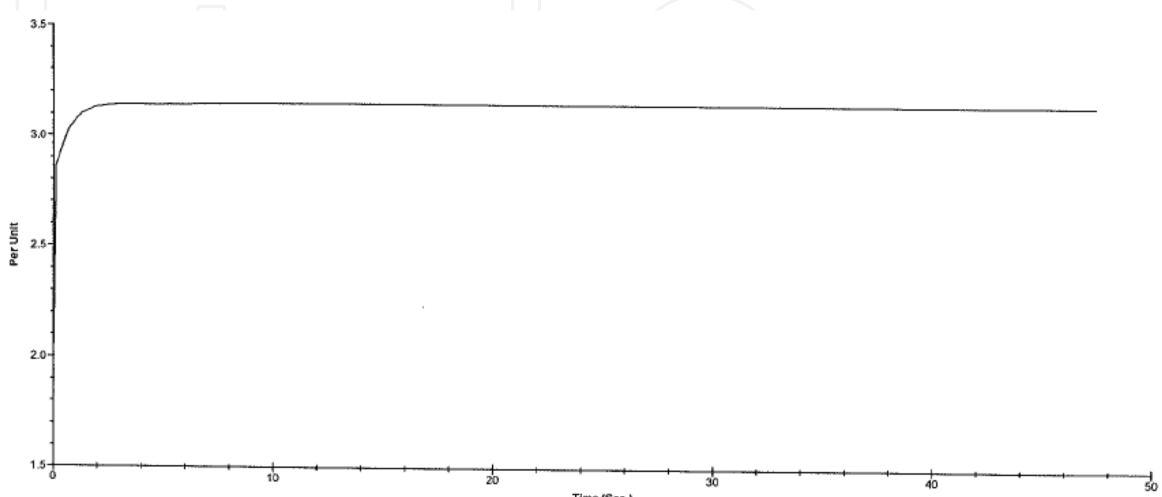


Fig. 11. Generator exciter current.

3.2 Application of knowledge base module

Applying this module, the plant conditions in each stage during generation drop and operation is investigated and printed out. By applying this module also, the module has selected the following load shedding steps so that the power system can operate in safe margins:

- Step 1. Flash gas compressor rated 1400kW (consumed power 1375kW) at 2 seconds,
- Step 2. Condensate export pumps each is rated 360kW (consumed power 160kW each) at three seconds,
- Step 3. Residential camp consumed active power of 280kW, and 470kW low voltage motor loads at 4 seconds.

The system new operating conditions after the execution of the load shedding 3 steps are shown in the following figures:

Fig.(12) shows that the generator speed rises up to 1500 RPM.

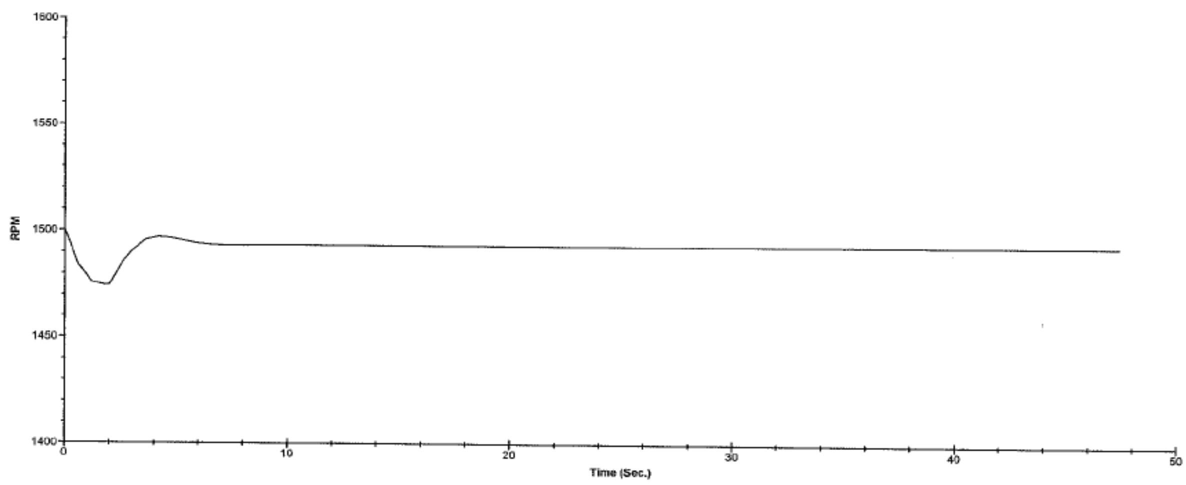


Fig. 12. Speed response after load shedding

Fig.(13) shows that the generator electrical power demand falls to 3 MW after the three steps which is machine safe limits.

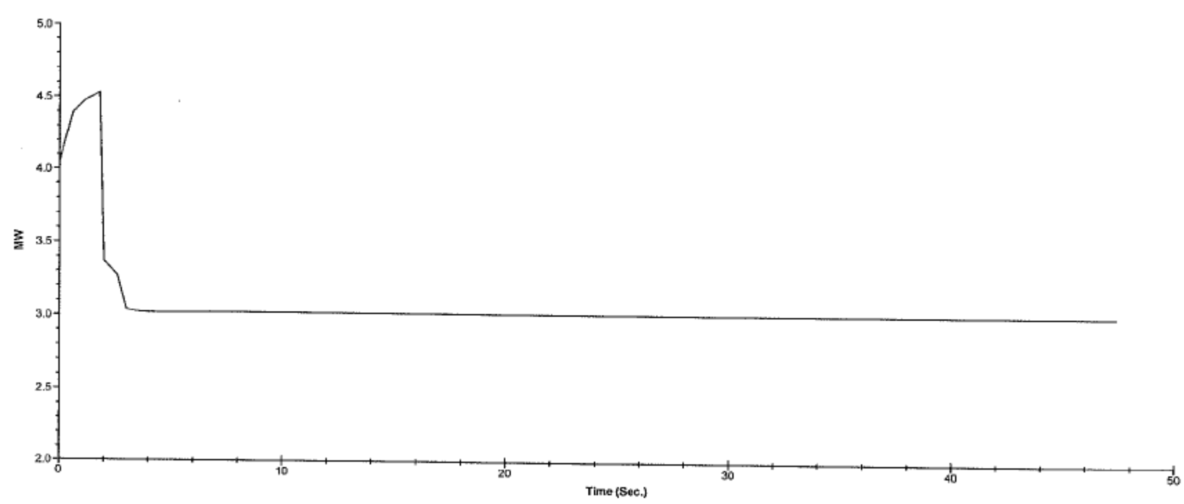


Fig. 13. Generator electrical power demand after load shedding.

Fig.(14) shows that the generator terminal current falls to 640A to reflect generator overload capability to supply the system requirements after load shedding.

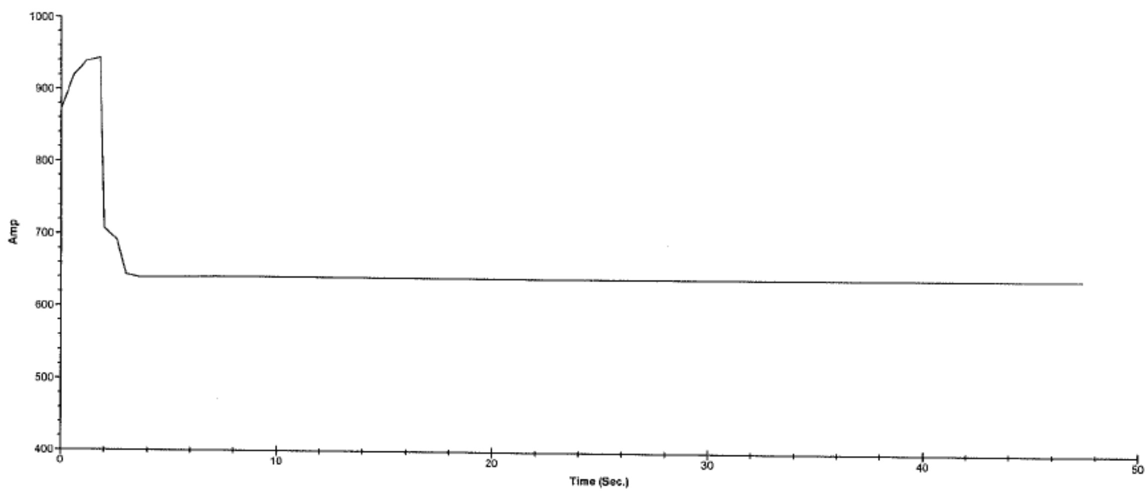


Fig. 14. Generator terminal current after load shedding.

Fig.(15) shows that the generator exciter voltage drops to 2.4 p.u. representing the behaviour of exciter after load shedding.

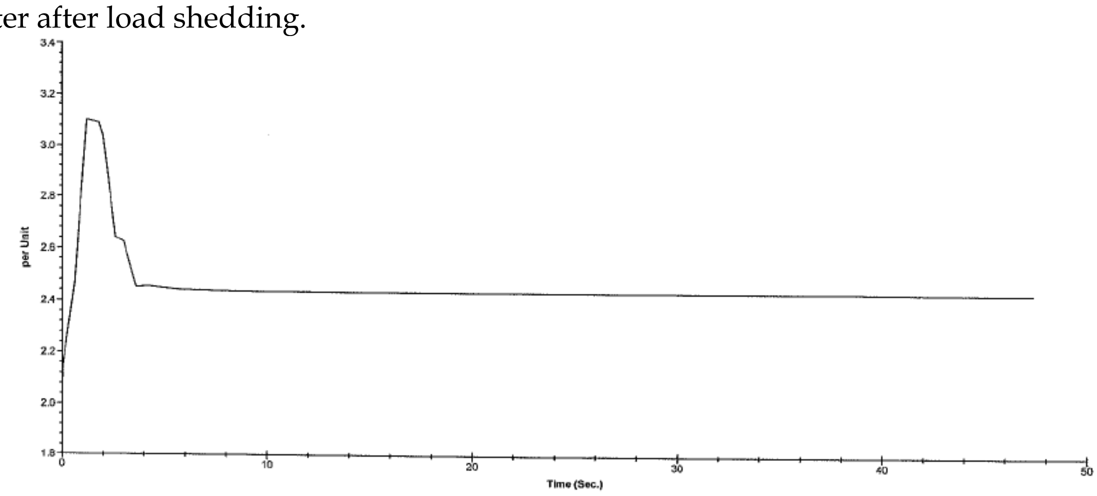


Fig. 15. Generator exciter voltage after load shedding.

Fig.(16) shows that the generator exciter current rises to 2.4 p.u. representing the behaviour of the exciter after load shedding.

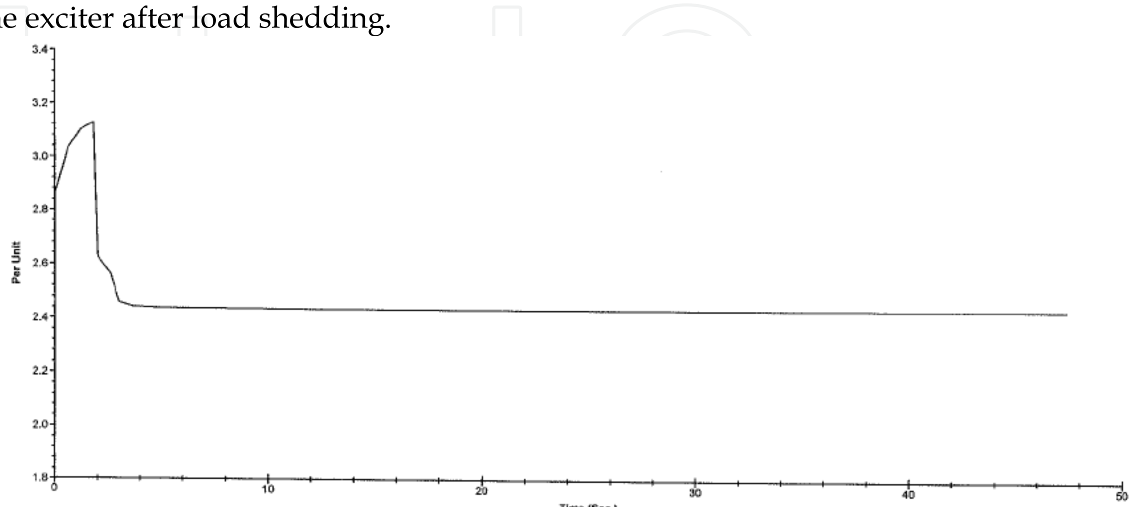


Fig. 16. Generator exciter current after load shedding

4. Conclusion

In this chapter, a new expert system for load shedding in large industrial plant is developed and has been presented.

This expert system is better than the traditional stand alone under frequency relays that sense the frequency and trip under pre-defined values which are not responsive dynamically to the system, whereas the new expert system presented in this chapter is a rule based system for generation monitoring and load shedding which is flexible with the system dynamics. It has been developed in MATLAB software.

This system is supported by ETAP software package for power system analysis to act as comprehensive tool for power system operation monitoring in large industrial plant. The system is tested and the results obtained for a study system are presented to assure reliable performance of the developed system.

5. References

B. Babcock, M. Datar and R. Motwani. *Load shedding techniques for data stream systems,2003.*

B. Babcock, M. Datar and R. Motwani. *Load shedding techniques for aggregation queries over data streams*. In ICDE,2004.

Barzan Mozafari and Carlo Zaniolo. Optimal Load Shedding with Aggregates and Mining Queries. 26th IEEE International Conference on Data Engineering, March 1-6, 2010, Long Beach, California: 76-88.

Cheng-Ting Hsu; Hui-Jen Chuang; Chao-Shun Chen. *Artificial Neural Network Based Adaptive Load Shedding for an Industrial Cogeneration Facility*. Industry Applications Society Annual Meeting, 2008. IAS '08. IEEE .

Electrical Transient Analyzer Program ETAP. *Power station 4.0 Analysis module,* Operation Technology, Inc., February 2002.

Electrical Transient Analyzer Program ETAP. *Power station 4.0 user guide,* Operation Technology, Inc., February 2002.

Horowitz, S.H.; Politis, A.& Gabrielle, A.F. (1971). *Frequency Actuated Load Shedding and Restoration part II-implementation,* IEEE trans. Power App. Syst. Steven Rovnyak (1994). Decision trees for real-time transient stability prediction. IEEE trans. On Power System Vol.9 No.3.

IEEE STD.399, IEEE Recommended practice for industrial and commercial power system analysis.

Malizewski, R.M.; Dunlop, R.D. & Wilson, G.L. (1971). *Frequency Actuated Load Shedding and Restoration part I-philosophy,* IEEE trans. Power App. Syst.

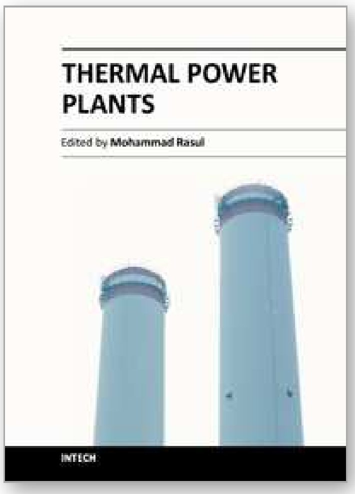
Steven Rovnyak (1995). Predicting future behaviour of transient events rapidly enough to evaluate remedial control options in real-time. IEEE trans. On Power System Vol.10 No.3.

Tatbul,N.,ET AL. *Load shedding in data stream manager*. In Proceedings of intl.conf. on very large data bases 2003,pp.309-320.

Yasser, G.M. (2004). A Knowledge Based Integrated Motor Protection and Monitoring System for Large Industrial Plant , *Proceedings of Scientific Bulletin of Faculty of Engineering Ain Shams University,* vol.39 # 1, ISBN 842-6508-23-3, Cairo, Egypt, March 31, 2004.

Yijian Bai, Haixun Wang, Carlo Zaniolo. *Load shedding in classifying multi-source streaming data: A Bayes risk approach*. Technical report TR060027,UCLA CS Department 2006.

Yun Chi, Philip S. Yu, Haxiun Wang and Richard Muntz. *Loadstar: A load shedding scheme for classifying data streams*. In Proceedings of SIAM intl. conf. on data mining 2005.



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