Faculty of Engineering Science and Technology, Department of Electrical Engineering

Temporary Load Shedding

Optimization of power distribution system using load shedding Techniques

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Abstract

In today's world, electrical energy is a necessity. The dependency on electricity is increasing day by day which caused the system to work under a stress state close to stability limits and disturbances. An efficient power system supplying electrical energy must be reliable, stable, secure, and reasonable to meet consumer needs. The power demand depends on several factors and weather is one of the main in them.

The thesis is done with the cooperation of Arva As. for the Tromsøya region in northern Norway. In Northern Norway, during the winter season, the temperature falls to -20˚C which eventually causes the rise in demand for electricity to meet the heating needs. The heating of households plays a big role in increasing demand.

To avoid contingency and keep the distribution grid stable during the winter season a temporary load shedding scheme has been proposed by using the load curves and grid model that was analyzed through power flow analysis. It includes procedures for detection of voltage stability on buses with voltage stability indexes and plans to temporarily shut the heating system and sources to avoid the stress on the grid in peak hours with available communication possibilities.

Keywords: Load Shedding, Voltage Stability, Power system analysis, operation, System Stability, Controls, MATLAB, Distribution Grid

Preface

The thesis comprised the final work of last semester of master's in electrical engineering department at UiT the Arctic University of Norway Campus Narvik.

I would like to thank my supervisor professor Pawan Sharma and his Ph.D. researcher Raju Wagle for their invaluable help and feedback throughout the semester. I also want to thank Professor Muhammad Shakeel Virk for guidance in choosing this interesting topic. I also want to thank Arva As for offering the thesis topic and Øivind Viktor Blix for always supporting, providing the necessary data, and motivating me throughout the thesis. I would also like to thank Alexander Pankratov for the help in access of NetBas and guide me about it.

Finally, thanks to my family for their love and support. After, I would like to thank UiT for a worthy journey to experience, and thanks to my flat mates for keeping my motivation up and sharing the journey at UiT with me, it would not have been the same without you people.

Abdul Basit
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Table of Contents

List of Tables

List of Figures

Abbreviations

FVSI	Fast Voltage Stability Index
LSI	Line Stability Index
IPP’S	Independent Power Producers
NVE	Norge Vann Og Energi Direktorate
Disco’s	Distribution Companies
Genco’s	Generation Companies
LAN	Local Area Network
MCU	Meter Data Collection Unit
SMS	Smart Metering System
NAN	Neighbor Area Network
ALM	Appliance Load Monitoring
NILM	Non- Intrusive Load Monitoring
ILM	Intrusive Load Monitoring
RFMESH	Radio Frequency Mesh
AMR	Automatic Meter Reading
DLMS	Device Language Message Specification
CS	Compulsory Load Shedding
NR METHOD	Newton Raphson Method
PLC	Programmable Logic Controller
UFLS	Under Frequency Load Shedding

HAR	Human Activity Recognition
WAMS	Wide Area Measurement System
SMT	Smart Meter Technology
FLC	Fuzzy Logic Controller
AVR	Auto Voltage Regulator
WAN	Wide Area Network
UVLS	Under Voltage Load Shedding

1 Introduction

1.1 Background

Electrical energy is the backbone of many things happening in our present-day life. Without electrical energy the life stops at one point. The availability of huge amount of electricity plays a vital role for the survival of industrial and social structures. A large amount of energy is needed in industry, domestic households, transportation, communication and so on [1].

The survival of industrial undertakings and social structures depends primarily on low cost and uninterrupted supply of electrical energy. The basic structure of a contemporary electrical power system is illustrated in Figure 1. It shows the power system to be divided into three parts: generation, transmission, and distribution. The power supply industry tended to be vertically integrated with each utility responsible for generation and transmission and distribution area [1].

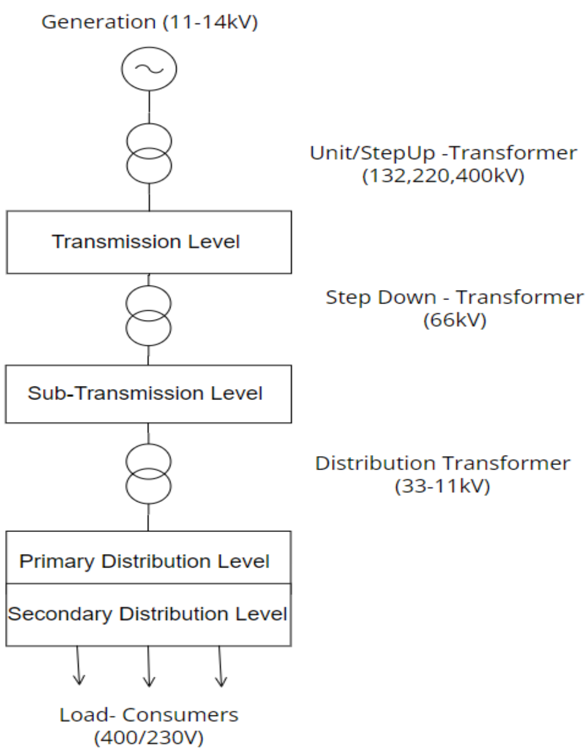

Figure 1:Power Supply System [1]

1.1.1 Conventional Power System:

The process of supplying the electrical power from power stations to consumer premises worked in different stages. These stages are categorized according to the different voltage levels. In low voltages, system operates less than 1kV. The voltage used in distribution system varies between 1kV to 100kV also known as medium voltages. The range of 100kv to 300kv known as high voltages, used in sub-transmission network. While transmission network used greater than 300kV in extra high voltages range to supply the electrical energy.

1. Generation

The two important things always be considered in design of power plant. Firstly, the placing and selection of generating equipment so that a maximum of return will be achieved with less expenditures. Secondly the operation of plant should be low cost, efficient and reliable.

In generation different kinds of energies transform into electrical energy. These different energies (chemical energy, pressure head of water, nuclear energy) derived from several natural sources. The sources include fossil fuels (coal, oil, and gas), nuclear and these days most popular renewable energy (solar, hydro and wind). These derived energies feed with mechanical force on prime mover (turbine). This prime mover relates to synchronous generator also know as alternator that converts the mechanical energy into electrical energy.

The generation voltages vary from 10 to 20kV. There are number of generators connected to supply power. The generator output shaft connected with step up unit transformer to step-up the voltage levels and transfer the electrical power to transmission system.

2. Transmission

The transmission network consists of large overhead mesh networks to provide electrical power to consumer with possible and viable route. As the line losses are directly proportional to square of current, to improve the efficiency and saving the cost of conductor it is always practiced to used high voltages in transmission line.

The transmission system is subdivided into two stages primary and secondary transmission depend on step downed voltage levels 66 or 33kv. This gives ease to the deliver the line or power to big demanding industrial and commercial consumers. The transmission network always works as a bridge between markets, Genco’s and Disco’s.

3. Distribution

In last stage the voltages received from transmission system, the voltages further step down to 11kV by distribution transformer/feeders. For efficient and reliable supply at the distribution side, the voltages are further classified into two categories. Primary and secondary distribution. Primary distribution used for consumer that have power demand of more than 50kW. On the other hand, in secondary distribution the 11kV voltages step down to 400 and 230V to supply electrical energy to households.

In addition to these stages there are several auxiliary components/equipment used to operate and control electrical energy throughout the process includes, switch gear, circuit breaker, relays, fuses, conductors, and insulators, etc.

1.2 Deregulation of Power System

Now days the economy and consumption relate with the relation between the energy used per person and standard of living. To meet the growing needs of consumer demands it is necessary for electrical energy to be supplied upon low cost, stable and uninterrupted [1].

To optimize the overall power system planning and operation, since 1990's world has decided to introduce a competitive market with the unbundling of vertically integrated utilities for the industry. In a deregulated model, the generation sector is divided into several private companies competing as independent power producers (IPP's). The transmission tends to be operated by one monopoly company, referred to as the system operator, which is independent of the generation and regulated by an industry regulator. The distribution is also often split into separate distribution companies (wires businesses) which own and manage the distribution network in each area, while retail, that is buying power on the wholesale markets and selling it to final customers.

This unbundle of power system enable consumers to choose suppliers by their own choice. Although, according to Ministry of Petroleum and Energy Norway, the 98% power is generated by renewable energy resources mostly hydropower. Noregs vassdrags- og energidirektorat is an energy regulator. There are several genco's (generation companies) include Statkraft work for the power generation than Statnett TSO (Transmission System Operator) work as a monopoly. In last, Troms Kraft Nett AS, Nord Kraft AS, Hafslund Nett AS, etc. As disco's distribution companies supply the power from distributed grid station to consumers [2].

The unexpected increase in consumer demand forces the power plants to run at high power plant capacity factors that made the system inefficient and unreliable.

1.3 Motivation:

There are several factors include plant's power capacity, fuel source, site, and water supply, etc. that are considered in the designing and planning of power plants. Power plant capacity is one of the major factors that are designed with the expected load forecasts and on the basis previous load curves of the years. It is always practiced having reserved power sources in plant to supply power. Using reserved power and centralized system helps to supply power in blackout sites. But now a days due to unexpected increase in power demand it is hard to reserve power. The power systems are working at their peak capacities.

From the previous years there was a massive power blackout occur in the world. These power blackouts resulting in industrial sector economic loss, effect on human lives specially in the health sector and communication sectors etc. This Power blackout refers to the interruption in a power system leading to the absence of power supply in a particular area over a specific period.

The blackout can be occurred through Technical or Non-technical (Natural Disaster) faults. Natural disasters include flood, earthquake landslide, snowstorms, Icing or falling off trees on power lines. The technical Faults caused by overload transmission lines, faulty equipment, stability issue, power imbalances and human errors. The Table 1 shows the major blackout happen in the last decade in different parts of Norway. According to table data, the most power blackout caused due to voltage instabilities that referred to overload of power system [3].

Table 1: Massive Blackout across Norway.

Year	State	Hours of Outage	Reason
2022	Tromsø [4]	20	Landslide
2021	Oslo (Søndre Nordstrand) [5]	2	Power Lines Tripped
2020	Eastern Part [6]	26	Transmission line Defect
2020	Østfold & Akershus [7]	16	Transformer fault/ voltage drop
2020	Central Oslo [8]	18	line Defect
2018	Agder [9]	24	Snowstorm

The motivation behind the project is to save the reserved power and regulate the stable voltages in the system with the security of reliable power supply to consumers. Reserve power can be saved by managing the unnecessary load with load shifting and shedding techniques. Load shedding is one of the stable solutions to manage the consumer load under current condition with efficient planning to keep the system under controlled.

1.4 Problem Statement

This research thesis offered by Arva As. Tromsø, it is one of the biggest distribution companies in Tromsø municipality. In tromsø, Tromsøya is the most populated area covered with a lot of residential and commercial sites. Every year, with an increase in power demand the distribution system in Tromsøya area operated in a stress state mostly during the winter season. Today power systems operated nearly close to their stability limits and disturbances which may cause the system to lose its stability. Therefore, there is a need to do research in online planning or scheduling of power system to ensure the secure and reliable supply of power at Tromsøya. Further details about the case problem are explained in the chapter 3.

1.5 Objectives

The following objectives are expected after an efficient load shedding scheme:

1. Avoid system stress in peak hours:

The peak hours are the time when consumer demanded power greater than the normal average power demand during the day. In the peak hours, system went close to instability state, as in peak hours the power plant uses its maximum capacity with additional equipment and reserve systems to supply the demanded load. With the proper planning and load shedding scheme, it will enable the power plant to detect the overloading and shut the unnecessary loads.

2. Stable power system:

In the load shedding technique, it is very important to track the amount and location of overloading. The load shedding technique will ensure the system to remain the stable keeping the voltages under controlled. The load shedding scheme with the controller and communications should be respond with short delay to keep the system tracked before the blackout or peak power occurred. Voltage compensation methods are used to drive the voltages of system in a stable state. There are automated PLC (Programmable logic Controller) used to detect any kind of fault and respond it for recovery [10].

3. Avoid unnecessary interruption in customer side:

Now a days, the unbundling of power system structure gave the opportunity to consumer in choosing the electricity supplier. To keep the industrial and social structure working the consumer prefers uninterruptable, reliable, low cost and stable power system with the regulated voltage and frequency. During the load shedding it should be tracked to avoid the priority consumers and only shut the unnecessary load. After the load shedding as voltages getting stable the power should be supplied back to consumers to safe consumer from being disturbed.

1.6 Scope of the Work

In this thesis, During peak hours maximum power transfer from grid due to heating systems in winter. This additional will be mapped with the help of annual load curve. After the mapping, a load shedding scheme will be introduced, where demand side will be used efficiently to reduce the system stress. The power system stability is a multifaced wide scale problem, in this thesis voltage stability problem will be covered. The work is done using grid model of Arva As. All the data and models are analyzed with excel, NetBas And MATLAB.

The main contribution includes:

1. Simulate the load flow analysis of grid model.
2. Use voltage stability indexes and nose curve, the instability of buses will determine the location and amount load.
3. Proposed a plan and procedures to perform temporary load shedding scheme at Tromsøya.

1.7 Limitations

There are several limitations due to time and restricted data:

- A standard heating consumption power has been rated without considering the house size or number of houses. The power rating is multiplied based on the number of individuals.
- Results are limited because some values include bus impedances, etc. are taken from IEEE standard bus system (lack of features in exporting the data from old version of Netbas)

- The solution applicable to hardware but due to short time and equipment the system is only analyzed on simulation software's.

1.8 Structure of the Report

The thesis report is organized as follows: In chapter 1, A background of power system, objectives, problem statement and its motivation behind the report is given. Chapter 2 will preview the previous approaches that has been done and review the basic properties of power system that are relevant to this report. In chapter 3, a brief overview of voltage stability, causes of instability and load curve analysis has been analyzed. Chapter 4 contains proposed solution's mathematical model and its operations. Simulations and results are being analyzed in Chapter 5. In chapter 6, the report is concluded with the work that is done and its future expansion.

2 Literature Review

To meet the uncontrolled consumer, demand the suppliers should take measures for its consumers to deliver acceptable, reliable, and efficient power. Usually during the planning and design combined patterns of load curves are used for load forecasting to get a predictable system that allowing the generation schedule to be planned and controlled in predetermined pattern. But even though individual consumer load may vary unpredictable from time to time. The energy demand must be met by corresponding generation at any instant. A power should consist of following properties:

1. Reliability of power system:

Reliability is a fundamental component of electrical power system. Any major interruption causes inconvenience to any consumer includes industrial, household, etc. may lead to life threatening situations and financial losses. High reliability of system is ensured by:

- High quality of installed elements.
- Employing large, interconnected power systems capable of supplying each consumer via alternative routes.
- A high level of system security.

2. Supplying Electrical Energy of Good Quality:

Electrical energy of good quality is provided by automatic voltage and frequency control methods and interconnected systems which are less effected to load variations and other disturbances. A good quality of electrical energy has:

1. Regulated and defined voltage levels with low fluctuations.
2. A regulated and defined value of frequency with low fluctuations.
3. Low harmonic content.

3. Economic Generation and Supply:

The price of electricity depends on the different supply and demand conditions which include weather conditions, network costs, taxation, etc. Generally, a strategy is being used for customers in which bulk power industrial consumers have some relief as compared to low power residential consumers. Tariff of transmission and distribution of electricity should be fair based on the economic criteria which cover not only the grid marginal short term and long-term investment cost, losses, and congestion as well as it will be reasonable for the consumers.

Although with these power systems properties, the increasing demand of power is still unpredictable and uncontrollable. In current infrastructure it is not reasonable and efficient either to use additional equipment to supply the excess power or force the system to work at stress state. As discussed in section 1.4 and in our case study temporary load shedding is one of the suitable options to control the power system and keep it in stable state.

Load Shedding is a process of reducing the power demand stress on power systems by shutting down the load at consumer side. The shutdown of power is done by distribution companies to prevent the failure in entire system and limit the power demanded with in the capacity of power plant [12].

2.1 Power System Stabilities

It is the ability of an electric power system for given initial condition to regain its equilibrium state after being subject to disturbances. There are three main types of power system stabilities that includes rotor angle stability, voltage stability and frequency stability. The power system stability is classified based on size disturbance, time span and, main system variable affect by instability [11].

2.1.1 Voltage Stability

Voltage stability refers to the ability of a power system to regain is steady state and operate with balanced voltages after subjecting to disturbances. The voltage instability mostly caused by overloading, involuntary outage of line that demand reactive power from system which causes blackout. Figure 2 shows the stability and instability properties of system with the nose curve.

This PV-curve used by system planners to observe the system utility of obtaining real power transfer across transmission interface to supply load. Once line trips, the voltage decays it makes a nose curve. The nature of load determines the shape of curve [3].

In the curve analysis, the curve A nose is the stable state, power and voltage transfer the load under balanced form smoothly without any contingency. On the other hand, if something happen a fault/contingency (N-1) occurs the nose point shift to curve B and system is about to collapse. If both generator and transmission failure occur at same time with the fault (N-2) the voltage drops very rapid and nose point shifts to curve C [3].

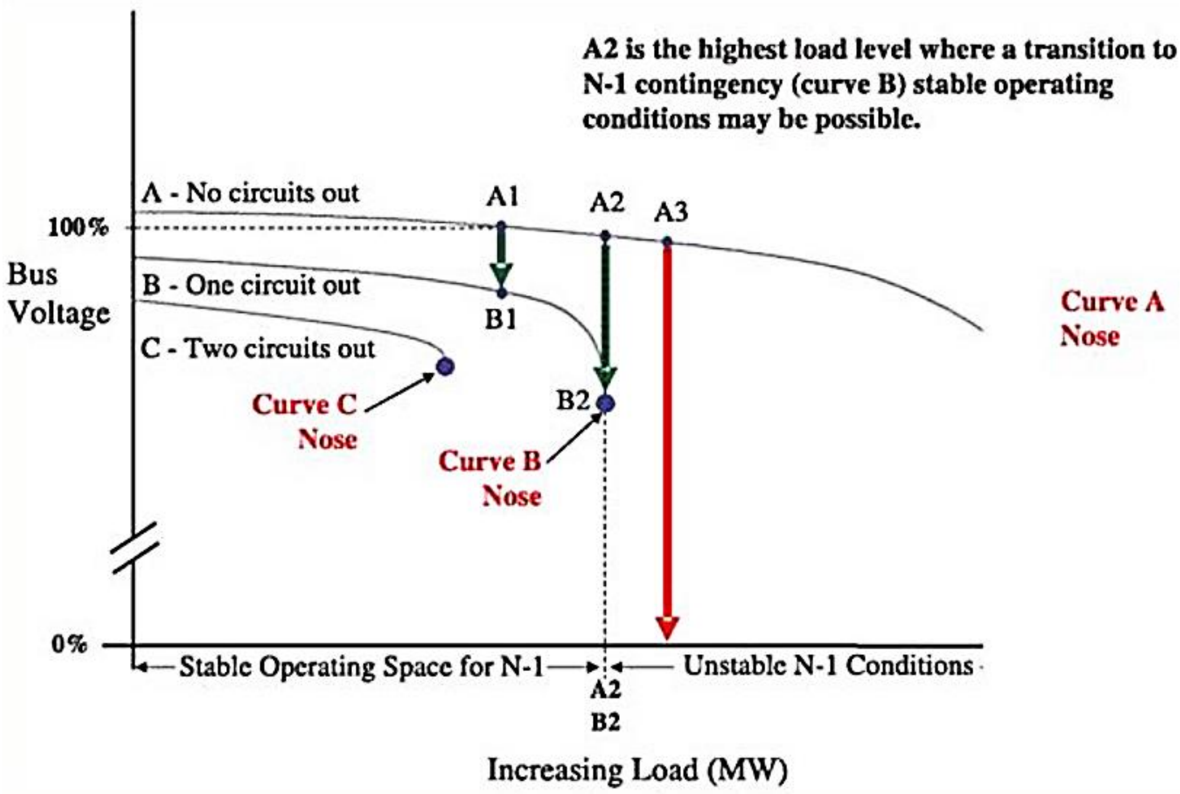

Figure 2: Voltage stability Curve [3]

2.1.2 Classification of voltage stability

There are several types of voltage stabilities depend on the time duration and effect of fault on the system:

2.1.2.1 Short Term Voltage Stability:

Short term voltage stability refers to dynamic nature of load i.e., induction machines. The period of shot voltage stability is in second. The short-term voltage stability usually occurs mostly because of time varying characteristics of load. The short-term voltage stability can be solved using linearization methods unless if dynamic non linearities occur [10].

2.1.2.2 Long Term Voltage Stability:

Long term voltage stability refers to the duration of several minutes. These disturbances are nonlinear often caused due to system fault, outage of equipment and different faults in system. This over and under voltage problem are involved in the large term voltage stability that results a blackout in part or whole grid system [10].

2.2 Review of Load Shedding Schemes

There are several techniques of load shedding are used in the power systems. Under voltage load shedding (UVLS) and Under frequency load shedding (UFLS) are the most common ones. The UFLS is the method of controlling frequency. The frequency 60 or 50 Hz depend on region always remain constant throughout the system. It usually controls from generation side with governor control systems. Under voltage load shedding is used to control the voltages in the system [3]. As the focus of study in this report is related to voltage stability in system, the under-voltage load shedding will be considered and discussed. These are several approaches to control the voltages that will explain later in section 3.4 in the report.

In under voltage Load shedding (UVLS) technique if fault or over voltage occur measure should be taken under stability margins to resume the system after clearing the fault. UVLS is inherently a multistep process as voltage varies at every bus according to load nature while UFLS is a single step because the frequency remains constant for whole system [3].

In past years, a lot of research has been done with several approaches, many techniques and algorithms are used to solve this problem in reliable and efficient way. Some of them are described as follows:

2.3 Conventional Approaches

2.3.1 Load Shedding Through Point Estimate Method

In this study [13], point estimate method was used to perform under voltage load shedding. Point based estimation is a robust process of finding best estimate from sample data. Through method a scheme was developed by converting non-linear continuous distribution functions into discrete model while considering all load uncertainties. The drawback of this computational method was its long simulation times.

2.3.2 Automatic Undervoltage Load Shedding Under Emergency Condition

This researcher in [14] overviews the impact and difference of using manual and automatic under voltage load shedding techniques. In manual every work done was dependent on the forecast of system operator, which is not suitable if the load varies against the forecast. And in automatic load shedding relay integrated system was proposed by tripping the line if voltage reaches below 90% and shed load 5% at each step. Disadvantage of this system is simulation time and performance and efficiency. This method is only applicable for offline applications.

2.3.3 Load Shedding Method Based on the Active Participation of Smart Appliances

In todays advanced power systems and intelligent smart appliances using wide area measurement systems (WAMS) a methodology was proposed in [15] to control the voltage and frequency variations in grid by changing the regulation capacity of smart appliances i.e., heating systems aggregation to conduct smart load shedding. The downside of this systems is complex, computational burden and if amount of load drop is non-optimal, or the voltage drop maximum than stated settings there will be large variations and complete system will be collapsed.

2.3.4 Voltage Stability Margin Index Using Synchro-phasor Measurement Technology

As in the previous research the method was not adopted due to inefficiency and computational burdens. In this research [16] an advanced system of WAMS was adopted to control the voltage instabilities of the system. The temporary load shedding done with the analysis of power system using SMT (Synchro-phasor Measurement Technology) by computing the continuous voltage stability margin index and applied in the Thevenin equivalent system configuration. Comparing the data with the rated voltages, the maximum power transfer will be work as a reference to monitor the system and determine the required load shedding amount. It will help the operator to shed load in appropriate amount with efficient way.

2.4 Computer intelligence algorithms and techniques

Due to average performance and efficiency drop of conventional system that causes blackout and inappropriate load shedding of nonlinear system it is recommended to use advance hybrid computational intelligence techniques for estimation optimal load shedding with preferred multi-objective speed and time. The increase in complexity of power systems made it necessary to use computational techniques due to its efficiency and robustness.

A lot of research has been done to control the voltages stability through load shedding based on computational algorithms as follows:

2.4.1 Genetic Algorithm (GA):

In the research study [17] genetic algorithm was used to find the optimal load shedding at point of convergence. Genetic Algorithm known as global optimization technique with a good accuracy that enables the system to achieve the accurate minimal amount of load shed. By using its selection, mutation, and crossover properties apply the properties on the objective function of load shedding amount. GA is viable on finding viable non-linear multi-objective function, but the drawback of system was slow convergence time that is not suitable for online applications.

2.4.2 Particle Swarm Optimization (PSO):

Particle swarm optimization technique was used in [18] to increase the convergence time of the system. Each sample is termed as particle of population called "swarm", which work as a potential solution point in a solution space and then calculate the fitness function for initial population. To check convergence the best previous position is recorded. PSO is fast in non-differential problems the drawback of PSO is effortlessly stopped by partial optimization.

2.4.3 Fuzzy Logic Control (FLC):

One of the research works have used fuzzy logic control. According to [19] , in fuzzy logic control, a typical fuzzy interference system is initiated with to map an input and output of systems under fuzzy rules. Three main components of fuzzy logic are used in the process, fuzzification, fuzzy interference mechanism and defuzzification. The advantages of fuzzy logic are that its design is simple, improve performance and implementation robustness. Fuzzification convert a problem statement into fuzzy statement under fuzzy rules and fuzzified statements are evaluated by rules that lead to conclusion in last defuzzification convert back the fuzzy statement to viable solution for better understandings of controllers. The main key point is fuzzy needs prior information for membership parameters.

2.4.4 Compulsory Load Shedding based on Load forecasting

In this research work [20] the load shedding has been done using energy management system for the central part of Sweden. Zigbee communication and smart meters with advanced load forecasting techniques were used. The method and process are efficient, but this research work is not applicable for autonomous load shedding and load shedding for specific appliances to reduce the stress on system.

2.5 Literature Limitations

From the study of approaches, it is observed during the overloading and stress on power system it is necessary to work on temporary load shedding schemes to increase system flexibility. All these optimization techniques proposed and used in the power systems have some limitations, i.e., some either suffer from suboptimal load shed or long convergence time. To overcome these limitations, it is concluded that either by combining the strengths of optimization algorithms or design an online automated two-way communication system, multi objective and robust system to achieve the operation of load shedding.

3 Voltage Stability

3.1 System Feasibility

Voltage Instability is generally caused by a load response that makes the supply system to transfer power with its maximum limits and keep on exceeding it until the system enters a stress state which as result it causes disturbances. There are several factors which forces the system to transfer maximum power, these factors can be illustrated by a simple network of 2-bus system supplying power from generator ta a load through transmission line as illustrated in Figure 3.

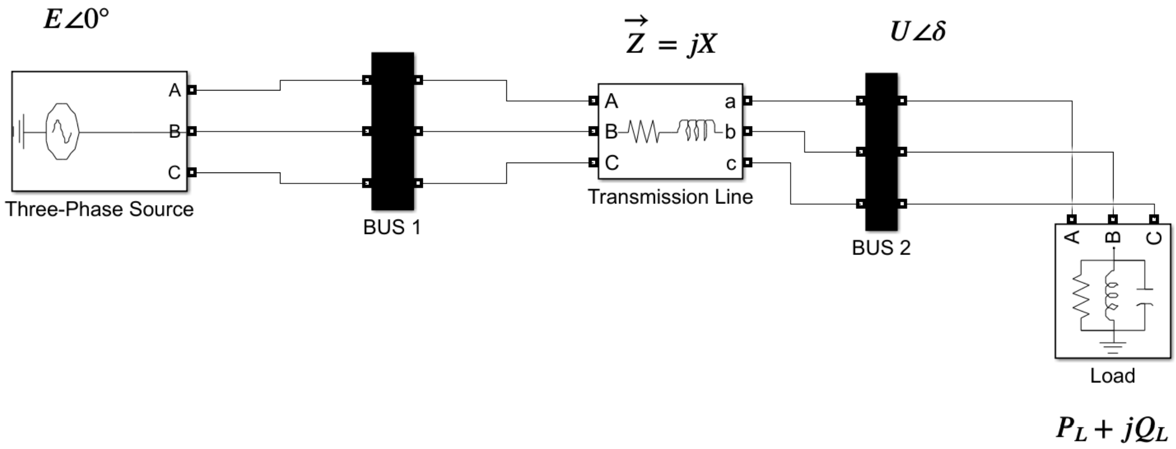

Figure 3: 2-BUS System

In Figure 3, the system is assumed to be in steady state. The load is constant and independent of voltages. Under normal conditions the generator AVR system will regulate the terminal voltages and keep them constant. The active and reactive power absorbed by the load referred to the power flow equations as follows [11]:

$$P_L = \frac{EV}{X}\sin\delta \tag{3.1}$$

$$Q_L = \frac{EV}{X}\cos\delta - \frac{V^2}{X} \tag{3.2}$$

E and V are the voltages at generator and load buses respectively, δ is angle difference between E and terminal voltage V and X represents the reactance of transmission line.

By using the identity $\sin^2\delta + \cos^2\delta = 1$, δ can be eliminated from equation (3.1):

$$\left(\frac{EV}{X}\right)^2 = P_L^2 + \left(Q_L + \frac{V^2}{X}\right)^2 \tag{3.3}$$

Rewriting equation (3.3) in the form of quadratic equation w.r.t V^2:

$$(V^2)^2 + (2XQ_L - E^2)V^2 + X^2(P_L^2 + Q_L^2) = 0 \tag{3.4}$$

Solving the relation between P_L and Q_L using power factor, $Q_L = P_L \tan\Theta$, the quadratic equation (3.4) gives two solutions.

$$V = \sqrt{\frac{E^2}{2} - XP_L\tan\Theta \pm \sqrt{\frac{E^4}{4} - X^2{P_L}^2 - XE^2P_L\tan\Theta}} \tag{3.5}$$

Solving the terminal voltage equation (3.5) for different values P, we get PV curve as shown in Figure 4.

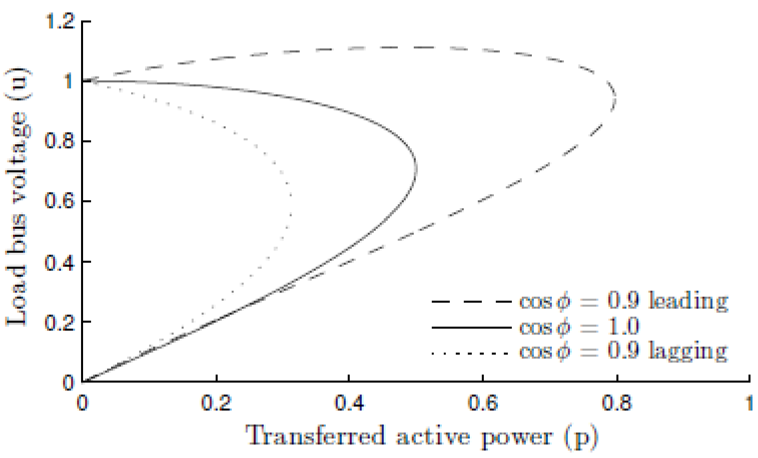

Figure 4: PV Curve with different power factors [10]

As described in section 2.1.1, this characteristic pattern of PV curve also known as Nose Curve and tip of curve represents maximum power transfer from system to the load. Key point that is derived from the different patterns of PV curve shows that load ability limit is different for every different type of load.

3.2 Voltage Instability Causes

There are several factors which effects voltage instability the most common are:

3.2.1 Increase in Load Demand

Increase in load demand is one of the possibilities for the system to became unstable. The voltage collapse occurs when the voltage reaches level reaches to its technical limits. In general, during the daytime or cold winters normally maximum power demanded can be seen from the consumers that causes the lack of power generation and supplying from grid. This stress state of weak grid forces the system to reach its load ability limit.

3.2.2 Transmission Line Contingencies

Transmission line contingence is one of the factors in weakening of voltage stability in network, it can be studied by considering a PV curve equation derived in section 2.1.1 [21]:

$$V = \sqrt{\frac{E^2}{2} - XP_L Q \pm \sqrt{\frac{E^4}{4} - X^2 {P_L}^2 - XE^2 Q}} \tag{3.6}$$

Assume the load is resistive by setting $Q = 0$, the load will only absorb the real power that led equation (3.6) to:

$$V = \sqrt{\frac{E^2}{2} \pm \sqrt{\frac{E^4}{4} - X^2 {P_L}^2}} \tag{3.7}$$

The maximum power transfer can be found by taking inner root of equation (3.7) equal to zero,

$$\frac{E^4}{4} - X^2 {P_L}^2 = 0 \tag{3.8}$$

$$P_L = \frac{E^2}{2X} \quad (3.9)$$

It can be observed from the figure that before the contingence the total reactance of transmission line is $X/2$. After contingency occur the nose curve expands and the reactance became double to $X/4$.On the other hand, with the increase in reactance the decrease in maximum power transfer will occur at same time [21].

$$P_{nose,prior} = \frac{E^2}{2X} \quad (3.10)$$

$$P_{nose,post} = \frac{E^2}{4X} \quad (3.11)$$

3.3 Voltage Stability Indices

Voltage stability indices are used to indicate the weak buses and best location of load shed in a system. Different types of indices are used for power system stability operations, by using Figure 5 some of them are discussed below with mathematical model as shown.

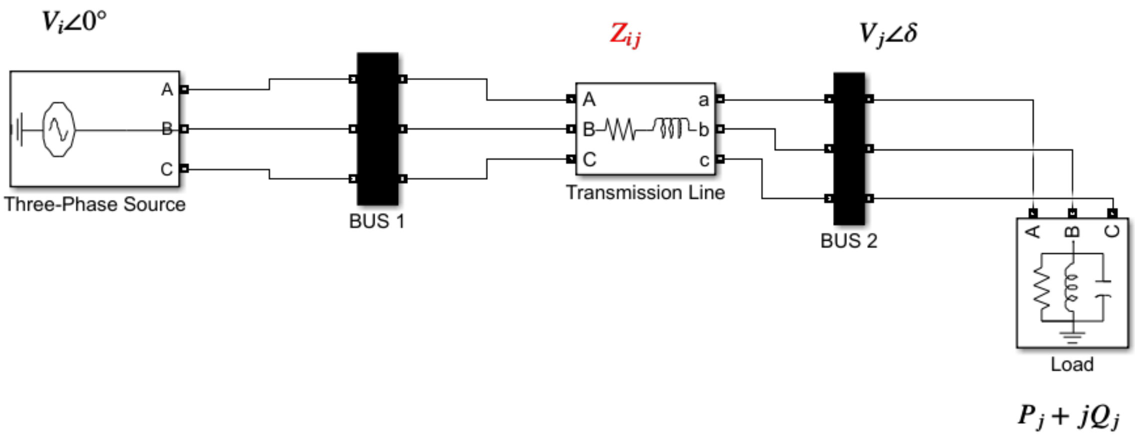

Figure 5: 2-Bus System with ij reference

3.3.1 Fast voltage stability index

The fast voltage stability index referred as FVSI used to identify the weak bus or the critical bus with maximum load ability in large power systems. FVSI, with the detection of critical lines in an interconnected online voltage stability assessment provides option to use as a warning for a system operator before the system reaches its bifurcation point. The mathematical equation is followed as [10]:

$$FVSI_{ij} = \frac{4Z_{ij}^2 Q_j}{{V_i}^2 X_{ij}},$$

Where, Z_{ij} is the line impedance between bus i and j. V_i, V_j are sending and receiving end voltages, Q_i, Q_j represent the reactive power. P_i, P_j represents the real power at buses.

3.3.2 Line stability index (L_{mn})

The stability index L_{mn} measures voltage stability for each line. The index L_{mn} implies critical state it should be less than or equal to 1. Higher the value of index L_{mn} greater the instability. The model of stability index is [3]:

$$L_{mn} = \frac{4X_{ij}Q_j}{V_i^2 \sin(\theta - \delta)^2}$$

3.3.3 Line stability factor (LQP)

The mathematical model of line stability factor in is stated as:

$$LQP = \frac{4X}{V_i}\left(Q_j + \frac{P_i^2 X}{V_i^2}\right)$$

The line stability factor should be less than 1 to maintain the voltage stability [3].

3.4 Methods of Mitigating Voltage Instability

When the system reaches it load ability limit and system gets close to instability. There are several methods that can used before the voltage collapse occur. In this process of mitigation, the methods include reactive power compensation by reducing the consumption or decrease the system impedance to increase the voltages at steady state. Before choosing one of the methods, it is very important to consider the method according to time delay or time to take actions according to the type of voltage instability.

3.4.1 Load Shedding

It is efficient method in use to reduce the risk of voltage collapse by reducing the active and reactive power load. Usually, the approach used with planning and operations.

The weather is one of the factors in utility of electricity. During summer, the weather is quite good and sunny and residents likely to do outdoor activities and because of that the electricity from consumer demand is less the most grids operated under the base loads as well as with the excess supply of sources like water in hydro power plant they can easily manage peak loads in this period. On the other side as the temperature decreases towards freezing, the weather make necessity for the usage of heating systems. Different type of heating systems is used in householdings that includes traditional wood burning chimney, heating pumps, district heating and electric heating's etc.

3.4.2 Switching of Reactive Compensation Devices

This process used with the risk of unknown faults during the condition of stress state. Reactive compensation devices include injection of reactive power in system via shunt capacitors for power balancing or removal of shunt reactors to reduce the effect of reactive load.

3.5 Case Overview and Choice of Load Shedding

Load Shedding is one of the last approaches usually adapted by the power suppliers to control the power flow and keep the system stable. It is usually done through a schedule plan. This schedule plan of load shedding is based on the previous load curves and future load forecasts.

In the thesis Tromsøya substations are analyzed to adapt temporary load shedding scheme. In Tromsø, the population is around 70,000 where Tromsøya is the central part of municipality and most populated area of the city. Around place Arva As. grid station which have distribution lines mostly around 11 kV and 132 kV voltage ratings. According to Figure 6, the area that has been covered from these substation transformers include Tromsø hospital, UIT Tromsø etc.

Figure 6: Substation Transformers Coverage [22]

Tromsø is close to the northern part of world, close to the arctic region, where the temperature varies between -5 ˚F to 70˚F [23]. The power demand varies accordingly with the weather conditions and load curve.

The power demand is independent of supply and if the demand increases until the max capacity of power supplier is reached to supply power. The distribution operator's like Arva have installed the grids with such capability but during the peak load demand without shutting down the whole grid to increase the system sustainability, reliability, and flexibility Arva As wants to do temporary load shed the heating system of household consumers in Tromsøya without effect the consumer liability and convenience.

3.6 Load Curve

Load Curve Analysis is an efficient instrument aimed at carrying through studies and planning, necessary for developing electric energy distribution networks and for reducing the electric energy internal consumption. It shows a graphical presentation of load in proper time sequence.

Climate change is a factor that affects electricity consumption behavior and influences for the change in load of the network. Temperature is major factor because of using of heating and cooling devices in different weathers. The load curve differs from day to day and season to season depend on power demanded by consumer.

When the load curve is plotted against 24 hours duration it is knows as daily load curve.

In annual or yearly load curve the load variation is plotted for the time of one year.

The following information is derived from the load curve described as:

- It indicates the maximum demand at power station
- The area under the load curve gives the total energy generated in period under consideration
- The area under the curve divided by the total number of hours gives the load demand.

3.6.1 Load Curve Properties:

3.6.1.1 Peak Load:

It is time of high-power demand. This peak demand often occurs for shorter durations

3.6.1.2 Base Load:

A continuous necessary load demanded by consumer to power the necessities over the whole period.

3.6.2 Load Duration Curve:

The load duration curve is defined as the curve between the load and time in which the ordinates representing the load, plotted in the order of decreasing magnitude.

3.7 Load Curve Analysis

A load Curve has been observed from the year of 2020 to 2021. The following data has been observed from the curve with the help of load duration curve. Because as in load duration curve with the curve demand in descending order it is easy to estimate the peak demand and base demands around the period of one year. In load curve the time is taken w.r.t the number of days in the year.

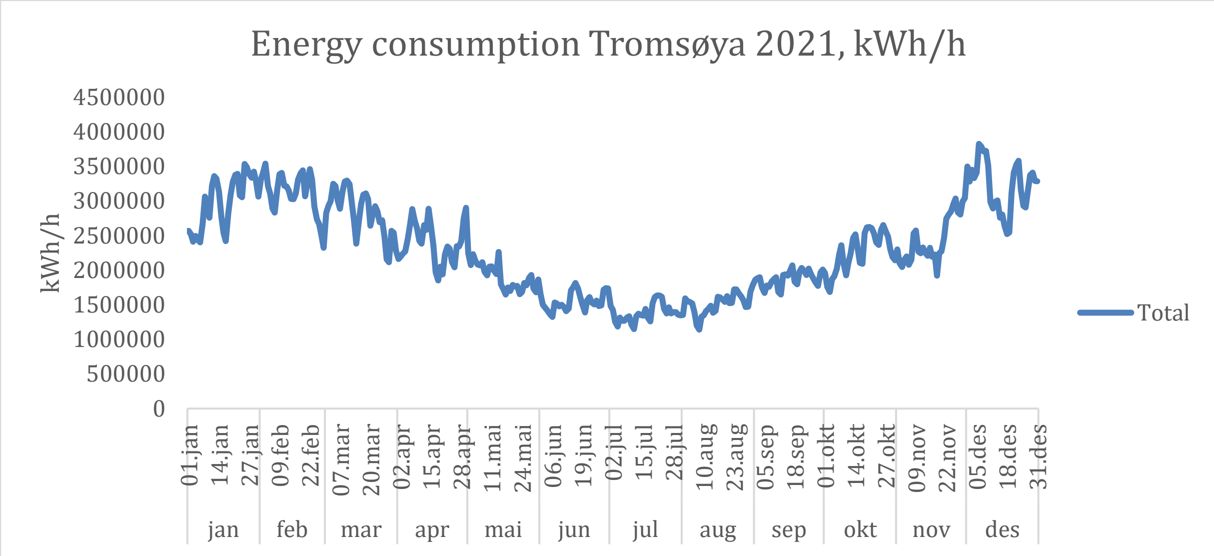

Figure 7: Annual Load Curve

According to the Figure 7, From the month of October till March end is the peak winter season where people need heating system to warm up their houses and other utilities. While from the month of April to September Tromsø have sunny days of summer.

Tromsøya facility is covered by nearly 6 substations. These substations rating includes 11kV distribution and one 132kV transmission lines. As with the annual load curve Figure 7, it is suitable to use load duration curves to gather data of base load and peak load demands from a large amount of data for each substation.

In Figure 4, the Charlottenlund substation is analyzed. From Figure 6, the Charlottenlund substation is situated near the populated part of the city. There are 3 lines operated by Charlottenlund. Two distribution line of 11 kV and one 132kV transmission line connected end to end with Varden substation. The peak demand and load demand are observed in Table 2 against the hours in a year.

Table 2:Load Duration Curve Data station 1

Transformers Line	Peak Demand (kWh/hr.)	Hours	Base Demand (kWh/hr.)	Hours
T1-11kV	24400	386	7300	8760
T2-11kV	25850	294	8450	8760

132kV	36600	174	7200	8760

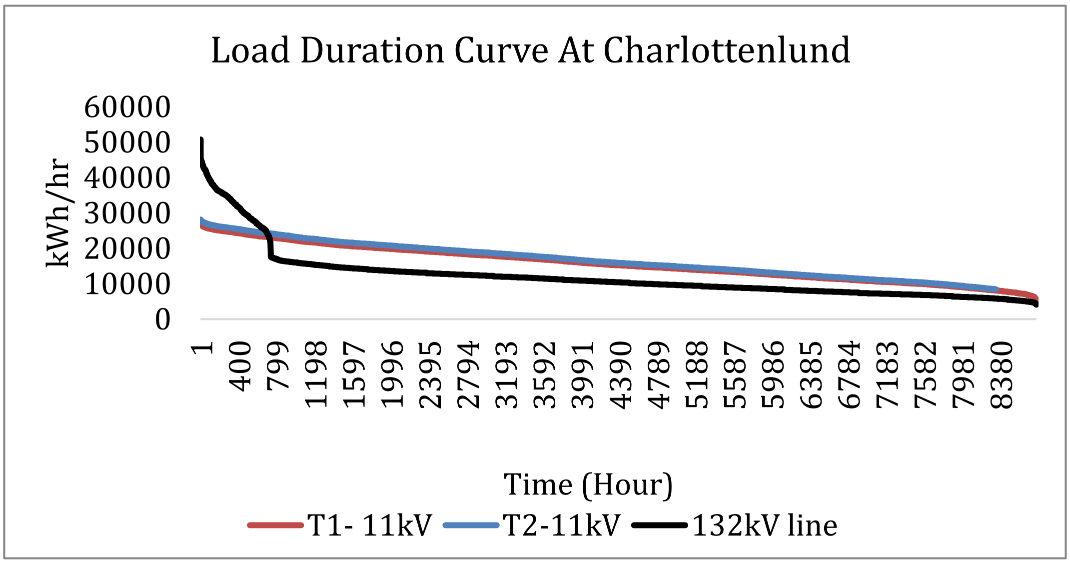

Figure 8:Load Duration Curve at station 1.

Gimle Substation is observed with two 11kv distribution lines. Gimle substation is in center of Tromsøya which is responsible to supply power in commercial building and few residential buildings. From curve it has been observed that curve drops after supplying power almost 6859 hours in a year. It should be possible that electricity supplied is shared from other nearby 66kV line Kroken for rest of year.

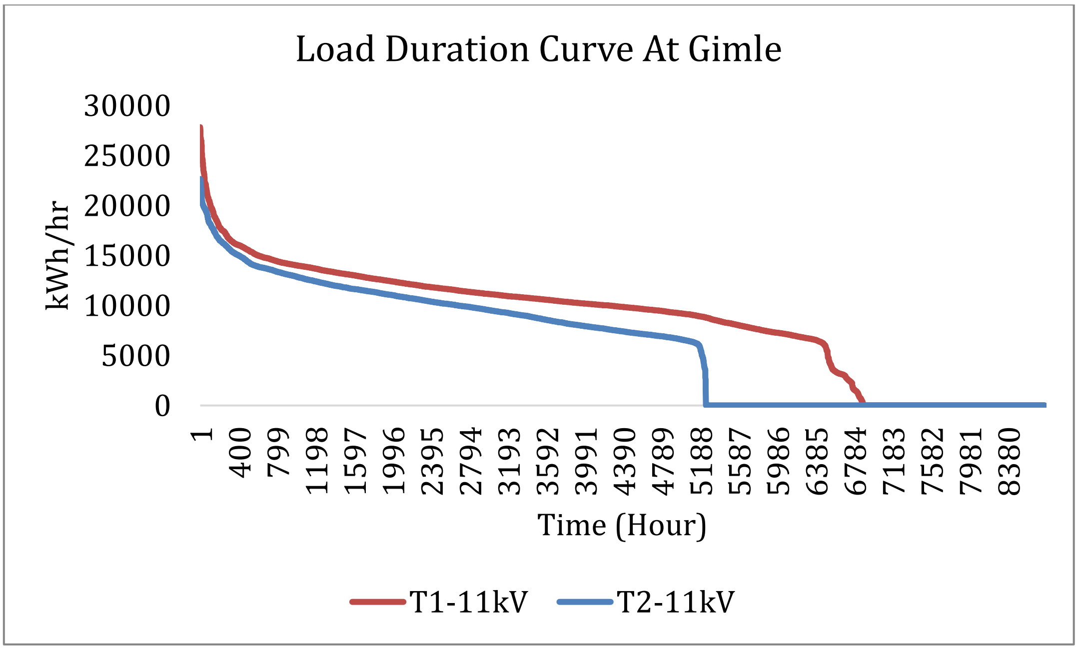

Figure 9: Load Duration Curve station 2

Table 3: Load Duration Curve Data station 2

Transformers Line	Peak Demand (kWh/hr.)	Hours	Base Demand (kWh/hr.)	Hours
T1-11kV	18528	165	5472	6502
T2-11kV	14848	428	5120	5205

The city center is covered with Sentrum substation with two 11kV lines. In this substation almost both transformer lines share approximately equal amount of load.

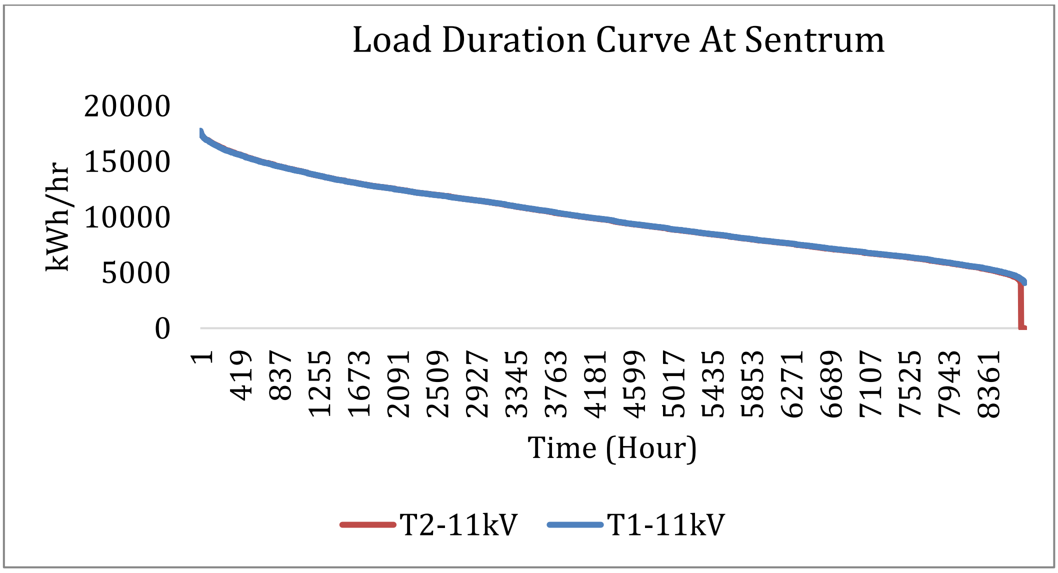

Figure 10: Load Duration Curve station 3

Table 4: Load Duration Curve Data station 3

Transformers Line	Peak Demand (kWh/hr.)	Hours	Base Demand (kWh/hr.)	Hours
T1-11kV	15900	316	4050	8760
T2-11kV	15960	311	3930	8719

The southern part of Tromsøya is covered by Strand Vegen with two 11kV distribution lines. This line is originally supplied by a 66 kV transmission line from Hungeren.

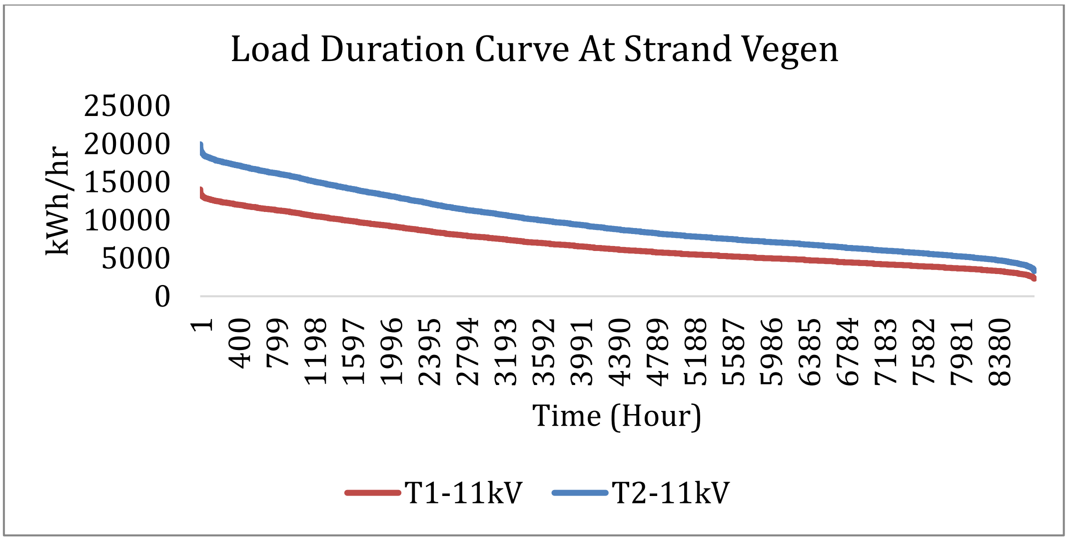

Figure 11: Load Duration Curve station 4

Table 5:Data drive from Load Duration Curve station 4

Transformers Line	Peak Demand (kWh/hr.)	Hours	Base Demand (kWh/hr.)	Hours
T1-11kV	12500	175	2400	8760
T2-11kV	17650	233	3400	8760

3.8 Mapping of Domestic Thermal Load Installations:

To determine the effect and potential of power system flexibility it is important to overview the proportion and amount of electricity used in households for different purposes. A large proportion of household energy consumption is used for stationary purposes such as washing, lighting, cooking and other household uses. A large percentage of Norwegian households use more than one source to heat their homes in which a combination of electricity and wood burn stoves.

According to the Statistics Norway Energy Survey [24] , several surveys of consumer expenditure were conducted. In these surveys, specific questions related to types of heating equipment and energy consumption were asked to estimate the end use consumption. Around 2200 household gross sample were gathered.

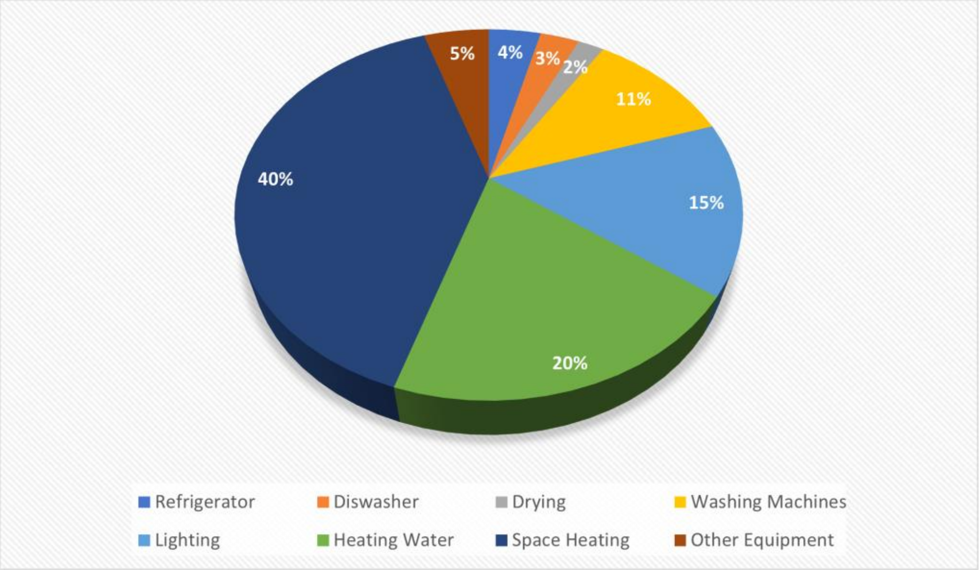

Figure 12: Electricity consumption in households by purpose [25]

According to data issued by Norway ministry of petroleum and energy in 2020, 211 TWh of electricity was consumed in Norway around which 46 TWh was utilized from households [24]. As we can examine from the Figure 12, around 60% energy was used for heating purposes. In the past two decades there is a big revolution of switching of sources for heating is reached. In 1990 the source for heating was fossil fuel but now most of the heating's are based on electricity.

Different types of heating sources are used in residential places for the heating of homes and hot water utilities. These include:

1. Traditional Wood burn stoves
2. Electric Power based heaters
3. Water based central heating

3.8.1 Traditional Wood burn stoves

These wood burn stoves are beyond the scope because there is no connection of source with it. In general concept, in wood stove, there is a need of proper space and can be located almost anywhere in a big space with an appropriate route of chimney. Most ideal locations are the central part of the house so heat will be spread all around and burning smoke go out through chimney. This provides the efficient installation but when fossil fuels burned carbon dioxide is released. Increase concentration of gases cause the average global temperature to rise. Because of this drawback and expensive wood mostly resident switch these stoves with electric heating systems and solutions.

Figure 13: Wooden Stove [26]

3.8.2 Electric Power based heaters

Because of intensive and reliable electric supply in Norway, almost everything including stove, water boiler and room heating is done by electrical supply. In electric heaters, it converts electric energy into heat energy by passing electric current through high resistance filaments. The power rating of heater is in kilo watts (kW), the higher the rating the more power will be produced. Normally heaters with rating used in Norway are around 1500kW or people installed radiator-based heater, which circulates the hot water connect with boiler in basement of house.

Now a days, many companies have introduced the smart heaters with the several features of thermostat and internet/ Bluetooth control-based heaters. Thermostat have improved the efficiency of heater because it will automatically turn off when room temperature is reached.

Internet server-based heater enable consumers to control their heating appliances of their smart homes, even if they are not in the building boundaries.

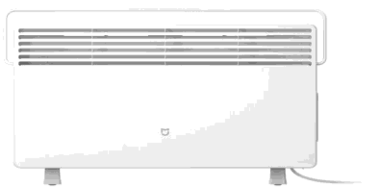

Figure 14: Electric Heater [27]

3.8.3 Water based central heating

Water Based central heating also known as district heating. District heating is mainly based on the recycle of energy. It can be produced using different fuels which includes, gas/diesel oil, water, electricity, waste heat, and biogas etc. In Norway according to statics almost 50% of district heating was produced from waste in the year of 2019 [24].

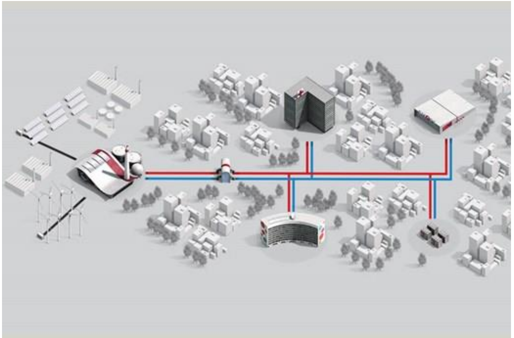

Figure 15: District Heating [28]

In district heating network, the distributing heat generated at unit location and distributed with a system of insulated pipes to fulfill commercial and residential heating requirements. The hot water from get heat in heat exchanger where the heat transfers between water supplied and hot water coming out of taps.

In tromsø KviteBjørn Varme is one of them major district heating supplier. The company produces over 130 GWh of heat annually from its heating plants. They have major distribution units around Tromsøya [28]. It supplies water-borne hot and hot tap water to several customers, including the University Hospital of Northern Norway, the Courthouse, the University of Tromsø, the sports halls in Tromsø, kindergartens, schools, and several residential areas such as Strandkanten. They destroy the residual waste and preserve the waste heat from the waste incineration.

Figure 16:Units installed by KviteBjørn Varme [29]

3.8.4 Under Floor Heating

In under floor heating, heating cables also known trace cable used to heat the floors and keep the temperature constant across the place. These heating cables are submerged under the floor of any space type i.e., concrete, wood etc. Under floor heating done by electrical resistance elements heating cables or sometime by hot flowing fluid mostly water across the pipes [30].

Heating cables consist of tray filament. There ratings are different according to space size, purpose, and installation space. With the technology advancements, the self-regulated heating cable system are now controlled by programmable thermostats and sensor to make the efficient use of energy and save the cost of electricity. Programmable thermostats control the constant temperature with automatic turn on and off according to the requirements.

Due to high initial cost, heating cables are less common in normal households.

3.9 Effect of Thermal Loads

There are several effects of thermal load that includes:

3.9.1 Power system Stability issue:

Electricity suppliers do have to regulate the voltage supplies. They must manipulate the flow of reactive power through the system. These Thermal loads created a large impact on power system operations, that cause stress on the power system which endanger the power reserves and push the system close to blackout and faults.

3.9.2 Quality of Power Supply:

Power system companies must maintain the power factor approximately close to 1 otherwise customer have to pay for the extra penalty in bill. As the load demand increases there will be increase in apparent power that leads to low power factor and less regulate voltage supply.

3.9.3 Increase the power supply cost:

In district heating system if recycle heat is not enough than mostly electricity is used in electric boiler to heat water and supply them in distribution lines.

In winter, a grid must manage all the consumer loads with addition of heating system. To supply the amount of power and maintaining the system the grid has to setup additional equipment.

3.10 General Mapping of Thermal Load Installation

For load mapping as mentioned in section 1.7 , The electric heaters are considered as a general load it is assumed that a standard electric heater of rating 1500 Watts is used in one house. The load is purely resistive.

According to weather spark [23], the winter season varies from November 13 March 31st and summer season lasts from April to November 12, respectively. Concluding the data in table related to the consumption of power during the months from the yearly load curve in figure

Table 6: Winter Season

Stations / Month	**Chalottenlund (kWh)**	**Gimle (kWh)**	**Sentrum (kWh)**	**Strandvegen (kWh)**
January	41668600	14277440	19208700	17487200
February	37992550	13994272	18503670	16912750
March	38370550	14440256	18198150	16792150
(13-30) November	22760650	3959840	10768410	8675550

December	56397950	6889536	19763400	16777000
Total Consumption	197190300	53561344	86442330	76644650

Table 7: Summer Season

Stations / Month	**Chalottenlund (kWh)**	**Gimle (kWh)**	**Sentrum (kWh)**	**Strandvegen (kWh)**
April	32120450	11670048	14937000	12957150
May	27034000	10211328	12233910	9648950
June	20614950	9051616	9613530	7221050
July	18958850	8189088	9080700	6555300
August	20569050	8638528	9825570	7777500
September	24642250	11678240	11354280	8663950
October	31464800	13125504	14520570	11138300
(1-12) November	13264500	2800256	6215010	4694150
Total Consumption	188668850	75364608	87780570	68656350

Table 8:Power stress on grid in winter season

Stations / Season	Chalottenlund (kWh)	Gimle (kWh)	Sentrum (kWh)	Strandvegen (kWh)
Winter	197190300	53561344	86442330	76644650
Summer	188668850	75364608	87780570	68656350
Load Consumption	8521450	-21803264	-1338240	7988300

From equation (3.12) it shows that:

- Positive sign of load consumption shows the additional load that a grid must manage

$$\text{Load Consumption} = \text{Winter} - \text{Summer} \tag{3.12}$$

  with additional equipment and facilities during the winter season.
- Negative sign shows a flexibility of grid to manage demanded power in winter season with ability to manage more additional load.

3.10.1 Estimation of Householding Influence in total Consumption

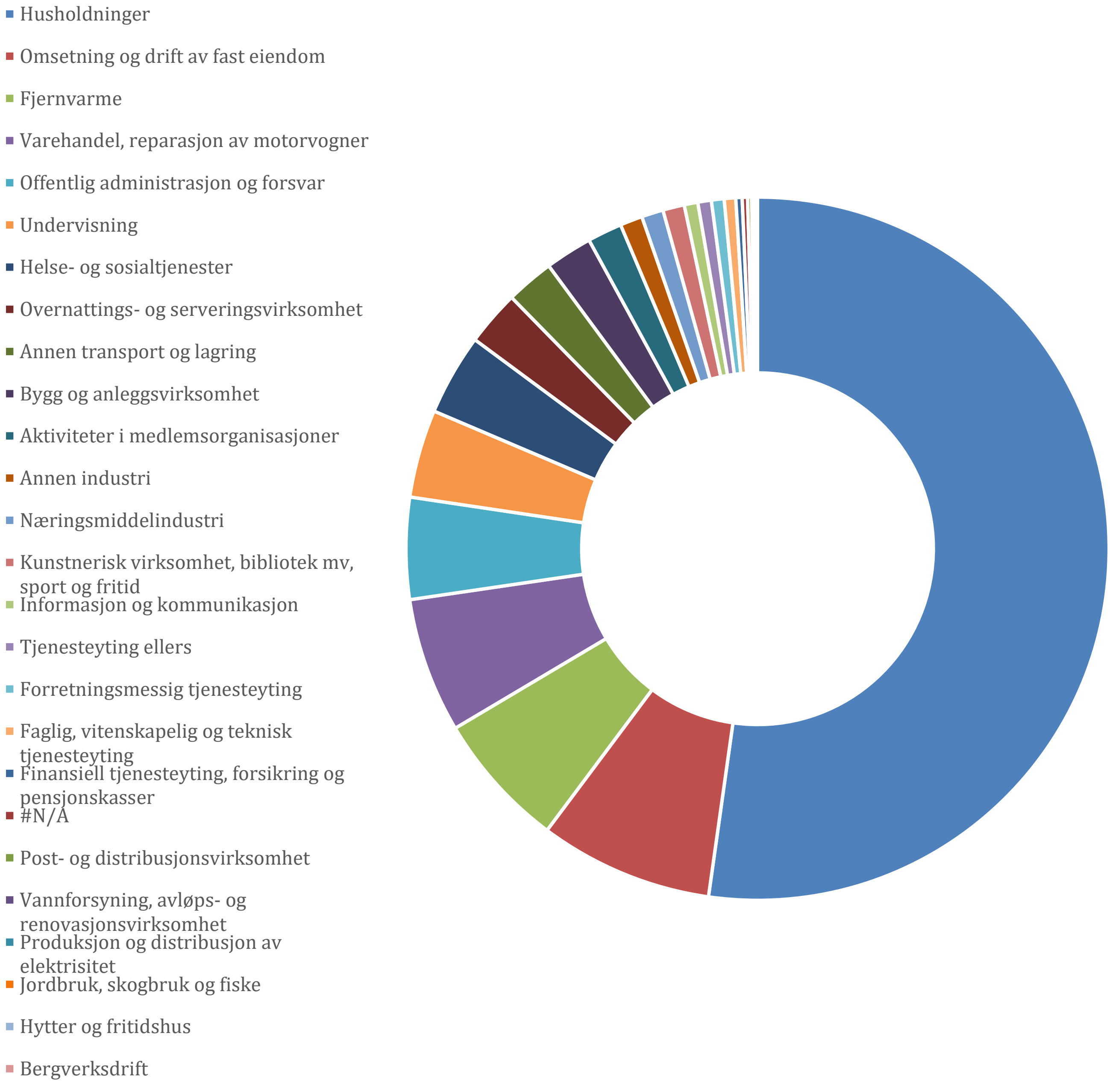

Figure 17: Services facilitated by Arva grid in Tromsøya

According to data in Figure 17 provided by Arva As. It is observed that approximately 52% energy is consumed by 20,167 house holdings in Tromsøya from the grid.

For estimation of loading and power usage consider a power consumption in gird from Chalottenlund substation using Figure 7, Let observe the consumption for one day of 01 Jan 2021.

Power Consumed= 1193500 kWh

52% Householding Consumed Power= 1193500*0.52=620620 kWh

Per house Consumption in one day= 30.77kWh

3.10.2 Appliances influence in one day power consumption

According to Figure 12, there are certain appliances and facilities consumed electricity as calculated below in Table 9, averagely in every house in a day.

Table 9: Consumption of electricity by appliances

Facilities	Percentage Influence (%)	Consumption (W hr.)
Heating	60	18462
Lightning	15	4615.50
Refrigerator	4	1230.80
Dishwasher	3	923.10
Drying	2	615.40
Washing Machine	11	3384.70
Other Equipment	5	1538.50

4 Proposed Method

4.1 Overview

From the study of approaches in section 2.3, it is observed during the overloading and stress on power system, it is necessary to work on temporary load shedding schemes to increase system flexibility. All these optimization techniques proposed and used in the power systems have some limitations, i.e., some either suffer from sub-optimal load shed or long convergence time. To overcome these limitations, it is concluded that either by combining the strengths of optimization algorithms we can achieve multi objective and robust system or using efficient energy management system of power with robust communication to shed the loads. Solution is based on the data that has been gathered from the current grid model of Tromsøya.

4.2 Automatic Load Shedding

In the system number of smart meters connected with MCU (Meter data collection unit) and with the system communication of Wide Area Network (WAN). the whole data send to Central system for analysis of forecasted load values under switching times. The model estimates the amount of load shedding and customers (except prioritized i.e., hospitals, schools etc.) and location. Each customer's load forecasted is trained that made easy to design and measure the estimated load shedding time, load flow in buses. The load flow of the customer was observed by distribution operator to estimate the system power quality, compare the total, and enable for stability indexes to detect voltage instability with P-V curves [20].

The focus of load shedding in Tromsøya is to shut down the heating systems of household exclude prioritized customers in this way the system should be accompanied with the several options:

4.2.1 Current Grid Control and Temporary Load Shedding Approach:

The system operation is divided in three states. Stable, emergency and disturbance state. In stable state the power system will be in balanced conditions. In emergency states the DSO will ask the transmission system operator to get supply reserves from generation facility for peak demand and system about to fluctuate. Grid system at distribution side will work under states and continuously operate by comparing the receive signal voltages with the rated voltages to ensure its steady state balanced operations.

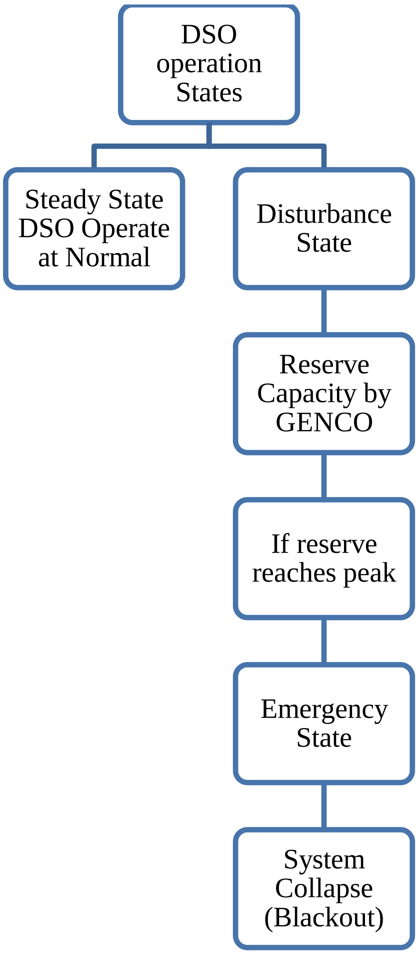

Figure 18: DSO Working States

To prevent the blackout in the system and keeping the reserves in safe limit, The load voltages will be compared at every peak demand. If the peak demand occurs greater than rated capability, the system enters in an emergency state, trigger a warning, and send a signal to start the load shedding of heating systems of customer homes.

4.2.1.1 Detection of Householding Heating system:

There are several methods adapt by researchers to monitor and detect the household power consumption that helps to motivate consumers in reducing their power consumption. These methods are knowing as Appliance Load Monitoring (ALM). There are two types of methods used in ALM.

Intrusive load monitoring (ILM) and Non- Intrusive load monitoring (NILM). In ILM, each appliance or facility is installed with a sensor to observe the operation individually. This method is costly and complex. And due to consumer privacy concerns it is not preferred. On the other hand, in NILM is a more convenient and reasonable to install, a single sensor in the main circuit board which monitored the total aggregated power consumption. The challenging task of NILM is the classification and differentiation of data about appliances of same power rating/consumptions.

To overcome the problem of identification in NILM, the researchers in [31], [32] have proposed the method to identify the activity of specific appliance via Human Activity Recognition (HAR).

In [31], the appliance can be detected based on the load profile of consumer over a specific period. That raw data will be used to train the controller. Controller will identify the specific appliance i.e., Electric Heater usage in winter etc. Based on the given data and load profiles this method is recommended to use in this thesis work.

While the edge computing method is used in the research article [32], in smart meter energy measurement it uses pattern recognition and match the current appliance (load waveform) with the trained raw waveform of different loads depend on the load nature.

4.2.2 Communication Possibilities:

Communication is one of the most difficult and critical part of smart metering. Each consumer data must be sent to central server in a secure and efficient way. Before the technological advancements, the remote monitoring was done through digital transmission lines with the advanced concept of telephone line identification system. Now a days, by taking all the aspects including environments, locations, etc. in consideration a lot of research has been done to find he optimal solution with the combination of multiple communication technologies [33].

An efficient outperformed smart meter should have following properties:

- Theft Detect and Reduction
- Low expense and less maintenance
- Improve energy monitoring
- Flexible for consumers
- Remote Functions Accessibility (Communication with less signal loss)

Wired and Wireless ways are parent modes in two-way communication medium that are upgraded by time. They are categorized by their efficiency and transmission medium.

4.2.2.1 Wired Communication:

There are different types of wired communication depend on their pros and cons:

4.2.2.1.1 Power Line Communication (PLC):

A PLC module is installed in meter without any additional equipment in the current widespread power line infrastructure. Because of ease in installation, this technology was used mostly commonly for metering. However, there are some disadvantages that downgraded it:

- Voltages signals affected by Load Impedance variations
- Noise and magnetic Interference by switching and inverters at grid.
- Frequency Attenuation due to switching variation of electric devises at distribution side.

These cons can be overcome with the combination of different technologies i.e., RF Mesh.

4.2.2.1.2 Digital Subscriber Line (DSL):

Telephone lines are used in Digital Subscriber Line to transmit data. It is flexible with the infrastructure that is already exist. The disadvantage is the distance between consumer and supplier.

4.2.2.1.3 Fiber Optics:

It is efficient technology with high transmission rate. Unlikely it is not commonly used because of high installation cost.

4.2.2.2 Wireless Communication:

Smart Metering is evolving with advanced technological research and make the system suitable for today's need.

4.2.2.2.1 Radio Frequency Mesh:

Radio Frequency Mesh is a wireless communication that enable Automatic Meter Reading (AMR). It is used to measure, collect the power transfer data, and send it back to the grid. Its advantages include embed modules that are easy to integrate with existing meters, addition with PLC it provides better accuracy and coverage and efficient operations. The drawbacks of this technology are interference, detection in same frequency signals, to achieve low-cost operation, less modules need to be in restricted range.

4.2.2.2.2 Zigbee:

Zigbee is standard IEEE 802.15.4 specification used for high communication protocols. Now days it is commonly used in smart energy management system. In Zigbee, a mesh network can be created in smart meters with easy and low-cost installation.

The cons of Zigbee are licensing access difficulties and limited to 65000 devices connection at a time.

4.2.3 Smart Metering:

The energy metering is one of the important factors in power system operation and control. This technology has been upgraded by time and it is continuously spanning to discuss the problem, consumer reliability and help power systems work more efficient and sustainable [20].

In early stages, metering was done through electromechanical meters that have a spinning disc and a mechanical counter display. In this type of meters, it counts the revolution of metal disc proportional to speed at which power drawn it. As technology evolves, solid-state electronic meters replaced them with the ability of measure power through integrated chips i.e., analog to digital converters, etc. and display the consumption on liquid crystal display (LCD). Through this advancement it also gave path to one way communication feasibly to Automatic meter reading (AMR) that eliminates the meter reader usage to visit consumers individually.

Now a days this technology upgraded to smart metering with accessibility of two-way communication which makes flexible both for consumer and supplier to retrieve the data visa remote access.

According to Figure 19, in smart metering, it comprises of Advance metering infrastructure (AMI) with different meters, communication network, data collection units and management systems. It provides near real time measurements of PQ monitoring, outrage notifications and can be used for smart homes.

4.2.3.1 Smart Metering Components and Stages:

In two-way communication, it involves four different stages of data and information exchange from consumer to grid side as well as giving access to consumer about information of their usage. These stages and components involved in the process are stated as in Figure 19:

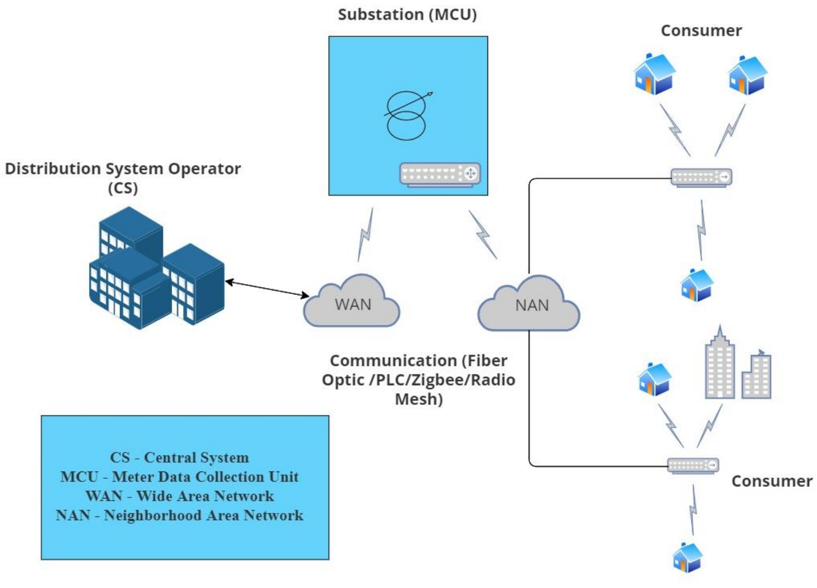

Figure 19: Smart Meter Communication

4.2.3.1.1 Smart Meter:

The smart meter is electronic based meter that measures and deliver the consumption data of electricity utility of households, industries, etc. with the ability of two-way communication data to nearby neighborhood nan. Additionally in two-way communication, it also provides accessibility to consumer to access their data regarding consumption, online tariff information as well as allow the grid to remote access for controlling of power supply to consumer. These smart meters are equipped alarms with theft systems to control the meter tempering [20].

In Arva As, the smart meters that are used at the customer end to measure electrical power output is provided by Kamstrup. Omni-power single phase and 3-phase model meters are used, depend on the customer need. Omni power is a remotely readable or near real time, two-way DLMS (Device Language Message Specification) supported communication capability smart meter that send data back to DSO (Distribution system operator, Arva As.). Smart Meter has a lot of advanced features and specification stated as follows [34]:

1) Omni power meter is fully electronic without movable parts. Thus, energy. registration is not affected by shock or impact during transport and mounting.
2) The shunt measuring principle secures good linearity and a considerable dynamic range. At the same time, the shunt measuring principle is immune to magnetism and DC currents.
3) The easily readable display scrolls automatically between readings, and data can be collected via Radio Mesh network, optical output or from the module area.
4) As default, Omni power single-phase meter can generate load profiles in all four quadrants. A load profile provides detailed information about consumed and produced energy. These load profile support to do main grid analysis i.e., measurement of THD (Total Harmonic Distortion), power factor, voltage unbalance and variations, etc.

4.2.3.1.2 Neighborhood Area Network (NAN):

The NAN is the base network such as Zigbee which controls communication between the consumer side smart meters and responsible for connection between meter data control unit (MCU).

Zigbee is preferred as it will connected with nearby devices. So, it will be easy to communicate and divided network in the form of societies/stations. The data will collect according to the specific time schedule. For example, in load profile daily load curve the data is measured hourly and send it to MCU once in an hour.

4.2.3.1.3 Meter Data Collection Unit (MCU):

The MCU supervise and collect the data from all connected and assigned NAN (Zigbee) controllers. It acts as a bridge between central system and consumers. It detects the activities do the actions i.e., forward information, firmware upgrade, if any problem occur in NAN or NAN is not responding in a particular time, it will send an error report back to central system. The MCU usually located a low-voltage side for a reliable communication.

4.2.3.1.4 Wide Area Network (WAN) and Central System (CS):

RF Mesh and PLC modules are used in WAN. WAN connects the central system to MCU's. Central System (Distribution grid) act as a control head of overall system that decides, gave commands for actions in the system through the MCU's to NAN and NAN to smart meters. CS have ability to monitor, control and configure different units i.e., planning, operation like load shedding, tariff, and invoices etc.

4.2.4 Methodology

By reviewing the communication possibilities and features of currently installed smart energy meter. It is possible to develop a workflow of two-way communication for temporary load shedding scheme. In most stages to keep the system updated with a synchronized plan the load analysis of data will be done and train the controllers in an hourly duration of one year load curve.

As illustrated in Figure 20 below, the process will be consisted of several stages. In the workflow, NILM Controller will be installed at meter to detect the appliance activity (Heating in this case) from trained load profile data. That controller data will be transferred to smart meter in the main circuit board.

Distribution operator like Arva must prepare a plan with the pre-defined list of customers for example householdings. Those household consumers who do not want to participate in temporary load shedding of heating system will be added to prioritized in the list. By MCU's at LV substations the load analysis data with hourly duration access the ability to alert the CS and look after the correspondence and load shedding activities at customer side to keep the system stable and consumer reliable. These MCU's also monitor the pre and post amount of load shedding, voltage, and powers, respectively.

At the central system monitor and receive the load profile and voltage stabilities of each bus at substations. Based on trained load profiles and received (almost real time) load curves the controller at CS performs the load flow analysis, do the fast voltage index at each bus. In case of over voltage and instability occur in system the DSO will initialize the temporary load shedding.

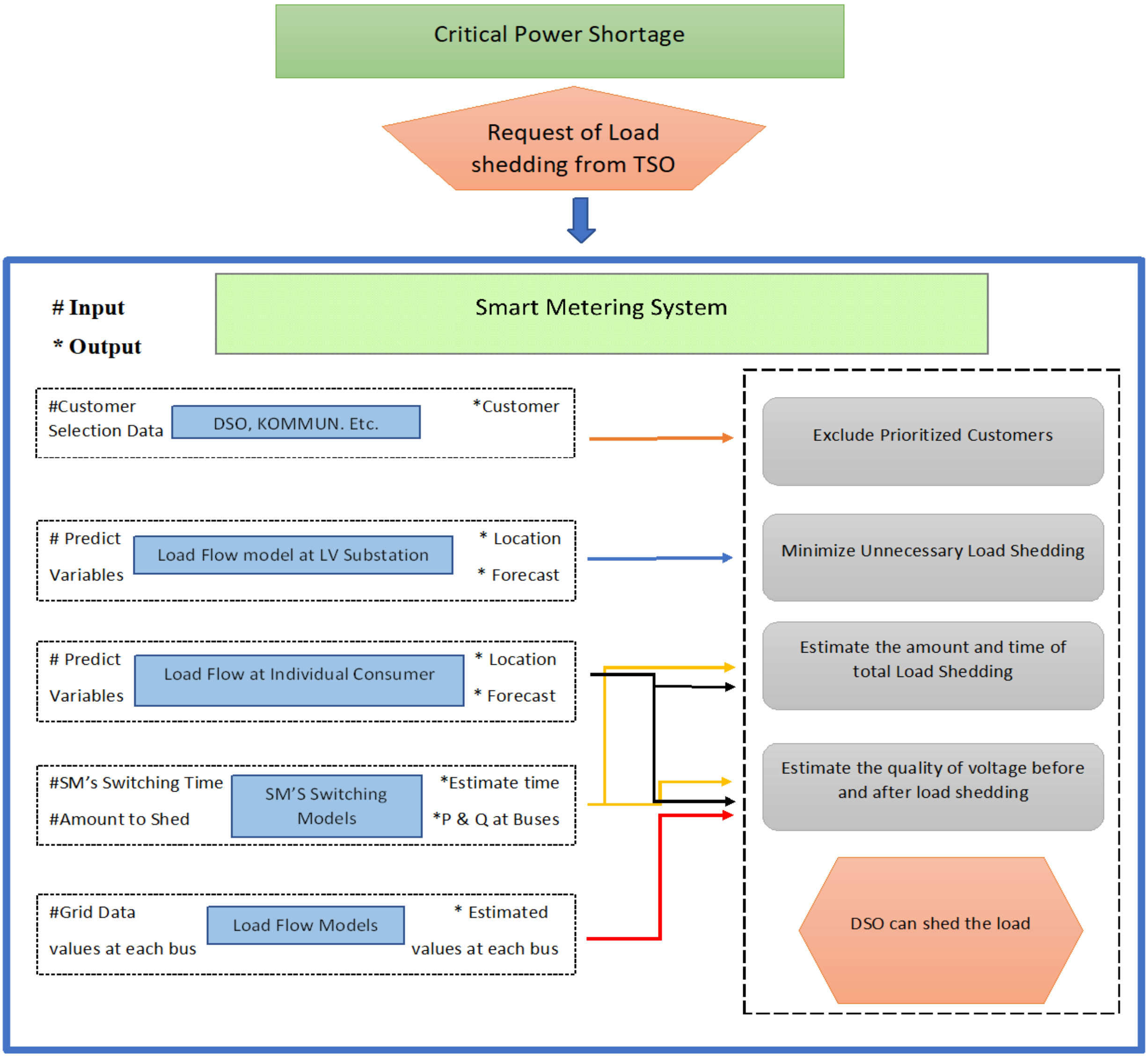

Figure 20: Temporary Load Shedding Flowchart

During the peak hours, in temporary load shedding, the energy management will work. In preload shedding with load profile are compared with trained to detect the amount and location of bus. The difference from the rated amount will be stated as additional load that need to be shed on required bus. This information will be sent to NAN through MCU. The NAN will pass out the information to Smart Meter. NIML module receive that specific amount compare with already sent. This comparison detects the appliance. This appliance information will be forward to smart meter. The smart meter will shut down the breaker of that specific load in the main circuit board along with the acknowledge to NAN. The NAN will receive the confirmation and forward it to the CS. CS will do the post load shedding load flow analysis and monitor the system will be back to normal.

After the whole day, in planned forecasted time as the system get back to normal under stated states, the CS launch the load restoration command to the NAN to restore the already shed loads by smart meters. The smart meter will turn on the breaker on main circuit board. NIML module will also verify the appliance acknowledge about it (appliance turn back on). After the loads turn back, the CS will again do the load flow analysis of system. In parallel MCU will verify the operation of NAN's and send the smart meters operation verification to central system.

4.2.5 Temporary load shedding by planning (Current Infrastructure):

First, the awareness will be created among customers with additional benefits about peak demand and supplies for understanding. The consumers who agreed with the auto load shedding the heating system should be turn on before the appropriate time or as the load demand decreases on the grid to increase consumer reliability and keep the household temperature warm under the extreme cold weather.

Moreover, in everyday load shedding will be done on a specific schedule depend on previous daily or monthly load supply curves. For example, with the previous load curves as the load demand with household and commercial load increases in the morning. The system should be focused to shed the complete households that are empty and for that the inhabitant should be in communication with supplier and aware with the load shedding activity in advance. There should be a manual option at customer side to keep the supply control if customer do not want their system to shut down.

The auto load shedding system done by human activity recognition (HAR) with appropriate time operation, and load curve based on that location. For example, in morning the grid system is in peak and supplying both commercial and household consumers. Commercial load demand supply mostly in the morning during the working hours from 08:00 to 16:00. In this case the whole supply would be shed during the hours and turn on again around 14 or 15:00 to ensure the system supply and make the household warm for the consumers in the winters.

On the other hand, in chapter 3, we reviewed that now a days, district heating is also one of the sources used in heating. To keep the system safe from peak loading. It can be planned with district heating provider to generate heating in base time and supply it during the peak time. District heating provider will also consult with customers to save them from inconvenience. In the peak time the supplier will used it already saved heating and generate/recover the heating's in normal base hours.

4.2.6 Mathematical Model

From [3] , Load Shedding technique may be characterized as static, and dynamic based on the way they shed load. The behavior of system under the load conditions are usually studied under time domain, which can reflect the system dynamics in voltage instability. Depend in rate of change of load the power system will be shed automatically. The power system depends on the initial operating conditions of power system, before and after occurrence of contingency. For secure system and reliable operation, the parameters that effect the operation of power system should be defined. Load flow analysis during the load shedding will be conducted by Newton Raphson (N-R) based on the mathematical structure as below:

Equation (4.13) shows interruption cost by incorporating the sensitivity term, which is usually the objective of load shedding.

$$Min\left[\sum_{i=1}^{N_K} C_i\left(\frac{\Delta P_{Di}}{\frac{\partial\lambda}{\partial P_i}}\right)\right] \tag{4.13}$$

$$P_{G_i}^0 - P_{D_i}^0 + \Delta P_{Di} = \sum_{j=1}^{N} |V_i||V_j||Y_{ij}|\cos(\delta_{ij} + \delta_j - \delta_i) \tag{4.14}$$

$$Q_{G_i}^0 - Q_{D_i}^0 + \Delta Q_{Di} = -\sum_{j=1}^{N} |V_i||V_j||Y_{ij}|\sin(\delta_{ij} + \delta_j - \delta_i) \tag{4.15}$$

Equation (4.14) and (4.15) describe initial operating conditions of a power system having index "0", where "G_i" and "D_i" account for generation and demand at bus *i*, respectively, whereas P and Q are related to active and reactive power. Moreover, ΔP_{Di} and ΔQ_{Di} are control variables, which show a change in active and reactive demands that helps to obtain optimal solution, Y_{ij} shows admittance of line *i* and *j*; δ_i, δ_j shows voltage angle at bus *i* and *j*, respectively; and δ_{ij} shows the difference of voltage angle at buses *i* and *j*. Index "c" in equation (4.16) and (4.17) shows the of the power system in contingency or stressed condition along with minimum loading margin.

$$(1+\lambda_{min})\left(P_{G_i}^0 - P_{D_i}^0 + \Delta P_{Di}\right) = \sum_{j=1}^{N} \cos|V_i^c|\left|V_j^c\right|\left|Y_{ij}\right| \cos\left(\delta_{ij} + \delta_j - \delta_i\right) \quad (4.16)$$

$$Q_{G_i}^0 - (1+\lambda_{min}) = -\sum_{j=1}^{N} \cos|V_i^c|\left|V_j^c\right|\left|Y_{ij}\right| \sin\left(\delta_{ij} + \delta_j^c - \delta_i^c\right) \quad (4.17)$$

Equation (4.18) and (4.19)3.7 show the minimum and maximum voltages,

$$V_i^{min} \leq V_i \leq V_i^{max}, i_\varepsilon \in N_L, \quad (4.18)$$

$$V_i^{c\_min} \leq V_i \leq V_i^{c\_max}, i_\varepsilon \in N_L, \quad (4.19)$$

Transmission lines limits between bus *i* and *j* in normal and stressed condition relate to equations (4.20) and (4.21). In equations (4.22) and (4.23), reactive power and change in active power limits were shown:

$$\left|P_{ij}\right| \leq P_{ij}^{max}, \forall ij \in Transmission\ lines, \quad (4.20)$$

$$\left|P_{ij}^c\right| \leq P_{ij}^{c\_max}, \forall ij \in Transmission\ lines, \quad (4.21)$$

$$Q_{Gi}^{min} \leq Q_{Gi}, \qquad Q_{Gi}^c \leq Q_{Gi}^{max}, \quad i \in N_G, \quad (4.22)$$

$$\Delta P_{Di}^{min} \leq \Delta P_{Di} \leq \Delta P_{Di}^{max}, i \in N_D, \quad (4.23)$$

Equation (4.24) shows the ratio of control variables at fixed power factor.

$$\frac{\Delta P_{Di}}{P_{Di}^0} = \frac{\Delta Q_{Di}}{Q_{Di}^0}\ Fixed\ Power\ Factor, \quad (4.24)$$

Equation and (4.26) represent the variables after load shedding when contingencies occur.

$$P_{G_i}^{c} - P_{D_i}^{c} + \Delta P_{Di} = \sum_{j=1}^{N} |V_i^C||V_j^C||Y_{ij}| \cos(\delta_{ij} + \delta_j^C - \delta_i^C), \qquad (4.25)$$

$$Q_{G_i}^{c} - Q_{D_i}^{c} + \Delta Q_{Di} = -\sum_{j=1}^{N} |V_i^C||V_j^C||Y_{ij}| \sin(\delta_{ij} + \delta_j^C - \delta_i^C) \qquad (4.26)$$

The most significant feature of N-R is that it is more practical and efficient. Moreover, the number of iterations required to obtain a solution is independent of the system size. Additionally, N-R load flow converges fast as compare with other load flow methods.

5 Simulation And Results

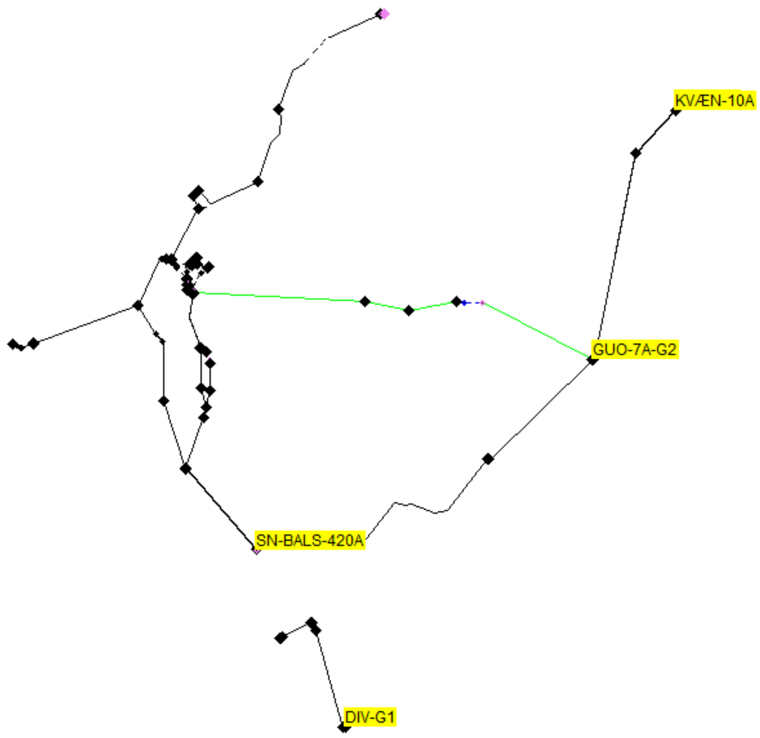

Figure 21:Tromsøya Network

The simulation is done in different steps with different software's as NetBas because of time constraints only have ability to do static system. For complete the load flow analysis results of NetBas was exported to excel file which then imported to MATLAB.

The network is designed in NetBas. NetBas do the convergence with minimum iteration and follow the methodology of Newton Raphson. The network is comprised of almost 221 buses. The data of the network is mentioned in APPENDIX.

As mentioned in section 3.10, the area is mostly comprised of residential householdings and some commercial places. The main focused area are householding's in the Figure 21. In the network, **SN-BALS-420A** bus is considered a slack bus. The green line shows the transmission line delivering the power between the bridge.

5.1 Current Scenario:

5.1.1 NETBAS:

Currently by running load flow analysis in the network the result is shown as:

Table 10: Bus Flow Data

Knutepunkt	Spenning	Last (MW)	Last (MVAr)	Prod (MW)	Prod (MVAr)	Komp (MVAr)	3.polt(kA)	Cos (FI)	Grk. P
BREN 132A	144,573	0	0	0	0	0	2,289	0,17	0,983
BREN 22A	21,905	0	0	0	0	0	3,883	0,049	0,983
CHAR 11AX	11,367	0	0	0	0	0	11,493	0,072	0,98
CHAR 11AY	11,367	0	0	0	0	0	11,749	0,077	0,98
CHAR 132A	144,329	0	0	0	0	0	3,926	0,158	0,98
CHAR 66A	69,895	0	0	0	0	0	4,098	0,091	0,98
CHAR 66B	69,895	0	0	0	0	0	4,099	0,091	0,98
CHAR 66C	69,895	0	0	0	0	0	4,099	0,09	0,98
DRAM-66B	69,897	0	0	0	0	0	4,009	0,093	0,98
FAK-22AXY	21,509	0	0	0	0	0	2,433	0,289	0,98
FAK-66A	70,979	0	0	0	0	0	0,986	0,346	0,98
FAKK.	70,952	0	0	0	0	0	1,138	0,361	0,98
GIML 11AX	11,804	0	0	0	0	0	7,302	0,05	0,98
GIML 11AY	11,804	0	0	0	0	0	7,324	0,059	0,98
GIML 66A	72,579	0	0	0	0	0	3,013	0,067	0,98
GIML 66B	72,579	0	0	0	0	0	3,013	0,067	0,98
GUO-0.23A	0,242	0	0	0	0	0	9,471	0,199	0,858
GUO-132-T1.3	140,943	0	0	0	0	0	3,265	0,14	0,871
GUO-132A	140,943	0	0	0	0	0	3,265	0,14	0,871
GUO-132B	140,943	0	0	0	0	0	3,265	0,14	0,871
GUO-22A	21,762	0	0	0	0	0	3,331	0,085	0,871
GUO-7A	6,995	0	0	0	0	0	45,452	0,053	0,858
GUO-7A-G2	7	0	0	45	-12,02	0	45,329	0,055	0,856
GUO-7B	6,995	0	0	0	0	0	45,452	0,053	0,858
GUO-7B-G1	7	0	0	45	-12,019	0	45,329	0,055	0,856
HAKO 132A	144,397	0	0	0	0	0	3,529	0,164	0,983
HESSFJ.	70,93	0	0	0	0	0	1,177	0,363	0,98
HUNG 11A	11,254	0	0	0	0	0	10,524	0,088	0,98
HUNG 132B	144,168	0	0	0	0	0	4,002	0,158	0,98
HUNG 22B	21,997	0	0	0	0	0	8,61	0,083	0,98
HUNG 66A	68,544	0	0	0	0	0	5,087	0,114	0,98
HUNG 66B	68,544	0	0	0	0	0	5,087	0,114	0,98
KROK 22A	22,674	0	0	0	0	0	5,783	0,081	0,98
KROK 66A	68,564	0	0	0	0	0	4,398	0,145	0,98
KVA-132B	144,412	0	0	0	0	0	3,826	0,159	0,981

KVA-66B	70,025	0	0	0	0	0	3,844	0,095	0,981
KVA-DEL2-RI	70,342	0	0	0	0	0	2,421	0,265	0,98
KVALS1	70,328	0	0	0	0	0	2,466	0,263	0,98
KVIT	141,645	0	0	0	0	0	3,046	0,194	0,907
KVÆN-10A	10,63	0	0	0	0	0	23,694	0,111	0,865
KVÆN-10B	10,63	0	0	0	0	0	23,85	0,113	0,865
KVÆN-132A	140,314	0	0	0	0	0	2,76	0,143	0,865
LARS	144,245	0	0	0	0	0	3,501	0,17	0,985
LASS-66A	67,487	0	0	0	0	0	1,856	0,232	0,833
LASS-G1	3,426	0	0	0	0	0	17,651	0,081	0,833
LYNG 132A	141,683	0	0	0	0	0	3,044	0,196	0,909
LYNG 22A	21,778	0	0	0	0	0	4,561	0,085	0,909
NORD	141,694	0	0	0	0	0	3,047	0,193	0,905
NORDR-132A	140,744	0	0	0	0	0	2,978	0,144	0,868
RING 66A	70,761	0	0	0	0	0	1,377	0,383	0,98
SAND 132A	143,82	0	0	0	0	0	3,761	0,17	0,984
SAND 22A	22,777	0	0	0	0	0	4,127	0,061	0,984
SEN-66A	69,897	0	0	0	0	0	3,989	0,095	0,98
SEN-66B	69,897	0	0	0	0	0	3,988	0,095	0,98
SENT 11A	11,689	0	0	0	0	0	12,177	0,066	0,98
SKI-10-G1	10,63	0	0	0	0	0	17,374	0,148	0,871
SKIB 132A	141,379	0	0	0	0	0	2,046	0,201	0,871
SMÅ-66A	67,486	0	0	0	0	0	2,081	0,156	0,833
SMÅV-G1	5	0	0	15	-11,076	0	20,851	0,093	0,826
SN-BALS-132A	142,02	0	0	0	0	0	5,513	0,074	1
SN-BALS-420A	420	0	0	-95,323	-15,901	0	3,611	0,108	1
SN-MEST-132A	142,869	0	0	0	0	0	4,752	0,104	0,995
STVN 11AX	11,148	0	0	0	0	0	11,002	0,073	0,98
STVN 11AY	10,849	0	0	0	0	0	13,604	0,088	0,98
STVN 66AX	68,545	0	0	0	0	0	5,004	0,133	0,98
STVN 66AY	68,545	0	0	0	0	0	5,003	0,133	0,98
TVERR 132A	144,567	0	0	0	0	0	2,385	0,17	0,983
ULLS 132A	142,255	0	0	0	0	0	3,107	0,206	0,932
ULLS 22A	22,179	0	0	0	0	0	4,865	0,079	0,932
VARD 132A	144,365	0	0	0	0	0	3,807	0,16	0,98
VARD 66A	72,569	0	0	0	0	0	3,064	0,065	0,98
VIK	144,201	0	0	0	0	0	3,503	0,17	0,985

Table 11: Load Flow Analysis Line data

Knutepkt Fra	Knutepkt til	Spg (kV)	Flyt (MW)	Flyt (MVAr)	Tap (kW)	Tap (kVAr)	Strøm (A)	Belastn. (%)
MIDD1	MEST-132SAN1	143.098	35.177	4.173	80.66	-364.59	143	20
SEL1	MIDD1	143.339	35.183	1.216	5.16	-2957.05	142.7	12
KGR-MES/HUN1	SEL1	143.407	35.207	1.101	24.69	-115.43	141.8	20
RAM1	KGR-MES/HUN1	143.558	35.25	0.899	42.85	-201.23	141.8	19
RAM2	RAM1	143.717	35.28	0.819	29.42	-80.13	141.7	37
AVGR-132SAN1	RAM2	143.8	35.289	0.776	9.13	-43.17	141.7	19
HUNG 132M1	AVGR-132SAN1	143.994	35.39	-0.166	83.62	-789.03	141.8	28
ULLS 132H1	HUNG 132U1	143.212	100.015	-42.547	2888.19	6870.16	441.1	88
KGR-ULL/LYNG	ULLS 132G1	142.11	100.65	-40.979	619.9	1566.88	442	61
LYNG 132U1	KGR-ULL/LYNG	141.824	101.362	-39.176	711.88	1803.84	442.8	61
LYNG 132A	LYNG 132U1	141.684	101.363	-39.174	0.71	1.81	442.8	61
KVIT	LYNG 132G1	141.665	101.494	-38.889	111.89	283.96	443	61
NORD	KVIT	141.67	101.606	-43.16	111.66	-4270.36	449.8	41
LY-INKA-GUOL	NORD	141.313	103.606	-38.02	1999.72	5139.38	452.1	62
GUOL 132U1	LY-INKA-GUOL	140.936	103.633	-38.744	27.44	-724.23	453.2	63
GUOL 132S1	SKIB 132G1	141.161	0.081	-5.585	3.54	-1922.85	22.9	3
SKIB 132A	SKIB 132T1	141.379	0.056	-0.035	0	-35.23	0.3	0
SKIB 132B1	BALS-132SKI	141.539	0.001	-3.627	1.01	-3626.51	14.8	2
NORDR-GUO1	GUOL 132N1	140.843	6.559	-5.092	11.25	-1665.67	34.1	5
KVAN 132N1	NORDR-KVÆ1	140.529	7.107	-7.029	20.47	-2110.19	41.1	6
KVAN 132N2	NORDR-KVÆ2	140.529	7.433	-6.746	17.15	-2198.82	41.3	5
NORDR-GUO2	GUOL 132N2	140.843	7.943	-4.374	5.51	-1801.69	37.2	3
KVA-132-HÅKO	KVAL- M90	144.412	25.437	-5.049	0.59	-1495.45	103.7	12
KVAL- M90	HAKO-132KV1	144.405	25.436	-3.554	21.88	-646.65	102.7	8
#440548	HAKO 132A	144.397	25.414	-2.907	0.02	-0.51	102.3	8
HAKO-132TV1	TVERR132 HA1	144.482	0.013	-3.689	0.41	-2547.03	14.8	1
TVERR132 BR1	BREN 132A	144.57	0.012	-1.142	0	-1142.4	4.6	0
HAKO 132A	#440550	144.397	25.402	0.783	0.02	-0.51	101.6	8
HAKO-132ME1	LARS	144.321	25.402	0.783	23.89	-297.51	101.7	14
LARS	VIK	144.223	12.844	0.59	3.54	-3483.05	53.9	16
VIK	KGR-MES/KVA	143.916	25.371	8.133	52.83	-570.19	107.6	19

KGR-MES/KVA	MEST-132KVA	143.25	25.318	8.704	69.11	-717.1	108.9	20
MIDD2	MEST-132SAN2	143.091	35.425	3.976	80.11	-354.24	143.9	20
SEL2	MIDD2	143.334	35.434	1.677	8.95	-2299.24	143.6	17
KGR-MES/HUN2	SEL2	143.424	35.464	1.539	30.31	-138.12	142.9	20
AVGR-132SAN2	KGR-MES/HUN2	143.648	35.531	1.231	66.95	-307.23	142.8	20
HUNG 132M2	AVGR-132SAN2	143.984	35.616	0.28	85.29	-813.57	142.7	29
HUNG 132C1	CHAR 132H1	144.249	25.873	-46.241	11.83	-8072.34	212.2	24
KRYSSKOBL	VARD 132CH1	144.361	0.083	-7.277	0.05	-3539.59	29.1	3
CHAR 132V1	KRYSSKOBL	144.343	0.083	-13.814	0.35	-6537.17	55.3	6
CHAR 132K1	KVA-132-CHA1	144.371	25.621	-23.371	6.91	-12200.18	138.7	16
AVGR-132SAN2	SAND 132HUM2	143.801	0	-0.137	0	-137.4	0.6	0
MEST-132BAL1	BALS-132MES1	142.444	47.532	9.072	131.98	-1036.33	197	12
MEST-132BAL2	BALS-132MES2	142.444	48.158	9.216	133.72	-1001.85	199.6	12
LARS	VIK	144.223	12.533	0.491	3.45	-3569.56	52.7	16
AVGR-132SAN1	SAND 132HUM1	143.82	0.017	-0.153	0	-153.03	0.6	0
SMÅVATNA	KVAN 66S1	67.573	14.915	-12.274	90.57	109.49	165.2	30
SMÅVATNA	LASS-66A	67.487	0	-0.069	0	-69.1	0.6	0
HUNG 66K1	KROK 66H1	68.554	0.026	-2.45	0.1	-2450.17	20.6	3
KROK	#68361	72.582	0	-0.107	0	-108.14	0.9	0
KROK	GIM	72.582	0.02	0.065	0.01	-443	4	2
GIML 66KR1	GIM	72.58	0	-1.749	0.08	-649.26	13.9	2
KVA-66AB-G1	GIML 66KV1	70.029	0	-1.789	0.07	-1788.8	14.7	3
KVA-66AB-R1	RI-INKA-KVA	70.026	0.064	-4.372	0.01	-31.15	36	6
RI-INKA-KVA	KVA-DEL1-RI	70.175	0.064	-4.34	8.82	-161.92	35.8	7
KVA-DEL1-RI	KVALS1	70.326	0.153	-3.489	0.11	-3.1	28.7	5
KVALS1	KVA-DEL2-RI	70.335	0.153	-3.486	0.16	-599.4	28.6	4
KVA-DEL2-RI	KGR-KVA/RI	70.434	0.055	-3.053	3.79	-152.8	25.1	5
KGR-KVA/RI	RING 66KV1	70.643	0.051	-2.9	4.56	-212.58	23.7	4
RING 66FA1	HESSFJ.	70.845	0.027	-2.688	1.21	-180.58	21.9	4
HESSFJ.	FAKK.	70.941	0.025	-2.507	0.12	-2020.39	20.4	3
FAKK.	FAK-132.KA1	70.965	0.025	-0.487	0.03	-186.33	4	0
FAK-132.KA1	FAK-66A	70.979	0.025	-0.3	0	-300.4	2.5	0
KVA-DEL2-RI	KVALT2	70.34	0.098	0.167	0.01	-47.54	1.9	0
KVALT2	KVALT1	70.337	0.098	0.214	0.02	-433.99	5.4	2
KVALT1	KVA-DEL1-RI	70.329	0.098	0.648	0.05	-41.41	5.7	1
CHAR 66S1	DRAM-66B	69.896	0.036	-0.984	0	-632.78	8.1	1
DRAM-66B	SENT 66H1	69.897	0.018	-0.176	0	-175.74	1.5	0
DRAM-66B	SENT 66C1	69.897	0.018	-0.176	0	-175.74	1.5	0
GIML 66C1	CHAR 66G1	72.58	0	-1.102	0.02	-1101.78	8.8	2

VARD 66GI1	GIML 66VA1	72.574	0.036	-3.758	0.08	-907.19	29.9	3
HUN-66T2-1	HUN-66-T2	68.544	0.345	7.087	0.06	-14.7	59.9	18
HUN-66-T2	HUN-66T2-2	68.543	0	-0.015	0	-14.76	0.1	0
HUN-66-T1	HUN-66T1-1	68.544	0.282	6.87	0.06	-14.7	58	17
HUN-66T1-2	HUN-66-T1	68.545	0	0	0	-14.76	0.1	0
HUN 66ST1	STVN 66H1	68.545	0.031	-1.1	0.02	-622.87	9.3	1
STVN 66S1	SENT 66S1	68.545	0	-0.477	0	-476.77	4	1
GIM	KROK	72.582	0.02	-0.592	0.01	-442.99	4.7	1
#68361	KROK	72.582	0	0.001	0	-105.38	0.8	0
LYNG 22T1	LYNG 22A	21.778	0	0	0	-0.04	0	0

Table 12:Transformer (3 winding)

Knutepunkt	Ytelse (MVA)	Flyt (MW)	Flyt (MVAr)	Belastning (%)	Tap (kW)	Tomgangstap (kW)	Spenning (kV)
VARD 132T2	70	0	0	0	0	0	0
VARD 66T2	70	0	0	0	0	0	0
VARD 22T2	70	0	0	0	0	0	0
VARD 132T1	70	0,083	-3,738	4,9	47,15	47,15	144,365
VARD 66T1	70	-0,036	3,758	4,9	0	0	0
VARD 11T1	70	0	0	0	0	0	0
GUO-132-T1.3	30	-29,988	16,691	113,6	231,518	26,995	140,943
GUO-7A	15	15,11	-5,828	108	0	0	0
GUO-7B	15	15,11	-5,828	108	0	0	0
GUO-132-T1.3	30	-28,999	4,777	97,3	193,179	26,995	140,943
GUO-7A	15	14,596	-0,347	97,4	0	0	0
GUO-7B	15	14,596	-0,347	97,4	0	0	0
GUO-132-T1.3	30	-30,265	16,861	114,7	235,404	26,995	140,943
GUO-7A	15	15,25	-5,889	109,1	0	0	0
GUO-7B	15	15,25	-5,889	109,1	0	0	0
KVAN 132T1	25	0	0	0	0	0	140,314
KVÆN-10B	25	0	0	0	0	0	0
KVÆN-10A	25	0	0	0	0	0	0
KVAN 132T4	25	-14,54	13,775	75,4	284,017	0	140,314
KVÆN-66A	12,5	14,824	-12,383	150,7	0	0	0
KVÆN-H2	12,5	0	0	0	0	0	0
HUNG 66T2	30	0,345	7,116	22,3	39,036	31,066	68,543
HUNG 22T2	30	-0,306	-6,976	23,3	0	0	0
HUNG 11T2	30	0	0	0	0	0	0

Table 13:Transformer (2 Winding)

Knutepkt 1	Knutepkt 2	Ytelse (MVA)	Spg (kV)	Flyt (MW)	Flyt (MVAr)	Tap (kW)	Tap (kVAr)		Tomgangstap (kW)	Belastning (%)
SN-BALS-132A	SN-BALS-420A	300	420	95,424	20,326	101,14	4424,93	101,14	-2	32
CHAR 132T3	CHAR 66T3	120	144,329	0,157	-0,983	61,47	0,91	61,46	3,34	1
SKIB 132T1	SKIB 10T1	80	141,379	0,056	0	56,39	0	56,39	-5	0
HUNG 132T4	HUN-66AB-T4	70	144,168	0,279	2,982	33,36	11,64	33,01	5,55	4
KVA-132B-T1	KVA-66-T1-N	60	144,412	0,1	-3,323	30,19	20,82	29,58	0	5
FAK-66A-T1	FAK-22-T1	60	70,979	0,025	0	25,33	0	25,33	10	0
KVA-132B-T2	KVA-66-T2-N	50	144,412	0,077	-2,799	54,44	17,53	53,88	0	5
HUNG 22T1	HUNG 66T1	50	68,545	0,306	6,976	23,55	120,4	20,03	10,5	15
STVN 66AY	STVN 11T2	50	68,545	0,017	0	17,2	0	17,2	12	0
HUNG 132T5	HUN-66AB-T5	45	144,168	0,033	-2,315	42,53	11,33	42,12	1,85	5
HUN-66AB-T3	HUNG 132T3	45	144,168	0,116	3,992	50,62	33,75	49,08	1,85	9
CHAR 66T2	CHAR 11T2	35	69,895	0,03	0	30,04	0	30,04	9	0
CHAR 66T1	CHAR 11T1	35	69,895	0,03	0	29,92	0	29,92	9	0
STVN 66AX	STVN 11T1	35	68,545	0,014	0	13,99	0	13,99	9	0
LYNG 132T1	LYNG 22T1	25	141,683	0,019	0	18,93	0	18,93	13,36	0
ULLS 132A	ULLS 22 T1	25	142,255	0,014	0	14,29	0	14,29	11,76	0
KROK 66T2	KROK 22T2	25	68,564	0,013	0	10,57	0	10,57	7	0
SENT 66T2	SENT 11T2	25	69,897	0,018	0	17,84	0	17,84	6	0
SENT 66T1	SENT 11T1	25	69,897	0,018	0	17,68	0	17,68	6	0
GIML 66T2	GIML 11T2	25	72,579	0,018	0	17,74	0	17,74	9	0
GIML 66T1	GIML 11T1	25	72,579	0,018	0	17,56	0	17,56	9	0
KROK 66T1	KROK 22T1	25	68,564	0,013	0	15,52	0	15,52	7	0
SKIB 132T2	SKIB 22T2	20	141,379	0,02	0	20,32	0	20,32	7	0
SMÅV-G1	SMÅ-66A	20	67,486	15	-11,076	85,18	1266,19	0	0	93
KVA-66AB-T11	KVA-22AB-T11	20	70,025	0,015	0	14,59	0	14,59	7	0
KVA-66AB-T12	KVA-22AB-T12	20	70,025	0,014	0	13,94	0	13,94	7	0
BREN 132A	BREN 22T1	20	144,573	0,012	0	12,26	0	12,26	10	0
SAND 132T2	SAND 22T2	20	143,82	0,017	0	17,34	0	17,34	10,02	0
GUOL 132T4	GUO-22A-T4	10	140,943	0,02	0	20,28	0	20,28	4	0
RING 66T2	RING 22T2	10	70,761	0,01	0	9,85	0	9,85	7	0
RING 66T1	RING 22T1	10	70,761	0,01	0	10,13	0	10,13	7	0
LASS-66A	LASS-G1	8,5	67,487	0	0	0	0	0	0	0

GUO-7A	GUO-0.23A	0,2	6,995	0	0	0	0	0	-5	0

From above Table 10 and Table 11, it can be seen the over voltage on buses by belastning/ percentage stress throughout lines.

5.1.2 MATLAB Part:

After the load flow analysis this data is exported to MATLAB in the form of .csv of file to check stability criteria PV curves. Our Simulation Model is made specific to represent the problem and on which data is tested to check the stability.

5.1.2.1 PV Nose Curve:

Using the mathematical model in section 3.1 the voltage instability has been done.

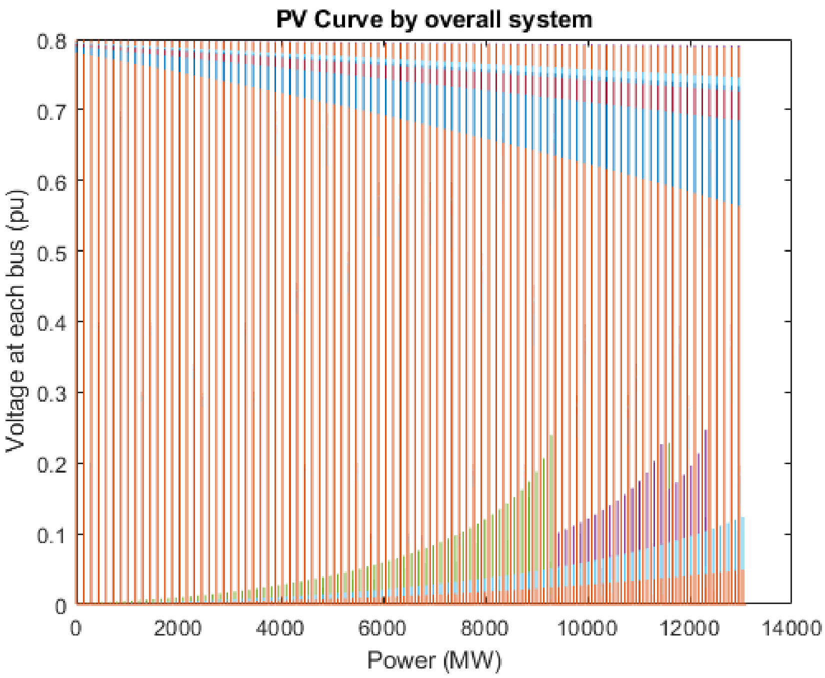

Figure 22:PV curve analysis by all bus in array

5.1.2.2 Voltage Stability Index

After the voltage stability curve, the approximated amount of load from section 3.10 has been shut to check the possibility of making the system stable. Using the mathematical model in section 3.3 the voltage instability indicators are used and compared among each other to get better observation:

Table 14: Voltage Stability Indicator

Line Stability Factor	Fast Voltage Stability Index	Line Stability Index
0.2990	0.2146	0.3269
0.1532	0.0563	0.1675
0.0650	0.0101	0.0711
0.0122	0.0003	0.0134
0.1656	0.0632	0.1810
0.0828	0.0158	0.0905
0.0319	0.0023	0.0349
0.0468	0.0048	0.0511
0.0409	0.0145	0.0448
0.0494	0.0054	0.0540
0.1055	0.0267	0.1153
0.1046	0.0261	0.1143
0.0301	0.0022	0.0329
0.0945	0.0214	0.1033
0.2453	0.1442	0.2682
0.0521	0.0064	0.0570
0.1121	0.0301	0.1225
0.1084	0.0282	0.1185
0.3747	0.3369	0.4097
0.2990	0.2146	0.3269
0.1279	0.0382	0.1398
0.0670	0.0108	0.0733
0.2761	0.1781	0.3019
0.0774	0.0139	0.0847

0.0756	0.0132	0.0826
0.1794	0.0739	0.1961
0.0604	0.0088	0.0660
0.1302	0.0389	0.1423
0.1487	0.0508	0.1626
0.2438	0.1365	0.2665
0.0754	0.0134	0.0825
0.1227	0.0343	0.1341
0.0586	0.0546	0.0640
0.2499	0.1424	0.2732
0.1311	0.0396	0.1433
0.1446	0.0488	0.1581
0.0595	0.0158	0.0650
0.0773	0.0132	0.0845
0.1319	0.0385	0.1442
0.2397	0.1377	0.2620
0.0508	0.0063	0.0555
0.1768	0.0738	0.1933
0.1510	0.0547	0.1651
0.1158	0.0321	0.1266
0.1907	0.0873	0.2085
0.3787	0.3441	0.4141
0.0156	0.0006	0.0171
0.0762	0.0134	0.0833
0.2177	0.1130	0.2380
0.0411	0.0041	0.0449

0.0144	0.0005	0.0158
0.0575	0.0092	0.0629
0.1625	0.0633	0.1777
0.2576	0.1638	0.2816
0.0828	0.0152	0.0905
0.0928	0.0206	0.1014
0.0747	0.0133	0.0816
0.2806	0.1888	0.3068
0.2070	0.1028	0.2263
0.3763	0.3300	0.4114
0.2577	0.1547	0.2818
0.1382	0.0445	0.1510
0.2079	0.1032	0.2273
0.1947	0.0907	0.2129
0.2898	0.2030	0.3168
0.0958	0.0220	0.1048
0.4953	0.5650	0.5415
0.4953	0.5650	0.5415
0.2852	0.2027	0.3118
0.0774	0.0148	0.0847
0.1153	0.0329	0.1261
0.2101	0.1091	0.2297

By comparing the result of indicator, it can be concluded that FVSI has been outperformed as compared to other voltage indicators.

6 Conclusion

During the study and comparing the load shedding approaches with each other and current infra structure to adopt the temporary load shedding scheme for Tromsøya several steps have been studies and recombined the workflow that includes, the newton Raphson for load flow with combination forward voltage stability index (FVSI) limit to indicate stability and Radio mesh communication has been recommended to perform the temporary load shedding with a set of pre-planned conditions in the system.

Human Activity recognition (HAR) can be adopted to detect the operation of heating systems in households and the stability has been tested upon gradual increase in load to check fast and optimal response to detect the bus. The bus number/name determines the amount and exact location. In implementation the SCADA system will be used to train, monitor and operations of whole system.

6.1 Future Work Expansion

There are further steps that can be considered in improving the system to get near real time observations and implementations:

- Load Modelling should be designed for every nature of load i.e., inductive etc. and HAR controller should be trained accordingly to overall optimize the system for every type of load response on grid.
- Stability indicators should be upgraded for better performance in real time system analysis as during the workflow fault may occurs in the system i.e., short circuit fault, etc.
- Optimization of load flow analysis to get minimum amount of load shedding via algorithm at fast convergence and response
- Several approaches need to be studied for better communication and increase consumer security and reliability for utility.

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8 APPENDIX

According to limitations, Due to security issues some data has been restricted by Arva and some data has not been detected due to old version of NetBas.

8.1 Data:

The bus data constitutes of all the buses include slack, generator and transformer associated.

```
%          |Bus | Type | Vsp | theta | PGi |  QGi | PLi |  Li |  Qmin |  Qmax |
busdat1=[
       1  ,          1,     1.00000,       0.0,  -95.323,  -15.901,     0.0,     0.0,
999.0,    -999.0; %SN-BALS- 420.000
       2  ,          3,     1.08234,    3.4667,      0.0,      0.0,     0.0,     0.0,
0.0,       0.0; %SN-MEST- 132.000
       3  ,          1,     1.08234,    3.4668,      3.0,     88.0,     0.0,    -0.8,
50.0,     -17.0; %MEST-132 132.000
       4  ,          0,     1.08581,    3.8832,     41.0,     21.0,    40.0,    -1.0,
60.0,     -10.0; %MIDD1     132.000
       5  ,          0,     1.08599,    3.9022,      0.0,      0.0,     0.0,     0.0,
0.0,       0.0; %SEL1      132.000
       6  ,          0,     1.08684,    4.0349,     13.0,      4.0,     0.0,     0.0,
0.0,       0.0; %KGR-MES/ 132.000
       7  ,          0,     1.08829,    4.2654,     75.0,      2.0,     0.0,     0.8,
25.0,      -8.0; %RAM1      132.000
       8  ,          0,     1.08924,    4.3691,      0.0,      0.0,     0.0,     0.0,
0.0,       0.0; %RAM2      132.000
       9  ,          0,     1.08954,    4.4182,    150.0,     22.0,   450.0,    62.1,
200.0,    -140.0; %AVGR-132 132.000
       10 ,          0,     1.09218,    4.8680,    121.0,     26.0,     0.0,     2.2,
9.0,      -3.0; %HUNG 132 132.000
       11 ,          3,     1.09218,    4.8681,      5.0,      2.0,     0.0,     0.0,
0.0,       0.0; %HUNG 132 132.000
       12 ,          1,     1.09219,    4.8685,      0.0,      0.0,     0.0,     0.0,
0.0,       0.0; %HUNG 132 132.000
       13 ,          3,     1.07769,   10.1063,    377.0,     24.0,   310.0,   128.5,
155.0,    -150.0; %ULLS 132 132.000
       14 ,          1,     1.07769,   10.1067,     18.0,      2.3,     0.0,     0.0,
0.0,       0.0; %ULLS 132 132.000
       15 ,          1,     1.07770,   10.1071,     10.5,      5.3,     0.0,     0.0,
0.0,       0.0; %ULLS 132 132.000
       16 ,          1,     1.07549,   11.2400,     22.0,      5.0,     0.0,     0.0,
0.0,       0.0; %KGR-ULL/ 132.000
       17 ,          3,     1.07336,   12.5432,     43.0,      3.0,     0.0,     0.0,
0.0,       0.0; %LYNG 132 132.000
       18 ,          3,     1.07336,   12.5445,     42.0,      8.0,     0.0,     0.0,
0.0,       0.0; %LYNG 132 132.000
       19 ,          3,     1.07336,   12.5445,     27.2,      9.8,     0.0,     0.0,
0.0,       0.0; %LYNG 132 132.000
       20 ,          1,     0.98989,   12.5397,      3.3,      0.6,     0.0,     0.0,
0.0,       0.0; %LYNG 22T  22.000
       21 ,          3,     0.98989,   12.5397,      2.3,      1.0,     0.0,     0.0,
0.0,       0.0; %LYNG 22A  22.000
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0.0,
        22 ,          1,     0.98989,    12.5397,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %LYNG 22P   22.000
        23 ,          1,     1.07336,    12.5449,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %LYNG 132 132.000
        24 ,          3,     1.07307,    12.7499,        6.3,        2.1,       0.0,       0.0,
0.0,        0.0; %KVIT      132.000
        25 ,          3,     1.07344,    12.8566,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %NORD      132.000
        26 ,          1,     1.06766,    16.4612,        6.3,        3.2,       0.0,       0.0,
0.0,        0.0; %LY-INKA- 132.000
        27 ,          1,     1.06774,    16.4902,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %GUOL 132 132.000
        28 ,          1,     1.06774,    16.4906,        9.3,        0.5,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        29 ,          1,     1.06775,    16.4910,        4.6,        2.3,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        30 ,          3,     1.06775,    16.4910,       17.0,        2.6,       0.0,       0.0,
0.0,        0.0; %GUO-132B 132.000
        31 ,          3,     1.06775,    16.4910,        3.6,        1.8,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        32 ,          1,     1.06775,    16.4911,        5.8,        2.9,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        33 ,          1,     1.06775,    16.4911,        1.6,        0.8,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        34 ,          1,     1.06775,    16.4910,        3.8,        1.9,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        35 ,          1,     1.06775,    16.4914,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %GUO-132A 132.000
        36 ,          3,     1.06775,    16.4910,        6.0,        3.0,       0.0,       0.0,
0.0,        0.0; %GUOL 132 132.000
        37 ,          1,     1.07105,    16.4442,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %SKIB 132 132.000
        38 ,          1,     1.07105,    16.4441,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %SKIB 132 132.000
        39 ,          1,     1.07105,    16.4441,       14.0,        7.0,       0.0,       0.0,
0.0,        0.0; %SKIB 132 132.000
        40 ,          1,     1.06300,    16.4408,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %SKIB 10T   10.000
        41 ,          1,     1.06300,    16.4408,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %SKI-10-G   10.000
        42 ,          1,     1.07105,    16.4441,        6.3,        3.0,       0.0,       0.0,
0.0,        0.0; %SKIB 132 132.000
        43 ,          1,     1.00098,    16.4391,        7.1,        4.4,       0.0,       0.0,
0.0,        0.0; %SKIB 22T   22.000
        44 ,          1,     1.07105,    16.4441,        2.0,        1.0,       0.0,       0.0,
0.0,        0.0; %SKIB 132 132.000
        45 ,          1,     1.07348,    16.4122,       12.0,        1.8,       0.0,       0.0,
0.0,        0.0; %BALS-132 132.000
        46 ,          3,     1.07591,     2.5666,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %SN-BALS- 132.000
        47 ,          1,     1.06775,    16.4911,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %GUOL 132 132.000
        48 ,          1,     1.06624,    16.7670,       29.7,       11.6,       0.0,       0.0,
0.0,        0.0; %NORDR-GU 132.000
        49 ,          3,     1.06624,    16.7670,        0.0,        0.0,       0.0,       0.0,
0.0,        0.0; %NORDR-13 132.000
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       50 ,          1,     1.06624,    16.7671,      18.0,       8.5,       0.0,       0.0,
0.0,       0.0; %NORDR-KV 132.000
       51 ,          1,     1.06299,    17.1712,      21.0,      10.5,       0.0,       0.0,
0.0,       0.0; %KVAN 132 132.000
       52 ,          3,     1.06299,    17.1713,      18.0,       5.3,       0.0,       0.0,
0.0,       0.0; %KVÆN-132 132.000
       53 ,          1,     1.06299,    17.1712,       4.9,       2.2,       0.0,       0.0,
0.0,       0.0; %KVAN 132 132.000
       54 ,          1,     1.06624,    16.7671,      20.0,      10.0,       0.0,       0.0,
0.0,       0.0; %NORDR-KV 132.000
       55 ,          1,     1.06624,    16.7670,       4.1,       1.4,       0.0,       0.0,
0.0,       0.0; %NORDR-GU 132.000
       56 ,          1,     1.06775,    16.4911,       6.8,       3.4,       0.0,       0.0,
0.0,       0.0; %GUOL 132 132.000
       57 ,          1,     1.06775,    16.4910,       7.6,       2.2,       0.0,       0.0,
0.0,       0.0; %GUOL 132 132.000
       58 ,          3,     0.98920,    16.4833,       6.7,       2.0,       0.0,       0.0,
0.0,       0.0; %GUO-22A-   22.000
       59 ,          1,     0.98920,    16.4833,      51.0,      27.0,       0.0,       0.0,
-5.0,      15.0; %GUO-22A    22.000
       60 ,          3,     1.06775,    16.4918,      20.0,       9.0,       0.0,       0.0,
0.0,       0.0; %GUO-132- 132.000
       61 ,          3,     0.99933,    24.4807,      39.0,      10.0,       0.0,       0.0,
0.0,       0.0; %GUO-7A      7.000

       62 ,          1,     0.99933,    24.4856,      30.0,      12.0,      -9.0,       0.0,
- 300.0,     300.0; %GUO-7B      7.000
       63 ,          1,     1.00000,    24.5523,      45.0,   -12.019,       0.0,     -0.40,
16.0,      -10.0; %GUO-7B-G    7.000

       64 ,          2,     1.00000,    24.5474,      45.0,    12.020,       0.0,       0.0,
16.0,      -10.0; %GUO-7A-G    7.000
       65 ,          3,     1.05192,    24.4807,      19.0,       2.0,       0.0,       0.0,
0.0,       0.0; %GUO-0.23    0.230
       66 ,          1,     1.06299,    17.1713,       0.0,       0.0,     -28.0,       0.0,
-300.0,     300.0; %KVAN 132 132.000
       67 ,          1,     1.06299,    17.1713,       0.0,       0.0,       0.0,       0.0,
0.0,       0.0; %KVAN 132 132.000
       68 ,          1,     1.06299,    17.1714,       0.0,       0.0,     450.0,       0.0,
-147.0,     200.0; %KVAN 132 132.000
       69 ,          1,     1.02514,    20.7493,      70.0,      23.0,       0.0,       0.0,
0.0,       0.0; %KVÆN-66A   66.000
       70 ,          1,     1.04355,    18.9279,      47.0,      10.0,      85.0,       0.0,
-35.0,     120.0; %KVÆN-H2    22.000
       71 ,          1,     1.04355,    18.9279,      34.0,      16.0,       0.0,       0.0,
0.0,       0.0; %KVÆN-CÅR   22.000
       72 ,          1,     1.02514,    20.7496,      14.0,       1.0,       0.0,       0.0,
0.0,       0.0; %KVAN 66S   66.000
       73 ,          1,     1.02252,    21.3477,      90.0,      30.0,       0.0,       0.0,
-10.0,      30.0; %SMÅVATNA   66.000
       74 ,          3,     1.02253,    21.3469,      25.0,      10.0,       0.0,       0.0,
0.0,       0.0; %LASS-66A   66.000
       75 ,          3,     1.14209,    21.3469,      11.0,       3.0,       0.0,       0.0,
0.0,       0.0; %LASS-G1     3.000
       76 ,          3,     1.02252,    21.3481,      60.0,      34.0,       0.0,       0.0,
-16.0,      50.0; %SMÅ-66A    66.000
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       77 ,         2,     1.00000,    24.5140,       15.0,   -11.076,       0.0,       0.0,
9.60,     -9.600; %SMÅV-G1     5.000
       78 ,         1,     1.06299,    17.1713,       18.0,       3.0,       0.0,       0.0,
0.0,       0.0; %KVAN 132 132.000
       79 ,         3,     0.96635,    17.1713,       14.0,       8.0,       0.0,       0.0,
0.0,       0.0; %KVÆN-10B  11.000
       80 ,         3,     0.96635,    17.1713,       10.0,       5.0,       0.0,       0.0,
0.0,       0.0; %KVÆN-10A  11.000
       81 ,         1,     1.00812,    10.1035,        7.0,       3.0,       0.0,       0.0,
0.0,       0.0; %ULLS 22    22.000
       82 ,         3,     1.00812,    10.1035,        0.0,       0.0,     -13.0,       0.0,
-300.0,     300.0; %ULLS 22A  22.000
       83 ,         3,     1.00000,     0.0000,        0.0,       0.0,     220.0,       0.0,
-47.0,      140.0; %HUNG 132 132.000
       84 ,         1,     1.09218,     4.8681,        0.0,       0.0,     314.0,       0.0,
-1000.0,    1000.0; %HUNG 132 132.000
       85 ,         1,     1.03854,     4.8540,       62.0,      13.0,      -9.0,       0.0,
-300.0,     300.0; %HUN-66AB  66.000
       86 ,         1,     1.03855,     4.8540,       17.0,       7.0,       0.0,       0.0,
0.0,       0.0; %HUN-66AB  66.000
       87 ,         3,     1.03855,     4.8540,       24.0,       4.0,       0.0,       0.0,
0.0,       0.0; %HUNG 66A  66.000
       88 ,         3,     1.00000,     0.0000,        0.0,       0.0,       0.0,       0.0,
0.0,       0.0; %HUN-66AB  66.000
       89 ,         3,     1.03855,     4.8540,       43.0,      27.0,       7.0,       0.0,
-300.0,     300.0; %HUNG 66B  66.000
       90 ,         1,     1.03854,     4.8540,       59.0,      23.0,       0.0,       0.0,
-14.0,      -42.0; %HUN-66AB  66.000
       91 ,         1,     1.03855,     4.8539,       23.0,       9.0,       0.0,       0.0,
0.0,       0.0; %HUN-66AB  66.000
       92 ,         1,     1.03855,     4.8539,       59.0,      26.0,       0.0,     -0.14,
-8.0,      24.0; %HUN-66AB  66.000
       93 ,         1,     1.03853,     4.8546,       33.0,       9.0,       0.0,       0.0,
0.0,       0.0; %HUN-66T2  66.000
       94 ,         1,     1.03856,     4.8534,       31.0,      17.0,       0.0,       0.0,
-8.0,      24.0; %HUN-66T1  66.000
       95 ,         1,     1.03855,     4.8540,        0.0,       0.0,       0.0,      0.25,
0.0,       0.0; %HUN-66AB  66.000
       96 ,         1,     1.03855,     4.8539,        0.0,       0.0,       0.0,       0.0,
0.0,       0.0; %HUNG 66K  66.000
       97 ,         1,     1.03885,     4.8489,       27.0,      11.0,       0.0,       0.0,
0.0,       0.0; %KROK 66H  66.000
       98 ,         3,     1.03885,     4.8489,       20.0,      23.0,     -46.0,       0.0,
-300.0,     300.0; %KROK 66A  66.000
       99 ,         1,     1.03885,     4.8489,       37.0,      10.0,       0.0,       0.0,
0.0,       0.0; %KROK 66T  66.000
       100,         1,     1.09973,     4.7961,       37.0,      23.0,     -59.0,       0.0,
-300.0,     300.0; %KROK 66G  66.000
       101,         1,     1.03885,     4.8489,       18.0,       7.0,       0.0,       0.0,
0.0,       0.0; %KROK 66T  66.000
       102,         3,     1.03063,     4.8453,       16.0,       8.0,       0.0,     -0.10,
0.0,       0.0; %KROK 22T  22.000
       103,         1,     1.03063,     4.8453,       53.0,      22.0,       0.0,     -0.10,
0.0,       0.0; %KROK 22A  22.000
       104,         1,     1.03063,     4.8453,       28.0,      10.0,      19.0,     -0.10,
-100.0,     100.0; %KROK 22P  22.000
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       105,        1,    1.09973,    4.7961,     34.0,       0.0,      0.0,      0.0,
0.0,       0.0; %#68361    66.000
       106,        1,    1.09973,    4.7961,     20.0,      11.0,      0.0,    -0.15,
0.0,       0.0; %KROK      66.000
       107,        1,    1.09971,    4.7984,     87.0,      30.0,    204.0,      0.0,
-85.0,     210.0; %GIM       66.000
       108,        1,    1.09968,    4.8016,     17.0,       4.0,      0.0,      0.0,
0.0,       0.0; %GIML 66K  66.000
       109,        3,    1.09968,    4.8016,     17.0,       8.0,      0.0,      0.0,
0.0,       0.0; %GIML 66A  66.000
       110,        1,    1.06112,    4.7146,     18.0,       5.0,      0.0,      0.0,
0.0,       0.0; %GIML 66K  66.000
       111,        1,    1.06099,    4.7193,     23.0,      11.0,      0.0,      0.0,
0.0,       0.0; %KVA-66AB  66.000
       112,        3,    1.00000,    0.0000,    113.0,      32.0,     48.0,      0.0,
-300.0,     300.0; %KVA-66A   66.000
       113,        3,    1.06099,    4.7193,     63.0,      22.0,      0.0,      0.0,
-8.0,      23.0; %KVA-66B   66.000
       114,        3,    1.06099,    4.7194,     84.0,      18.0,      0.0,      0.0,
-8.0,      15.0; %KVA-66AB  66.000
       115,        1,    1.06098,    4.7194,     12.0,       3.0,      0.0,      0.0,
0.0,       0.0; %KVA-66-T  66.000
       116,        3,    1.09403,    4.7406,     12.0,       3.0,      0.0,      0.0,
0.0,       0.0; %KVA-132B 132.000
       117,        3,    1.09403,    4.7406,    277.0,     113.0,    155.0,      0.0,
-60.0,     180.0; %KVA-132- 132.000
       118,        1,    1.09403,    4.7406,     78.0,       3.0,      0.0,      0.0,
0.0,       0.0; %KVA-132B 132.000
       119,        3,    1.09403,    4.7406,      0.0,       0.0,    160.0,      0.0,
-100.0,     300.0; %KVA-132B 132.000
       120,        3,    1.06098,    4.7194,     77.0,      14.0,      0.0,      0.0,
-20.0,      20.0; %KVA-66-T  66.000
       121,        0,    1.06099,    4.7194,      0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %KVA-66AB  66.000
       122,        1,    1.06099,    4.7193,      0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %KVA-66AB  66.000
       123,        1,    1.06100,    4.7191,      0.0,       0.0,    391.0,      0.0,
-67.0,     200.0; %RI-INKA-   66.000
       124,        3,    1.06551,    4.5970,     39.0,      18.0,    392.0,      0.0,
-67.0,     200.0; %KVA-DEL1   66.000
       125,        3,    1.06558,    4.5951,     28.0,       7.0,      0.0,      0.0,
0.0,       0.0; %KVALS1    66.000
       126,        3,    1.06579,    4.5916,      0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %KVA-DEL2  66.000
       127,        1,    1.06857,    4.5161,      0.0,       0.0,    516.4,      0.0,
-300.0,     300.0; %KGR-KVA/   66.000
       128,        1,    1.07214,    4.4193,     66.0,      20.0,      0.0,      0.0,
-10.0,      32.0; %RING 66K   66.000
       129,        3,    1.07214,    4.4193,      0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %RING 66A  66.000
       130,        1,    1.07214,    4.4193,      0.0,       0.0,    -12.0,      0.0,
-100.0,     100.0; %RING 66T   66.000
       131,        1,    1.07214,    4.4193,      0.0,       0.0,     -6.0,      0.0,
-100.0,     100.0; %RING 66T   66.000
       132,        1,    1.06365,    4.4156,     68.0,      27.0,      0.0,    -0.12,
-6.0,       9.0; %RING 22T   22.000
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        133,        1,     1.06365,     4.4154,      47.0,      11.0,      0.0,      0.0,
0.0,       0.0; %RING 22T   22.000
        134,        1,     1.07214,     4.4192,      68.0,      36.0,      0.0,      0.0,
-8.0,      23.0; %RING 66F   66.000
        135,        1,     1.07469,     4.3912,      61.0,      28.0,      0.0,      0.0,
-20.0,      70.0; %HESSFJ.   66.000
        136,        1,     1.07503,     4.3864,      71.0,      26.0,      0.0,      0.0,
0.0,       0.0; %FAKK.      66.000
        137,        1,     1.07544,     4.3807,      39.0,      32.0,      0.0,    -0.20,
0.0,       0.0; %FAK-132.   66.000
        138,        3,     1.07544,     4.3806,     130.0,      26.0,    477.0,      0.0,
-165.0,     280.0; %FAK-66A   66.000
        139,        1,     1.07544,     4.3806,       0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %FAK-66A-   66.000
        140,        3,     0.97767,     4.3776,      54.0,      27.0,      0.0,    -0.20,
0.0,       0.0; %FAK-22-T   22.000
        141,        3,     0.97767,     4.3776,      20.0,      10.0,      0.0,    -0.10,
0.0,       0.0; %FAK-22AX   22.000
        142,        1,     0.97767,     4.3776,      11.0,       7.0,      0.0,      0.0,
0.0,       0.0; %FAK-22-P   22.000
        143,        3,     1.06573,     4.5915,      24.0,      15.0,      0.0,      0.0,
-8.0,      23.0; %KVALT2     66.000
        144,        3,     1.06568,     4.5940,      21.0,      10.0,      0.0,      0.0,
0.0,       0.0; %KVALT1     66.000
        145,        3,     1.00000,     0.0000,       0.0,       0.0,      4.0,      0.0,
-100.0,    1000.0; %KVA-66AB   66.000
        146,        1,     1.06099,     4.7193,      48.0,      10.0,      0.0,      0.0,
0.0,       0.0; %KVA-66AB   66.000
        147,        1,     1.05259,     4.7157,       0.0,       0.0,    607.0,      0.0,
-210.0,     300.0; %KVA-22AB   22.000
        148,        1,     1.05259,     4.7157,      78.0,      42.0,    -85.0,      0.0,
-300.0,     300.0; %#95152     22.000
        149,        1,     1.05259,     4.7157,       0.0,       0.0,    -10.0,      0.0,
-100.0,     100.0; %KVA-22AB   22.000
        150,        3,     1.06099,     4.7193,      65.0,      10.0,      0.0,      0.0,
-3.0,       9.0; %KVA-66AB   66.000
        151,        1,     1.05259,     4.7160,      12.0,       7.0,      0.0,      0.0,
0.0,       0.0; %KVA-22AB   22.000
        152,        1,     1.05259,     4.7160,      30.0,      16.0,      0.0,      0.0,
0.0,       0.0; %#95208     22.000
        153,        1,     1.06098,     4.7194,      42.0,      31.0,      0.0,      0.0,
0.0,       0.0; %KVA-66-P   66.000
        154,        3,     1.09403,     4.7405,      38.0,      15.0,      0.0,      0.0,
0.0,       0.0; %KVA-132- 132.000
        155,        3,     1.09403,     4.7324,      15.0,       9.0,      0.0,      0.0,
0.0,       0.0; %KVAL- M9 132.000
        156,        3,     1.09392,     4.3902,      34.0,       8.0,      0.0,      0.0,
0.0,       0.0; %HAKO-132 132.000
        157,        3,     1.09392,     4.3901,       0.0,       0.0,    -42.0,      0.0,
- 100.0,     100.0; %#440548  132.000
        158,        3,     1.09392,     4.3898,      37.0,      18.0,    252.0,      0.0,
-50.0,     155.0; %HAKO 132 132.000
        159,        3,     1.09392,     4.3898,      22.0,      15.0,      0.0,      0.0,
0.0,       0.0; %HAKO-132 132.000
        160,        3,     1.09521,     4.3797,       5.0,       3.0,      0.0,      0.0,
0.0,       0.0; %TVERR132 132.000
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        161,        3,     1.09521,     4.3797,      23.0,      16.0,     40.0,      0.0,
-15.0,      40.0; %#443365  132.000
        162,        0,     1.09521,     4.3797,      38.0,      25.0,      0.0,      0.0,
-8.0,      23.0; %TVERR 13 132.000
        163,        3,     1.09521,     4.3797,      31.0,      26.0,      0.0,    -0.20,
-8.0,      23.0; %#443357  132.000
        164,        3,     1.00000,     0.0000,      43.0,      16.0,      0.0,      0.0,
0.0,       0.0; %TVERR 13 132.000
        165,        3,     1.09521,     4.3797,      28.0,      12.0,    -22.0,    -0.06,
-200.0,     200.0; %TVERR132 132.000
        166,        3,     1.09525,     4.3794,       2.0,       1.0,      0.0,      0.0,
0.0,       0.0; %BREN 132 132.000
        167,        3,     0.99568,     4.3759,       8.0,       3.0,      0.0,      0.0,
0.0,       0.0; %BREN 22T  22.000
        168,        3,     0.99568,     4.3759,      39.0,      30.0,      0.0,    -0.06,
-8.0,      23.0; %BREN 22A  22.000
        169,        3,     0.99568,     4.3759,       0.0,       0.0,     36.0,      0.0,
-100.0,    1000.0; %BREN P1   22.000
        170,        3,     1.09521,     4.3797,      25.0,      13.0,    -43.0,      0.0,
-100.0,    1000.0; %#443358  132.000
        171,        3,     1.09521,     4.3797,       0.0,       0.0,     -6.0,      0.0,
-100.0,     200.0; %TVERR132 132.000
        172,        3,     1.09521,     4.3797,       8.0,       3.0,      0.0,      0.0,
0.0,       0.0; %#443360  132.000
        173,        3,     1.09521,     4.3797,      22.0,       7.0,      0.0,      0.0,
0.0,       0.0; %TVERR132 132.000
        174,        3,     1.09521,     4.3797,       0.0,       0.0,    184.0,      0.0,
-1000.0,    1000.0; %#443363  132.000
        175,        3,     1.09521,     4.3797,      20.0,       8.0,      0.0,      0.0,
0.0,       0.0; %TVERR132 132.000
        176,        0,     1.00000,     0.0000,      33.0,      15.0,      0.0,      0.0,
0.0,       0.0; %#443387  132.000
        177,        1,     1.09392,     4.3896,       0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %#440550  132.000
        178,        1,     1.09391,     4.3895,       3.0,      88.0,      0.0,     -0.8,
50.0,     -17.0; %HAKO-132 132.000
        179,        1,     1.09276,     4.2117,      41.0,      21.0,     40.0,     -1.0,
60.0,     -10.0; %LARS     132.000
        180,        1,     1.09243,     4.2037,       0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %VIK      132.000
        181,        1,     1.08812,     3.8803,      13.0,       4.0,      0.0,      0.0,
0.0,       0.0; %KGR-MES/ 132.000
        182,        1,     1.08234,     3.4668,      75.0,       2.0,      0.0,      0.8,
25.0,      -8.0; %MEST-132 132.000
        183,        1,     1.08234,     3.4668,       0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %MEST-132 132.000
        184,        0,     1.08571,     3.8790,     150.0,      22.0,    450.0,     62.1,
200.0,    -140.0; %MIDD2    132.000
        185,        0,     1.08602,     3.8987,     121.0,      26.0,      0.0,      2.2,
9.0,      -3.0; %SEL2     132.000
        186,        0,     1.08708,     4.0597,       5.0,       2.0,      0.0,      0.0,
0.0,       0.0; %KGR-MES/ 132.000
        187,        1,     1.08940,     4.4157,       0.0,       0.0,      0.0,      0.0,
0.0,       0.0; %AVGR-132 132.000
        188,        1,     1.09218,     4.8680,     377.0,      24.0,    310.0,    128.5,
155.0,    -150.0; %HUNG 132 132.000
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       189,         1,     1.09218,     4.8681,      18.0,        2.3,       0.0,       0.0,
0.0,       0.0; %HUNG 132 132.000
       190,         1,     1.03855,     4.8539,      10.5,        5.3,       0.0,       0.0,
0.0,       0.0; %HUN-66AB   66.000
       191,         1,     1.03854,     4.8541,      22.0,        5.0,       0.0,       0.0,
0.0,       0.0; %HUN-66AB   66.000
       192,         1,     1.09218,     4.8681,      43.0,        3.0,       0.0,       0.0,
0.0,       0.0; %HUNG 132 132.000
       193,         1,     1.09218,     4.8679,      42.0,        8.0,       0.0,       0.0,
0.0,       0.0; %HUNG 132 132.000
       194,         1,     1.09340,     4.8127,      27.2,        9.8,       0.0,       0.0,
0.0,       0.0; %CHAR 132 132.000
       195,         1,     1.09340,     4.8125,       3.3,        0.6,       0.0,       0.0,
0.0,       0.0; %CHAR 132 132.000
       196,         1,     1.09340,     4.8125,       2.3,        1.0,       0.0,       0.0,
0.0,       0.0; %CHAR 132 132.000
       197,         1,     1.05901,     4.8035,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %CHAR 66T   66.000
       198,         3,     1.05901,     4.8034,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %CHAR 66C   66.000
       199,         3,     1.05901,     4.8034,       6.3,        2.1,       0.0,       0.0,
0.0,       0.0; %CHAR 66B   66.000
       200,         0,     1.00000,     0.0000,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %CHAR 66K   66.000
       201,         3,     1.05901,     4.8034,       6.3,        3.2,       0.0,       0.0,
0.0,       0.0; %CHAR 66A   66.000
       202,         3,     1.05901,     4.8034,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %CHAR 66S   66.000
       203,         3,     1.05904,     4.8031,       9.3,        0.5,       0.0,       0.0,
0.0,       0.0; %DRAM-66B   66.000
       204,         3,     1.05904,     4.8030,       4.6,        2.3,       0.0,       0.0,
0.0,       0.0; %SENT 66H   66.000
       205,         3,     1.05904,     4.8030,      17.0,        2.6,       0.0,       0.0,
0.0,       0.0; %#94430     66.000
       206,         3,     1.05904,     4.8030,       3.6,        1.8,       0.0,       0.0,
0.0,       0.0; %SEN-66B    66.000
       207,         3,     1.05904,     4.8030,       5.8,        2.9,       0.0,       0.0,
0.0,       0.0; %#94456     66.000
       208,         3,     1.05904,     4.8030,       1.6,        0.8,       0.0,       0.0,
0.0,       0.0; %SEN-66A    66.000
       209,         3,     1.05904,     4.8030,       3.8,        1.9,       0.0,       0.0,
0.0,       0.0; %#94464     66.000
       210,         3,     1.05904,     4.8030,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %#94455     66.000
       211,         3,     1.03857,     4.8525,       6.0,        3.0,       0.0,       0.0,
0.0,       0.0; %#182605    66.000
       212,         3,     1.05904,     4.8030,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %SENT 66T   66.000
       213,         3,     1.06268,     4.7992,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %SENT 11T   11.000
       214,         0,     1.00000,     0.0000,      14.0,        7.0,       0.0,       0.0,
0.0,       0.0; %SENT 11B   11.000
       215,         3,     1.06268,     4.7992,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %SENT 11A   11.000
       216,         3,     1.05904,     4.8030,       0.0,        0.0,       0.0,       0.0,
0.0,       0.0; %SENT 66C   66.000
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        217,         3,     1.05904,     4.8030,         6.3,         3.0,        0.0,        0.0,
0.0,        0.0; %SENT 66T   66.000
        218,         3,     1.06268,     4.7992,         7.1,         4.4,        0.0,        0.0,
0.0,        0.0; %SENT 11T   11.000
        219,         3,     1.05901,     4.8034,         2.0,         1.0,        0.0,        0.0,
0.0,        0.0; %CHAR 66T   66.000
        220,         3,     1.03340,     4.7997,        12.0,         1.8,        0.0,        0.0,
0.0,        0.0; %CHAR 11T   11.000
        221,         3,     1.03340,     4.7997,         0.0,         0.0,        0.0,        0.0,
0.0,        0.0; %CHAR 11A   11.000
        222,         3,     1.05901,     4.8034,         0.0,         0.0,        0.0,        0.0,
0.0,        0.0; %CHAR 66T   66.000
        223,         3,     1.03340,     4.7995,        29.7,        11.6,        0.0,        0.0,
0.0,        0.0; %CHAR 11T   11.000
        224,         3,     1.03340,     4.7995,         0.0,         0.0,        0.0,        0.0,
0.0,        0.0; %CHAR 11A   11.000
        225,         3,     1.09973,     4.7993,        18.0,         8.5,        0.0,        0.0,
0.0,        0.0; %CHAR 66G   66.000
        226,         3,     1.09968,     4.8016,        21.0,        10.5,        0.0,        0.0,
0.0,        0.0; %GIML 66C   66.000
        227,         3,     1.09968,     4.8016,        18.0,         5.3,        0.0,        0.0,
0.0,        0.0; %GIML 66T   66.000
        228,         3,     1.09968,     4.8016,         4.9,         2.2,        0.0,        0.0,
0.0,        0.0; %GIML 66T   66.000
        229,         3,     1.09968,     4.8016,        20.0,        10.0,        0.0,        0.0,
0.0,        0.0; %GIML 66V   66.000
        230,         3,     1.09968,     4.8016,         4.1,         1.4,        0.0,        0.0,
0.0,        0.0; %GIML 66B   66.000
        231,         3,     1.07308,     4.7978,         6.8,         3.4,        0.0,        0.0,
0.0,        0.0; %GIML 11T   11.000
        232,         3,     1.07308,     4.7978,         7.6,         2.2,        0.0,        0.0,
0.0,        0.0; %GIML 11A   11.000
        233,         3,     1.07308,     4.7979,         6.7,         2.0,        0.0,        0.0,
0.0,        0.0; %GIML 11T   11.000
        234,         3,     1.07308,     4.7979,        51.0,        27.0,        0.0,        0.0,
-5.0,        15.0; %GIML 11A   11.000
        235,         3,     1.09953,     4.8030,        20.0,         9.0,        0.0,        0.0,
0.0,        0.0; %VARD 66G   66.000
        236,         3,     1.09953,     4.8030,        39.0,        10.0,        0.0,        0.0,
0.0,        0.0; %VARD 66A   66.000
        237,         3,     1.09953,     4.8031,        30.0,        12.0,       -9.0,        0.0,
-300.0,       300.0; %VARD 66T   66.000
        238,         0,     1.09367,     4.8098,         0.0,         0.0,        0.0,      -0.40,
0.0,        0.0; %VARD 132 132.000
        239,         1,     1.10014,     4.8024,        52.0,        22.0,        0.0,        0.0,
-13.0,       50.0; %VARD 11T   11.000
        240,         1,     1.10014,     4.8024,        19.0,         2.0,        0.0,        0.0,
0.0,        0.0; %VARD 11T   11.000
        241,         1,     1.09367,     4.8098,         0.0,         0.0,      -28.0,        0.0,
-300.0,      300.0; %T1         132.000
        242,         0,     1.09367,     4.8099,         0.0,         0.0,        0.0,        0.0,
0.0,        0.0; %VARD 132 132.000
        243,         3,     1.09367,     4.8073,         0.0,         0.0,      450.0,        0.0,
-147.0,      200.0; %T2         132.000
        244,         3,     1.00000,     0.0000,        70.0,        23.0,        0.0,        0.0,
0.0,        0.0; %VARD 132 132.000
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       245,        3,     1.09367,     4.8073,      47.0,      10.0,     85.0,      0.0,
-35.0,      120.0; %VARD 132 132.000
       246,        3,     1.09367,     4.8035,      34.0,      16.0,      0.0,      0.0,
0.0,        0.0; %VARD 66T  66.000
       247,        3,     1.09367,     4.8031,      14.0,       1.0,      0.0,      0.0,
0.0,        0.0; %VARD 22T  22.000
       248,        3,     1.09367,     4.8031,      90.0,      30.0,      0.0,      0.0,
-10.0,       30.0; %VARD 22T  22.000
       249,        1,     1.09367,     4.8098,      25.0,      10.0,      0.0,      0.0,
0.0,        0.0; %VARD 132 132.000
       250,        1,     1.09367,     4.8099,      11.0,       3.0,      0.0,      0.0,
0.0,        0.0; %CH1      132.000
       251,        1,     1.09367,     4.8099,      60.0,      34.0,      0.0,      0.0,
-16.0,       50.0; %VARD 132 132.000
       252,        3,     1.09361,     4.8105,      45.0,      25.0,      0.0,      0.0,
-8.0,       24.0; %KRYSSKOB 132.000
       253,        1,     1.09340,     4.8125,      18.0,       3.0,      0.0,      0.0,
0.0,        0.0; %CHAR 132 132.000
       254,        1,     1.09340,     4.8124,      14.0,       8.0,      0.0,      0.0,
0.0,        0.0; %CHAR 132 132.000
       255,        1,     1.09403,     4.7407,      10.0,       5.0,      0.0,      0.0,
0.0,        0.0; %KVA-132- 132.000
       256,        1,     1.03854,     4.8541,       7.0,       3.0,      0.0,      0.0,
0.0,        0.0; %HUN-66T2  66.000
       257,        1,     1.03853,     4.8546,       0.0,       0.0,    -13.0,      0.0,
-300.0,      300.0; %HUN-66-T  66.000
       258,        1,     1.03853,     4.8546,       0.0,       0.0,    220.0,      0.0,
-47.0,      140.0; %HUNG 66T  66.000
       259,        3,     0.99986,     4.8643,       0.0,       0.0,    314.0,      0.0,
-1000.0,     1000.0; %HUNG 22T  22.000
       260,        1,     1.02307,     4.8906,      62.0,      13.0,     -9.0,      0.0,
-300.0,      300.0; %HUNG 11T  11.000
       261,        3,     1.02307,     4.8906,      17.0,       7.0,      0.0,      0.0,
0.0,        0.0; %HUNG 11A  11.000
       262,        0,     1.00000,     0.0000,      24.0,       4.0,      0.0,      0.0,
0.0,        0.0; %HUNG 22A  22.000
       263,        3,     0.99985,     4.8647,       0.0,       0.0,      0.0,      0.0,
0.0,        0.0; %HUNG 22B  22.000
       264,        1,     0.99985,     4.8647,      43.0,      27.0,      7.0,      0.0,
-300.0,      300.0; %HUNG 22P  22.000
       265,        1,     1.03855,     4.8539,      59.0,      23.0,      0.0,      0.0,
-14.0,      -42.0; %HUN-66T1  66.000
       266,        1,     1.03856,     4.8534,      23.0,       9.0,      0.0,      0.0,
0.0,        0.0; %HUN-66-T  66.000
       267,        1,     1.03856,     4.8533,      59.0,      26.0,      0.0,    -0.14,
-8.0,       24.0; %HUNG 66T  66.000
       268,        3,     0.99984,     4.8651,      33.0,       9.0,      0.0,      0.0,
0.0,        0.0; %HUNG 22T  22.000
       269,        1,     1.03855,     4.8539,      31.0,      17.0,      0.0,      0.0,
-8.0,       24.0; %HUN 66ST  66.000
       270,        1,     1.03856,     4.8527,       0.0,       0.0,      0.0,     0.25,
0.0,        0.0; %STVN 66H  66.000
       271,        1,     1.03856,     4.8527,       0.0,       0.0,      0.0,      0.0,
0.0,        0.0; %STVN 66A  66.000
       272,        1,     1.01344,     4.8503,      27.0,      11.0,      0.0,      0.0,
0.0,        0.0; %STVN 11T  11.000
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	273,	3,	1.01344,	4.8503,	20.0,	23.0,	-46.0,	0.0,
-300.0,	300.0; %STVN 11A  11.000
	274,	1,	1.03856,	4.8527,	37.0,	10.0,	0.0,	0.0,
0.0,	0.0; %STVN 66A  66.000
	275,	1,	0.98630,	4.8506,	37.0,	23.0,	-59.0,	0.0,
-300.0,	300.0; %STVN 11T  11.000
	276,	3,	0.98630,	4.8506,	18.0,	7.0,	0.0,	0.0,
0.0,	0.0; %STVN 11A  11.000
	277,	1,	1.03856,	4.8527,	16.0,	8.0,	0.0,	-0.10,
0.0,	0.0; %STVN 66S  66.000
	278,	1,	1.03857,	4.8525,	53.0,	22.0,	0.0,	-0.10,
0.0,	0.0; %SENT 66S  66.000
	279,	3,	1.08940,	4.4157,	28.0,	10.0,	19.0,	-0.10,
-100.0,	100.0; %SAND 132 132.000
	280,	3,	1.08955,	4.4182,	34.0,	0.0,	0.0,	0.0,
0.0,	0.0; %SAND 132 132.000
	281,	3,	1.00000,	0.0000,	20.0,	11.0,	0.0,	-0.15,
0.0,	0.0; %MEST-132 132.000
	282,	3,	1.00000,	0.0000,	87.0,	30.0,	204.0,	0.0,
-85.0,	210.0; %MEST-132 132.000
	283,	1,	1.08234,	3.4666,	17.0,	4.0,	0.0,	0.0,
0.0,	0.0; %MEST-132 132.000
	284,	1,	1.07591,	2.5667,	17.0,	8.0,	0.0,	0.0,
0.0,	0.0; %BALS-132 132.000
	285,	1,	1.07591,	2.5667,	18.0,	5.0,	0.0,	0.0,
0.0,	0.0; %BALS-132 132.000
	286,	1,	1.08234,	3.4666,	23.0,	11.0,	0.0,	0.0,
0.0,	0.0; %MEST-132 132.000
	287,	1,	1.07591,	2.5666,	113.0,	32.0,	48.0,	0.0,
-300.0,	300.0; %BALS-132 132.000
	288,	3,	1.14967,	4.8590,	63.0,	22.0,	0.0,	0.0,
-8.0,	23.0; %STO-INKA  66.000
	289,	0,	1.14967,	4.8590,	84.0,	18.0,	0.0,	0.0,
-8.0,	15.0; %MEST 66S  66.000
	290,	0,	1.14967,	4.8590,	12.0,	3.0,	0.0,	0.0,
0.0,	0.0; %MEST 66A  66.000
	291,	0,	1.14967,	4.8590,	12.0,	3.0,	0.0,	0.0,
0.0,	0.0; %MEST 66T  66.000
	292,	0,	1.15849,	4.8523,	277.0,	113.0,	155.0,	0.0,
-60.0,	180.0; %MEST 22T  22.000
	293,	0,	1.15849,	4.8523,	78.0,	3.0,	0.0,	0.0,
0.0,	0.0; %MEST 22A  22.000
	294,	0,	1.14967,	4.8590,	0.0,	0.0,	160.0,	0.0,
-100.0,	300.0; %MEST 66T  66.000
	295,	0,	1.15849,	4.8523,	77.0,	14.0,	0.0,	0.0,
-20.0,	20.0; %MEST 22T  22.000
	296,	0,	1.11452,	7.4769,	0.0,	0.0,	0.0,	0.0,
0.0,	0.0; %TAMO 66S  66.000
	297,	3,	1.11451,	7.4775,	0.0,	0.0,	0.0,	0.0,
0.0,	0.0; %TAM-66A   66.000
	298,	0,	1.11451,	7.4775,	0.0,	0.0,	391.0,	0.0,
-67.0,	200.0; %TAMO 66O  66.000
	299,	0,	1.11460,	7.4732,	39.0,	18.0,	392.0,	0.0,
-67.0,	200.0; %KGR-TAM/  66.000
	300,	0,	1.11462,	7.4722,	28.0,	7.0,	0.0,	0.0,
0.0,	0.0; %TAM-INKA  66.000
```

```
        301,        0,    1.11462,    7.4721,      0.0,      0.0,      0.0,      0.0,
0.0,       0.0; %OVER 66T  66.000
        302,        0,    1.11462,    7.4721,      0.0,      0.0,    516.4,      0.0,
-300.0,     300.0; %OVER 66A  66.000
        303,        0,    1.11462,    7.4721,     66.0,     20.0,      0.0,      0.0,
-10.0,      32.0; %OVER 66T  66.000
        304,        0,    1.11623,    7.4683,      0.0,      0.0,      0.0,      0.0,
0.0,       0.0; %OVER 22T  22.000
        305,        0,    1.11623,    7.4683,      0.0,      0.0,    -12.0,      0.0,
-100.0,     100.0; %OVER 22A  22.000
        306,        0,    1.11451,    7.4781,      0.0,      0.0,     -6.0,      0.0,
-100.0,     100.0; %TAMO 66D  66.000
        307,        0,    1.11206,    7.6715,     68.0,     27.0,      0.0,    -0.12,
-6.0,       9.0; %KGR-TAM/  66.000
        308,        0,    1.07841,   10.5114,     47.0,     11.0,      0.0,      0.0,
0.0,       0.0; %TAM-INKA  66.000
        309,        0,    1.07841,   10.5120,     68.0,     36.0,      0.0,      0.0,
-8.0,      23.0; %DIVI 66S  66.000
        310,        0,    1.07869,   10.5786,     61.0,     28.0,      0.0,      0.0,
-20.0,      70.0; %DIVI 66A  66.000
        311,        0,    1.07869,   10.5792,     71.0,     26.0,      0.0,      0.0,
0.0,       0.0; %DIVI 66T  66.000
        312,        0,    0.90908,   15.7217,     39.0,     32.0,      0.0,    -0.20,
0.0,       0.0; %DIVI 10A  11.000
        313,        0,    0.90909,   15.7505,     26.0,      0.0,      0.0,      0.0,
0.0,       0.0; %DIV-G1    11.000
        314,        0,    0.90908,   15.7217,      0.0,      0.0,      0.0,      0.0,
0.0,       0.0; %DIVI 10T  11.000
        315,        3,    1.03063,    4.8453,     20.0,     10.0,      0.0,    -0.10,
0.0,       0.0; %KROK 22T  22.000
        316,        3,    1.08955,    4.4182,     11.0,      7.0,      0.0,      0.0,
0.0,       0.0; %SAND 132 132.000
        317,        3,    1.08955,    4.4182,     24.0,     15.0,      0.0,      0.0,
-8.0,      23.0; %SAND 132 132.000
        318,        3,    1.03534,    4.4134,     21.0,     10.0,      0.0,      0.0,
0.0,       0.0; %SAND 22T  22.000
        319,        3,    1.03534,    4.4134,      0.0,      0.0,      4.0,      0.0,
-100.0,    1000.0; %SAND 22A  22.000
        320,        3,    1.03534,    4.4134,     48.0,     10.0,      0.0,      0.0,
0.0,       0.0; %SAND 22P  22.000
        321,        0,    1.0,        0.0000,      0.0,      0.0,    607.0,      0.0,
-210.0,     300.0;]; %SAND 22  22.00
```

8.1.1 Impedances (Line resistance And Reactance's)

```
1.09525,    4.3794
0.99568,    4.3759
1.08640,    4.7995
1.03340,    4.7997
1.09340,    4.8125
1.05901,    4.8034
1.05601,    4.9614
1.05841,    4.8534
1.05904,    4.8031
0.97767,    4.3776
```

```
1.07544,    4.3806
1.07503,    4.3864
1.07458,    4.7978
1.07308,    4.7979
1.09968,    4.1966
1.09698,    4.8016
1.05192,   24.4807
1.06743,   16.4918
1.06545,   16.4910
1.06775,   16.4910
0.98920,   16.4833
0.99933,   24.4807
1.00000,   24.5474
0.99933,   24.4856
1.00000,   24.5523
1.09392,    4.3898
1.07469,    4.3912
1.02307,    4.8906
1.09218,    4.8681
0.99985,    4.8647
1.03525,    4.8540
1.03855,    4.8224
1.03063,    4.8453
1.03885,    4.8489
1.09403,    4.7406
1.06099,    4.7193
1.06579,    4.5916
1.06558,    4.5951
1.07307,   12.7499
0.96635,   17.1713
0.96635,   18.1333
1.06299,   19.1713
1.09276,    4.2117
1.02253,   21.3469
1.14209,   23.8969
1.07336,   12.5445
0.98989,   12.5397
1.07344,   12.8566
1.06624,   16.7670
1.07214,    4.4193
1.08955,    4.4182
1.03534,   4.4134
1.05904,    4.8030
1.05904,    4.8030
1.06268,    4.7992
1.06300,   16.4408
1.07105,   16.4441
1.02252,   21.3481
1.00000,   24.5140
1.07591,    2.5666
1.00000,    0.0000
1.08234,    3.4667
1.01344,    4.8503
0.98630,    4.8506
1.03856,    4.8527
1.03856,    4.7127
1.09521,    4.3797
```

```
1.07769,   10.1067
1.00812,   10.1035
1.09367,    4.8099
1.09953,    4.8030
1.09243,    4.2037
```

8.2 Code:

8.2.1 Stability Indicators:

```
clc; clear all; close all; format compact;
% Bus Data in pu derived rom NETBAS powerflow
% |Bus#   |Vs |Angle |    R    |   X | Bus name    |   Base voltages    |Pr |Qr |
busdata=[Data imported]
Vs=busdata(:,4); % the data was taken and use in the array form
Vsan=busdata(:,5);
Vsm=abs(Vs); % Magnitude of Sending End Voltage
Vsa=angle(Vsan); % Angle of Sending End Voltage

Vr=busdata(:,2);
Vran=busdata(:,3);
Vrm=abs(Vr); % Magnitude of Receiving End Voltage
Vra=angle(Vran); % Angle of Receiving End Voltage
Delta=Vsa-Vra;
R=busdata(:,6);
X=busdata(:,7);
Z=R+j*X; % Line Impedance
Zm=abs(Z);
Theta=angle(Z);
Pr=busdata(:,8); % Receiving End Active Power
Qr=busdata(:,9); % Receiving End Reactive Power
Sr=Pr+j*Qr; % Receiving End Apprant Power
fprintf('Line Stability Index \n')
Lmn=(4.*X.*Qr)/((Vsm.*sin(Theta-Delta)).^2); % Line Stability Index
display(Lmn(:,45))
fprintf('Fast Voltage Stability Index \n')
FVSI=(4.*(Zm.^2).*Qr)/((Vsm.^2).*X); % Fast Voltage Stability Index
display(FVSI(:,67))
fprintf('Line Stability Factor \n')
LQP=4*(X/(Vsm.^2))*(Qr+(((Pr.^2).*X)/(Vsm.^2)));
display(LQP(:,67))% Line Stability Factor
```

8.2.2 Voltage Stability:

```
clc;
clear all
syms X
z=0.1+0.5*1j;
Vs=1;
A=1;
a1=real(A); a2=imag(A);
A=a1+a2*1j;
B=z;
b1=real(B); b2=imag(B);
```

```
fi=acos(1);
K1=a1*(b2-b1*tan(fi))+a2*(b1+b2*tan(fi));
K2=a1*(b1+b2*tan(fi))+a2*(b1-b2*tan(fi));
deltarcrit=(pi/4)+0.5*atan(K2/-K1);
Vrcrit=Vs/(2*(a1*cos(deltarcrit)+a2*sin(deltarcrit)));
K3=b1*cos(deltarcrit)+b2*sin(deltarcrit);
K4=a1*cos(deltarcrit)+a2*sin(deltarcrit);
Prcrit=((Vs^2)*(2*K3*K4-(a1*b1+a2*b2)))/((b1^2+b2^2)*4*K4);
Vr=[];
for P=0.1:0.01:1
        Qr=P*tan(fi);
        P1=a1^2+a2^2;
        P2=2*P*(a1*b1+a2*b2)+2*Qr*(a1*b2+a2*b1)-Vs^2;
       P3=((b1+b2).^2)*(P^2+Qr^2);
       equation=P1*(X^2)+P2*X+P3;
        these_roots = roots([P1 P2 P3]);
        mask = any(imag(these_roots) ~= 0,2);
        these_roots(mask,:) = nan;
        Vr=[Vr these_roots];
  end
        Pr=(0.1:0.01:1);
plot(Pr,Vr.')
display(Prcrit)
title('PV Curve by system')
xlabel('Power')
ylabel('Voltage at bus (pu)')
```