CHAPTER - 1

INTRODUCTION

Blackout can be defined as a large scale power outage which is a long term loss of an electric power which causes darkness in wide area for a long duration. The European Network of Transmission System Operators for Electricity defined the power outage situation as the interruption of electricity generation, transmission system, distribution system and consumption processes, when there is a termination of operation of the transmission system or a part.

The false operation or failure of a generator or a major transmission line trip out the generating system through the protection system, cause a long term power outage also known as blackout. False operation of the generating unit may be triggered because of the problem of over-frequency or under-frequency which starts the phenomenon of blackout in which whole grid is collapsed.

1.1 Types of Power Outage

There are three types of power outage categorized with respect to the duration of fault and effect of the outage.

• **TRANSIENT FAULT: A**ny temporary fault in power system when causes a power outage for very short duration, this type of power outage is called transient fault which remains only for few seconds. Power is restored automatically after the fault is cleared.

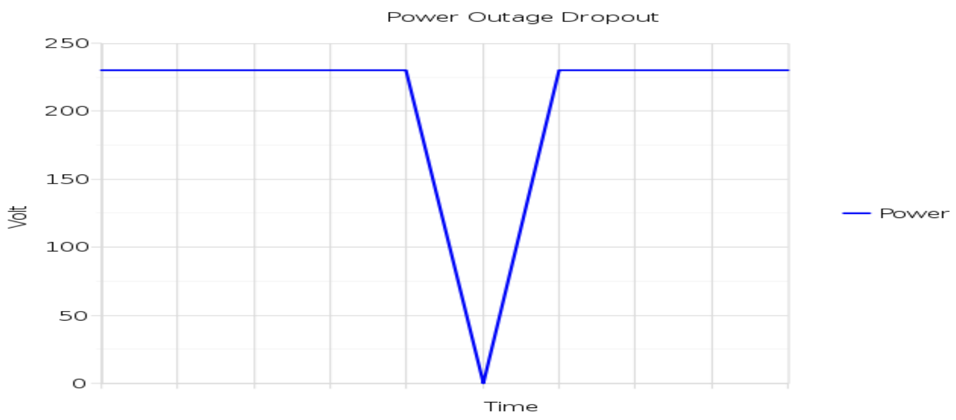

Fig. 1.1: Transient Power Outage

•**BROWNOUT**: In an electrical power supply when due to any false operation, a drop in voltage is observed which is called a sag or brownout. There are various adverse effects of brownouts such poor performance of equipment, incorrect operation of system, etc. This type of sag is called brownout because it causes lights to dim when voltage is dropped. During a brownout the industrial loads like three phase induction motors or diesel generator are mostly on risks during brownout as drop in voltage can overheat and damage their insulation. If the brownouts are frequently experienced due to erratic power supply, there should be a backup power system which automatically turns on and provides necessary power to the equipments.

• **BLACKOUT**: Blackout can be defined as a large scale power outage which is a long term loss of an electric power which causes darkness in wide area for a long duration.. After blackout it is very complex task to restore power that is why power stations must repair time frames depending on the configurations of the network that is affected by blackout. Blackouts which causes the tripping of the power station is particularly difficult to recover. Blackout may last from a few minutes to a few weeks that only depend upon the magnitude and nature of the blackout and the electrical network configuration.

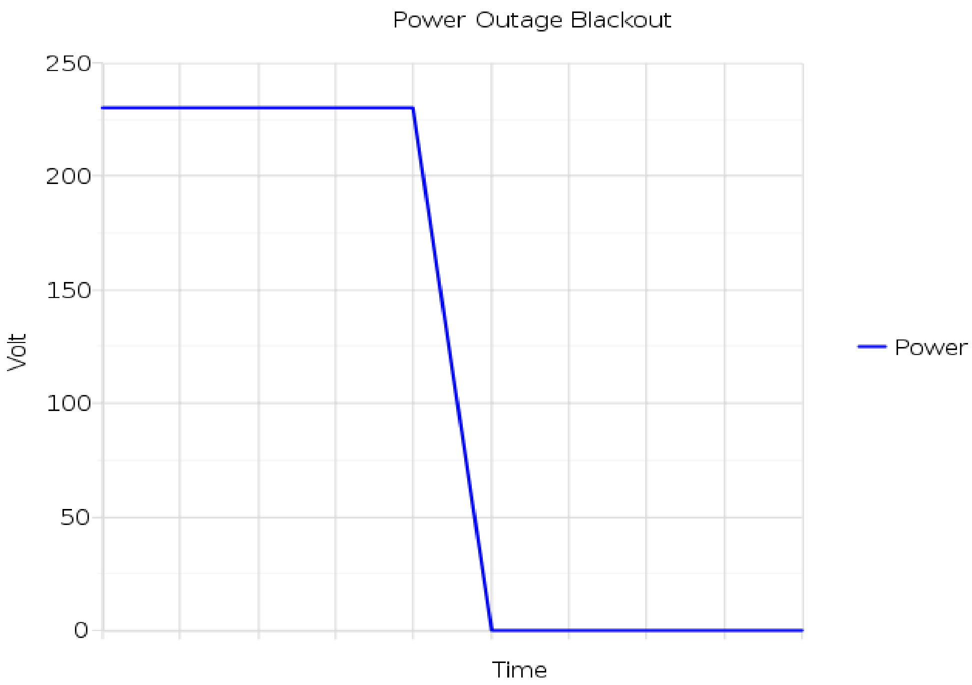

Fig. 1.2: Power Outage for long duration

1.2 Major Causes of Power Outage

1.2.1 Natural Causes - Weather Related:

Natural weather phenomena such as lightening, rain, snow, ice, wind, and even dust normally causes numerous power failures. Short circuits and power failures are caused by water and dust which is very expensive to ensure the protection. Dampness and excessive moisture can also lead to serious damages.

Historically world's most severe power outages are caused by natural disasters such as hurricanes, floods, wind storms, earthquakes, tsunamis, etc. These disasters can completely destroy critical power infrastructure and cause massive power outages that can leave a vat geographic area without any power from few hours to few weeks or even months.

1.2.2 Other Causes of Outages:

The animals coming into contact with power lines, accounted for 11% of outages in the United States of America as indicated by a study of Edison electric institute. Man made outages causes additional failures which are due to the vehicle and construction accidents with electric towers, power lines, etc.

1.3 PROTECTION SCHEMES

Following are the various schemes normally involved in power outage of powersystem:

1.3.1 Under frequency load shedding

In a load rich area, due to the generation shortage the system frequency drops. If the frequency reduces below the set point for example 48.5 Hz, the generation protection system will comes into play and trips the generator, which will further reduces the generation in the island and making the system frequency to decline even more. In the worst case, the entire island will blackout. Before the generation protection system takes action certain amount of load is to be shed so that the frequency is maintained in its permissible limits. This can protect the grid from blackout.

1.3.2 Under voltage load shedding

In some cases, when the tripping of transmission lines is observed due to the protection system, drop in the voltage in some areas is also observed. The voltage drop in some point of the system may cause the problem in the surrounded area and eventually bring the voltage collapse. According to this scheme, when the voltage drops below the allowed limit, the load surrounding that are must be shedde accordingly and when the system tends to be normal again, the loads may be restored.

1.3.3 Generation load shedding

Generally, the generating end and the load end are situated at a very far distance, and the transfer of power takes place via transmission line. There are number of transmission line used for transmission which collectively forms a very complex and congested system which has become a common problem for the world. Each line carries power according to its capacity and if a line carrying high power trips due to any fault condition, remaining network may not be enough to transfer whole power from generating end to the load end. This problem can cause a serious problem of power swing which can further results in islanding of the system and power system failure. Various alternative methods can be used to solve this problem, out of which one is to install additional transmission lines, having a controlled generator output, etc. However, installing additional transmission lines is not much economical as it requires heavy investment. So, generation shedding solution is more effective as compared to other methods.

1.3.4 Rapid load shedding

Direct load shedding method is also a solution which can be installed for the enhancement of the transient stability. This scheme detects the tripping of generating units in the southern system and operates as soon as possible to disconnect some predetermined load points so that the power flow exceeding the stability limits can be prevented. This direct load shedding scheme operates really fast enough to avoid the stability problems of the tie lines. Thus, the tele-protection signals are needed in this scheme. As this scheme operates very fast, it is also called the rapid load shedding scheme.

1. **HVDC stability scheme**

HVDC i.e. High Voltage Direct Current has the special control for the variation in the power system stability. There are four stability functions mentioned as following.

(a) Power Run-Up Function: To increase the HVDC power level to the required power set point, power run-up function will send the signal. The variation in power follows the pre-programmable ramp rate.

(b) Power Run-Back Function: Basically, power runback function and power run-up functions are used together simultaneously. This function is used to decrease the transfer of the HVDC power to the already set to a power level at designed pre-programmable ramp rate. The run-back function has also an alternative feature of fast power reversal. The fast power reversal function can immediately change the direction of HVDC power system immediately.

(c) Power Swing Damping Function: Normally, power swing damping function also known as dual frequency modulation function is used as the solution for the problem of power oscillation AC system. If the power swing damping function is enabled, the HVDC system will adjust the power transfer so that the oscillations can be damped out when there is a power oscillation problem in one side of the.

(d) Frequency Limit Control Function: The frequency limit control function operates when the system frequency is deviated from the specified normal range. It compares the frequencies on the both sides of the networks and calculates the difference in frequency. If the frequency of either system is lesser than the specified range by any reasons, this function will operate to compensate for the loss of power of the system by increasing the DC power and if the frequency is greater than the specified frequency, the DC power will be decreased to lower the frequency of the system. The duration of operation depends upon the frequency deviation.

2. **Other special protection schemes**

There are also various other protection schemes such as overload line protection, automatic switching capacitor, etc. The overload line protection protects the line from overloading especially the major lines which carries majority of the power to be transferred which can lead to the cascade events of tripping of the lines.

The automatic switching capacitor scheme is used to close the circuit breaker of the capacitor into the system when the voltage is dropped for some duration.

The combination of both of the special protection schemes can also be another alternative that can be used.

1.4 SCOPE OF THE WORK

Various papers have been published regarding power outage phenomenon also progressive work has also been done in this field. Few significant problems regarding blackout and its restoration studied during the several grid disturbances in Western Region (India) during the period 1988-2003. Several strategies and policies were recommended to enhance the grid security and robustness. Such as Controlling of generation of thermal and hydro power generators, may be one of the effective method to avoid power outages. Other methods include rapid load shedding, under/over frequency shedding, etc.

This research is basically based upon the simulation of the Indian grid which shows that how a grid is collapsed due to single fault. In the major blackout of India that happened in July, cascading events that initiates as the Agra-Gwalior transmission line connecting northern grid to western grid was taken out for maintenance that further leads to the blackout. All these events are analysed and studied in this research. This research paper gives the detailed description about how the grid collapsed in India which leads to one of the major blackouts of the world. Also some of the preventive measures are also discussed that can help in avoiding such serious conditions that can cause blackout.

1.5 ORGANISATION OF THESIS

In this thesis report with title “simulation of power outage in Indian grid”, following chapters are discussed in detail.

Chapter 2: In this chapter work and research of different authors are discussed briefly. The work related to the topic power outage has been carried out by several authors, is listed in this chapter .

Chapter 3: In this chapter there is a list of major blackouts of the world. Also the most severe blackout of the world that occurred in India is described in detail.

Chapter 4: This chapter gives the brief description about the grid system of India. Also the generation, transmission system, protection system, etc. installed in India are discussed

Chapter 5: In this chapter simulation has been carried out in DIgSILENT power factory software. The features of this software are discussed in this chapter. The protection system in this software is also discussed in details.

Chapter 6: It deals with the simulation which is carried out in DIgSILENT power factory software. A transmission line is taken out for the maintenance purpose as happened in reality and the events that occurred due to this maintenance which further turned out to be a massive blackout are observed in this chapter. This chapter comprise of all the graphs obtained through the simulation in power factory software. Also a flow chart is shown which describes step-wise occurrence of the events that concludes in blackout.

Further it includes conclusion, appendix, and references and detailed accordingly.

CHAPTER 2

LITERATURE SURVEY

Anjan Roy, P.Pentayya and S.A.Khaparde presented the paper on the topic "Experience of Blackouts and Restoration Practices in Western Region of India" in which they analyze significant features of various blackouts and restoration problems encountered during the several grid disturbances in Western Region (India) during the period 1988-2003.

Subrata Mukhopadhyay, Sushil K Soonee, Sundaram R Narasimhan and Rajiv K Porwal presented a paper on "An Indian Experience of defence against Blackouts and Restoration Mechanism followed". In this paper they discussed about the background of evolution of regional electricity grids in India aiming at the formation of National Grid, Indian experience of running the electricity grid with the procedure established to safeguard the system against possible blackouts has been detailed. This has been followed by the restoration measures adopted earlier in the event of such occurrences and as envisaged for future, particularly in the context of four out of five regional grids operating in synchronism and the remaining one connected asynchronously with the rest.

Power System Blackouts - Literature review given by Arulampalam Atputharajah
and Tapan Kumar Saha. This paper summarises the past history of major and properly reported blackouts in the world. Detail analysis on root cause of blackouts and the follow up actions taken are discussed. Some technical information related to how it occurs and which parameters have to be monitored to predict the next possible cascading step of the blackout is also discussed.

Black Start in Power System- A case study in Western Region, India is given by U K Verma, S R Narasimhan, A Gartia, Aditya P Das and A K Gupta. As per Charles Concordia, "Another aspect of robustness can be illustrated by the fact that a weaker system that has a well-tested plan for emergency procedures and for restoration may be more reliable than a stronger system with no such plan". The black start exercises assume paramount importance for any large interconnected power system since they not only testify the existing restoration facilities but also prepare the operators to restore the power system in minimum possible time by identifying systematic deficiencies and suggesting scopes for improvement.

Wei Huang, Varun Perumalla, Di Wu, S. Hossein Hosseini and John N. Jiang presented a paper on “a lesson learned from recent cascading outages: coupled interface and its impact on the smart grid development” discussed about the technical causes to cascading outages. They analysed that a coupled interface structure could be problematic to mitigation and prevention of cascading outages – in almost all reports, it can be found that such structure either directly imposed negative impact on the post-contingency stability, or increased the possibility of malfunction of grid protection system. They developed two simple examples to illustrate the possible mechanism of impact of coupled interface structure, according to the scenarios reported of the recent large-scale blackouts in India.
Moreover this paper discusses some of the possible reasons for having coupled interface structures in a large-scale power grid. The implications to the development of future smart-grid also are discussed.

“A Comprehensive Survey of Grid Failure in INDIA” presented by T.Halder, advocates massive Grid failure of power networks when excessive power is drawn by power utilities or more areas. As a regional grid may not prolong usage of power, other grids supply additional power to that area. If the automated system fails to recognize the surplus power drawl line, the overloaded grid will fail entirely, creating additional failures. This is how the failure took place within a number of power grids on 30-07-2012 at about 1 pm on havoc practical data collection and comprehensive survey basis. According to their research they proposed following remedial measures against grid failure:

• Monitoring of system parameters and security
• To ensure the integrated operation of power system grid in region
• System studies ,planning and contingency analysis
• Analysis of tripping , disturbances and facilitating immediate remedial
• Measures. Daily scheduling and operational lanning.Facilitating bilateral and inter-regional exchanges
• Computation of energy transmit and drawal values using SEMs.Augmentation of telemetry, computing and communication facilities
• Implementation of smart grid
• Less hydro power generation in dry season

• Enhancement of smart devices for isolation from overdrawal power lines

• Proper power share allocation

• Strict Government policy &Regulation

• Modernization of Power system

• Expansion of power Plant

• Use of non conventional energy

• Cutback of Transmission and distribution (T&D) losses

• Implementation of service quality

• Exemption of new Policy and regulation

Loi Lei Lai, Hao Tian Zhang,S. Mishra, Deepak
Ramasubramanian, Chun Sing Lai, and Fang Yuan Xu, written a paper on lessons learned from July, 2012 India blackout. They explained about the grid disturbances occurred in India on 30th and 31st July, 2012 and investigated about the main reasons for the occurrence of the blackout. According to their sensitivity analysis, they recommended certain policy and strategies to enhance the grid security and robustness. As per the case study they have done, they observed the behaviours of the entire grids when increasing the capacity investment or injecting more spinning reserve power into the Northern Region grid.

They analysed the Changes of Northern Region grid frequency when:

(a) Thermal generation in the northern region increased to 105%;

(b) Thermal generation in the northern region increased to 110%;

(c) Thermal generation in the northern region increased to 115%;

(d) Thermal generation in the northern region increased to 120%;

(e) Thermal generation in the northern region increased to 125%.

They observed the behaviour of the grid system by increasing the thermal generation power output and also by increasing the hydro generation output. In another case study they discussed about the wind generation investment in Western Region. This case is to study the frequency, rotor angle difference and power imported from Eastern grid to Northern Region.

In this case, the Western Region grid has wind farms with asynchronous machines. The wind farm Capacity is set in percentages of the output power generated by the thermal power plants in the Western Region grid.

investigation on July, 2012 Indian blackout carried out by loi lei lai and fang yuan xu, sukumar mishra, hao tian zhang and chun sing lai presented a report that has been generated by the enquiry committee which was organized by the Ministry of Power, Government of India, to investigate the factors which led to the initiation of the grid disturbance. Recommendations were also generated by the committee in order to provide the plan for Indian grid enhancement. Further to the recommendations by Enquiry Committee, this paper will give further suggestions to minimize blackouts in future. An insight into decision support requirement for power network operation will be made.

Rui Yao, Xuemin Zhang, Shaowei Huang, and Shengwei Mei presented a paper on "Cascading Outage Preventive Control for Large-scale AC-DC Interconnected Power Grid" in which they have given the preventive control method lowering cascading outage risk in large-scale AC-DC interconnected power grids. They simulated the possible cascading outages first using fast dynamics of OPA model. Then, to minimise the overall load power outage risk resulting due to cascading outages, they proposed cascading outages risk based security.

M. Vaiman (Lead), K. Bell, Y. Chen, B. Chowdhury, I. Dobson, P. Hines, M. Papic, S. Miller, and P. Zhang seeks to consolidate and review the progress of the field towards methods and tools of assessing the risk of cascading failure. This paper discusses the challenges regarding cascading failure and a brief summary is presented which consist of variety of state-of-the-art analysis and simulation methods, also analyzing observed data, and simulations relying on various probabilistic, deterministic, approximate, and heuristic approaches are also included. Limitations to the interpretation and application of analytical results are highlighted, and directions and challenges for future developments are discussed.

Hui Ren, *Student Member, IEEE*, and Ian Dobson, *Fellow, IEEE* studied the cascading outages regarding transmission line(200 lines) recorded over nine years in an electric power system. The average amount of propagation of the line outages is estimated from the data. The distribution of the total number of line outages is predicted from the propagation and the initial outages using a Galton–Watson branching process model of cascading failure.

Xiaoming Wang, *Student Member, IEEE*, and Vijay Vittal, *Fellow, IEEE* published a paper on System Islanding Using Minimal Cutsets with Minimum Net Flow. To deal with islanding the actual system they provides two comprehensive approaches which are based on the grouping information by using the cutest technique of graph theory. The issue of minimal cutsets has been widely discussed in areas related to network topology determination, reliability analysis, etc. The results of this paper also show potential in application to power system islanding.

Splitting Strategies for Islanding Operation of Large-Scale Power Systems Using OBDD-Based Methods proposed by Kai Sun, Da-Zhong Zheng, and Qiang Lu, *Fellow, IEEE*. System splitting problem (SS problem) is to determine proper splitting points (or called splitting strategies) to split the entire interconnected transmission network into islands ensuring generation/load balance and satisfaction of transmission capacity constraints when islanding operation of system is unavoidable. For a large-scale power system, its SS problem is very complicated in general because a combinatorial explosion of strategy space happens. This paper mainly studies how to find proper splitting strategies of large-scale power systems using an OBDD-based three-phase method. Then, a time-based layered structure of the problem solving process is introduced to make this method more practical. Simulation results on IEEE 30- and 118-bus networks show that by this method, proper splitting strategies can be given quickly. Further analyses indicate that this method is effective for larger-scale power systems.

"Islanding and Load Shedding Schemes for Captive Power Plants" presented by K.Rajamani described Various islanding schemes used in industrial plants with captive generation. Details of load shedding schemes after islanding are given. Some important design aspects and factors to be considered for –reliability improvement are presented in brief. Finally, the impact of SCADA on these schemes is described.

John Shortle, Steffen Rebennack, and Fred W. Glover discussed about the Transmission-Capacity Expansion for Minimizing Blackout probabilities. To determine an optimal plan for expanding the capacity of a power grid so that chances of cascading blackout can be minimised. To expand the Capacity of the power grid, new transmission lines have to be added and the capacity of pre existing transmission line must be increased.
The probability of a large-scale blackout is estimated via Monte Carlo simulation of a probabilistic cascading blackout model. A key conclusion is that the different expansion strategies lead to different shapes of the tails of the blackout distributions.

A paper titled "Challenges and opportunities in emergency management of electric power system blackout" published by Zhong Shaobo and Sun Zhanhui analyzes the core requirements and major challenges of prevention and response of blackout. And then, some potential advanced techniques on planning, monitoring and early-warning, emergency response, etc. are introduced in view of latest research progress.

B. A. Carreras, V. E. Lynch, D. E. Newman, and I. Dobson carried out the Blackout Mitigation Assessment in Power Transmission Systems. They investigated how these complex system dynamics impact the assessment and mitigation of blackout risk.
The studied OPA model shows that apparently sensible efforts to reduce the risk of smaller Blackouts can sometimes increase the risk of large blackouts. The mitigation measures that tend to reduce the probability of small blackouts, an increase in the frequency and/or the size of large blackouts may occur. Conversely, to eliminate the large blackouts, there is an increase in frequency of the small ones. When we combine both types of mitigation, we see very little net effect on the number or distribution of blackouts.

CHAPTER - 3

MAJOR BLACKOUTS OF WORLD

3.1 First power failure (reported)

The Northeast power failure on 9th November 1965 in the United States was the first power failure which was fairly reported. The transmission line between north-east and south-west which was not capable of transferring a certain amount of power was the main cause of the power failure. As a result during heavy load conditions, the back-up protection system tripped one of the lines out of five lines. This successively tripped out other four lines also which overloaded other transmission lines which finally results in overall system collapsed. During the study of this failure, it was also observed that there was not sufficient spinning reserve at the time when blackout was initiated. So after the detailed analysis of that failure, EHV transmission lines were installed, sufficient spinning reserve and also the load shedding method was proposed. This failure affected around 30 million people and leads to the darkness for about 13 hours.

Following is the list of some massive blackouts occurred in all over the world:

ARTCLE	**MILLIONS OF PEOPLE AFFECTED**	**LOCATION**	**DATE**
INDIA BLACKOUT	670	INDIA	30-31 JULY, 2012
JAVA-BALI POWER OUTAGE	100	INDONESIA	18 AUG, 2005
SOUTHERN BRAZIL BLACKOUT	97	BRAZIL	11 MARCH, 1999
BRAZIL AND PARAGUAY	87	BRAZIL, PARAGUAY	10-11 NOV, 2009
NORTHEAST BLACKOUT	55	UNITED STATES, CANADA	14-15 AUG 2003
ITALY BLACKOUT	55	ITALY, SWITZERLAND, AUSTRIA, SLOVENIA, CROATIA	28 SEPT, 2003
NORTHEAST BLACKOUT	30	UNITED STATES, CANADA	9 NOV, 1965

TABLE 3.1: Major Blackouts of World

3.2 Brief description of the Indian massive blackout

Today, about 110.000 MW is total demand which is fulfilled by the grids of India. The NEW Grid that is Northern, Western, Eastern and North-Eastern Grids are responsible for the demand of about 75,000 to 80,000 MW. The NEW grids are inter-connected synchronously whereas the Southern Grid is connected with NEW Grid asynchronously. Southern grid, individually met a demand of about 30,000 MW. The generation resources such as coal majority of which is located in eastern region of the country, hydro located in the north and North-East regions of country are main source of energy. The major load centres are located mostly in the Northern, Western and Southern parts of the country. Upcoming transmission lines to be converted to 765 kV lines as most of the lines are of 400 kV.

Various parts of the Indian Electricity Grids have been affected during the major grid failure occurred on the 30th and 31st July, 2012. Due to increasing load demand in northern region, the northern grid started overloading eastern and western grids of the country. Due to this conditions unbalanced generation was observed which causes instability in the system. This instability led to the triggering of back-up protection system which tripped out essential equipments and finally resulted in Blackout.

CHAPTER 4
DEVELOPMENT OF STUDY SYSTEM MODEL

4.1 Introduction

The national grid of India is composed of five regional grids, namely, the Northern Region (NR), the Western Region (WR) the Southern Region (SR), the Eastern Region (ER) and the North-East Region (NER). Except the SR, the national grid is synchronously interconnected. The SR connects to the rest of the country via two back-to-back substations. Note that the interfaces between NR, ER and WR are “coupled interface” consisting of multiple transmission lines of different voltage levels. For simplicity, only two lines of the interface are shown. In the model presented three grids are taken into account that is northern grid, western grid, and Eastern grid. Eastern grid shown here is the combination of eastern and north-eastern grid.

The simulated system is basically 6 bus system out of which three buses are considered as north, west and east bus. The voltages of these buses are stepped up to 400 kV with the help of step up transformers. The default frequency of overall grid has been taken as 50 Hz according to the Indian standards and the voltage is set to 11 kV. Each grid consists of several generators of thermal and hydro types whose parameters of the governors and the AVR have been taken as the default parameters available in the software. The North, east, and west buses are interconnected with each other through transmission lines. Three general loads indicated as northern, eastern, and western loads are also connected to north, east, and west buses respectively. The demand of whose are set according to the approximate demand of northern, eastern, and western region of India.

Two winding transformers are used to step up the generating voltage from 11kV to 400 kV.

Various relays are used as the protecting devices for almost all the equipments that are installed in this system. The over-current relays are used for the protection of transmission lines, over and under frequency relays are used for the generation section as violation of the permissible safety limits given in these relays, the performance of overall grid system will be degraded which is not desirable.

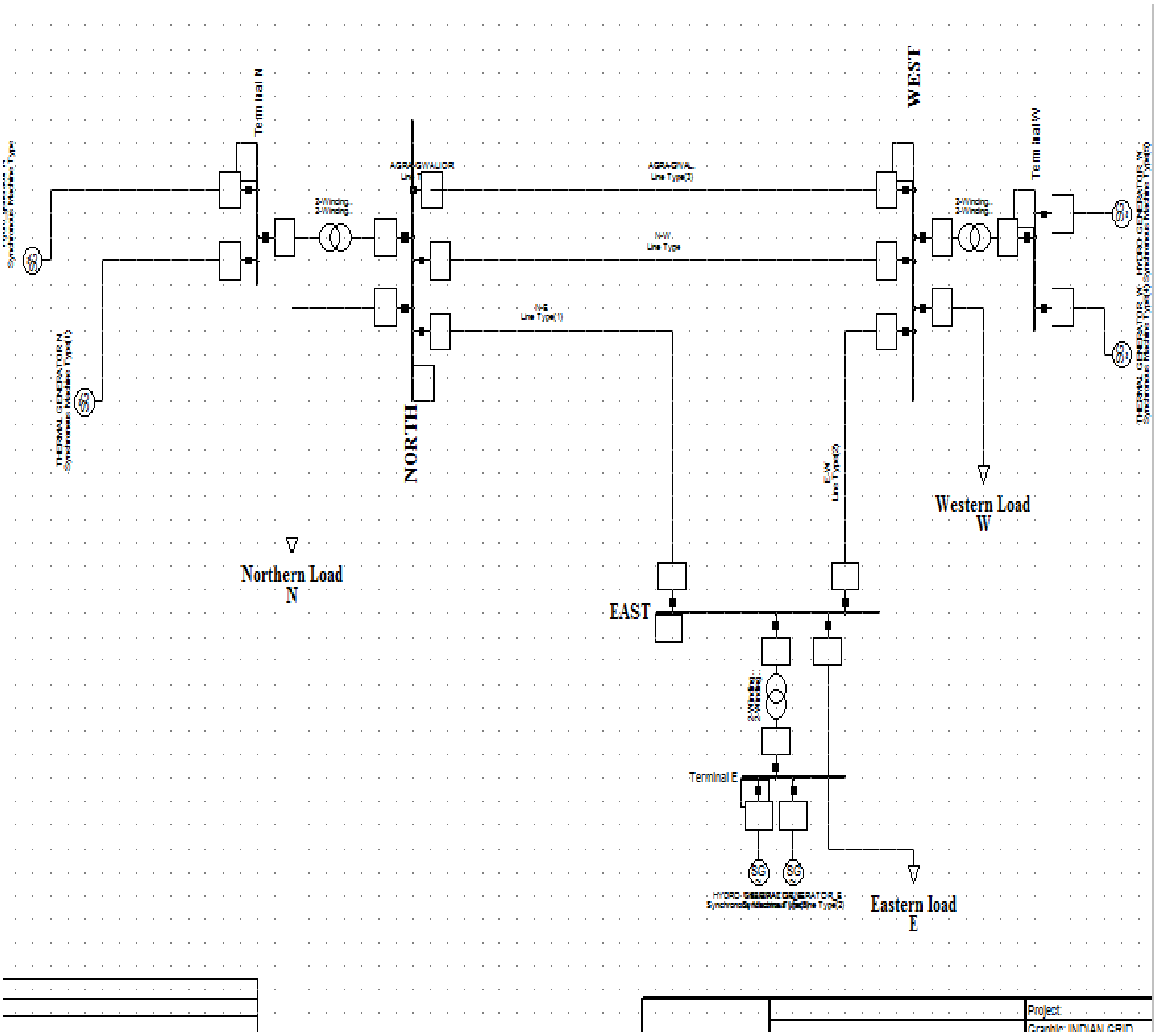

Fig. 4.1: Grid model

Fig. 4.1 shows the basic grid model used for the simulation in this research. The figure shows three main buses named as NORTH, WEST, and EAST to which three loads are connected named as northern, western, and eastern loads respectively. Two types of generators that are hydro and thermal are connected to each of the terminal buses. The voltage of terminal buses is levelled up through two winding transformers from 11kV to 400kV. Transmission lines are connecting all the grids, Agra-Gwalior line and N-W lines are connecting northern and western, N-E and E-W lines connect northern -eastern and eastern-western grids respectively. The transmission line named as Agra-Gwalior line was switched off for the purpose of maintenance due to which overloading of other transmission line is observed which cumulatively gave rise to the massive blackout that occurred in India.

4.2 GENERATION IN INDIA

There are various sources of energy that are used in India out of which two are used in this model. The two types of generation that are used are briefly explained about below:

4.2.1 HYDRO-GENERATION

Hydropower is a renewable resource of energy. It uses earth's water as the source to generate power and electricity. When the water flows downwards with certain speed, it develops kinetic energy which is fed to the turbines of the generators and due to generation action kinetic energy is converted into electricity. Every year, 2700 TWH of energy is generated every year. Almost 21.5% i.e. 38,106 MW of total power which is about 1,76,990 MW (June, 2011) is contributed by the hydro-generation process. During 2007-12, an addition of 78,700 MW by various conventional sources was observed. In which, about 15,627 MW was from the large hydro projects.

India is ranked 5th on global scenario in terms of exploitable hydro-potential. The basin wise assessed potential is as under:-

S.NO	**BASIN/RIVERS PROBABLE**	CAPACITY(MW)
1	INDUS BASIN	33,832
2.	GANGA BASIN	20,711
3.	CENTRAL INDIAN RIVER SYSTEM	4152
4.	WESTERN FLOWING RIVERS OF SOUTHERN INDIA	9430
5.	EASTERN FLOWING RIVERS OF SOUTHERN INDIA	14,511
6.	BRAMAPUTRA BASIN	66,065
	TOTAL	1,48,701

Table 4.1: Major Basins with their capacity

4.2.2 THERMAL GENERATION

For the generation of thermal power, coal and diesel are the major sources in India. In fact, coal is the major source of energy used for the production of electricity in those areas that either have no nearby water power sites or are located near coal mines. Coal is the major source of power in states like Uttar Pradesh, West Bengal, Bihar, Orissa and Madhya Pradesh. Industrial cities like Kanpur and Ahmedabad are totally dependent on the coal as their source of electric power. Moreover, diesel engines power plants having capacity of only a few hundred kilowatts have been installed for generating electrical power at small towns of country.

The modern world is well aware of hydro-electricity. Hydro-electricity is an important renewable energy as it is derived from a source, which is plentiful and easily available. On the other hand, thermal power plant uses coal, petroleum and natural gas to produce thermal electricity which are non-renewable sources of energy, also called as fossil fuels.. These sources are of mineral origin. As these are non-renewable so they are exhaustible resources and cannot be replenished by human which is the greatest demerit of thermal source of energy. Moreover, thermal generation process is responsible for pollution whereas hydro-generation process as it is conventional and renewable resource do not cause any pollution. However, electricity, whether thermal, nuclear or hydro, is most convenient and versatile form of energy. Today, energy is the main base of industry, agriculture, transport and domestic sectors. Some major thermal power plants are:

POWER STATION	STATE	CAPACITY(MW)
MUNDRA THERMAL POWER STATION	GUJARAT	4620
VINDHYACHAL THERMAL POWER STATION	MADHYA PRADESH	4260
MUNDRA ULTRA MEGA POWER PLANT	GUJARAT	4000
TALCHER SUPER THERMAL POWER STATION	ODISHA	3000
SIPAT THERMAL POWER PLANT	CHHATTISGARH	2980
NTPC DADRI	UTTAR PRADESH	2637
NTPC RAMAGUNDAM	ANDHRA PRADESH	2600
KORBA SUPER THERMAL POWER PLANT	CHHATTISGARH	2600
RIHAND THERMAL POWER STATION	UTTAR PRADESH	2500
JHARSUGUDA THERMAL POWER PLANT	ODISHA	2400

Table 4.2: Major Thermal Power Stations of India

4.2.3 TRANSFORMERS

Transformers are the static device that converts electrical energy into magnetic energy and again convert it into electric energy. It basically works on the self-induction and mutual induction principles. It consists of two coils- primary and secondary coils. Transformers are generally used to step-up or step down the voltage and current levels. The ac supply is fed into the primary coil which due to self induction principle induces an electromotive force

voltage which opposes its cause as per the lenz's law. The ac current generates the flux in primary coil which further links to the secondary coil through high permeability material. The flux linking the econdary coil induces an e.m.f. as per the mutual induction principle which further flows a current to the load. The turns ratio(K) that is the ratio of number of primary coil turns to the number of secondary coil turns.
Following are the different conditions of turn's ratio:

$\mathbf{K} = \frac{\mathbf{N1}}{\mathbf{N2}} > \mathbf{1;}$ step-down transformer

$\mathbf{K} = \frac{\mathbf{N1}}{\mathbf{N2}} < \mathbf{1}$; step-up transformer

$\mathbf{K} = \frac{\mathbf{N1}}{\mathbf{N2}} = \mathbf{1;}$ unit transformer

When turns ratio is unity the transformer is called as unit transformer which is basically used for physical isolation between equipments.

Thus the voltage level can be increased or decreased by changing the number of turns. As a magnetic medium forms the link between the primary and the secondary windings there is no conductive connection between the two electric circuits. The transformer thus provides an electric isolation between the two circuits. It is also known as a constant frequency machine as the frequency remains constant on both sides that are primary and secondary sides. Also there is no change in the power, that is power rating of the transformer is same on both sides, only the voltage and current values increased and decreased according to the requirement. The electric power at one voltage/current level is only 'transformed' into electric power, at the same frequency; to another voltage/current level that is why it is called transformer.
Even though most of the large-power transformers can be found in the power systems, the use of the transformers is not limited to the power systems. The use of the principle of transformers is universal. Transformers are also very useful as instrument transformers. The voltage or current levels in power systems are relatively very high to be handled by the normal instruments like voltmeters and ammeters, that is why a transformer is installed which first decreases the level of the parameters upto the desired value to be measured by the ordinary measuring instruments. These type of transformers are called as instrument transformers.
Transformers can be utilized in the frequency range going from a few hertz to several mega hertz. Power rating may varies from a few milli-watts to several hundreds of megawatts. The

use of the transformers is so wide spread and is one of the most essential equipment that it is practically impossible to think of a large power system without transformers.

4.2.4 TRANSMISSION LINES

The country has been divided into five electrical Regions viz. Northern regions(NR), Eastern region (ER), Western region(WR), Southern region(SR) and North Eastern region(NER). However, NR, ER, WR and NER have been interconnected synchronously and operating as single grid named as Central Grid having capacity of about 110,000MW. The Southern region is asynchronously connected to the Central Grid through HVDC links.

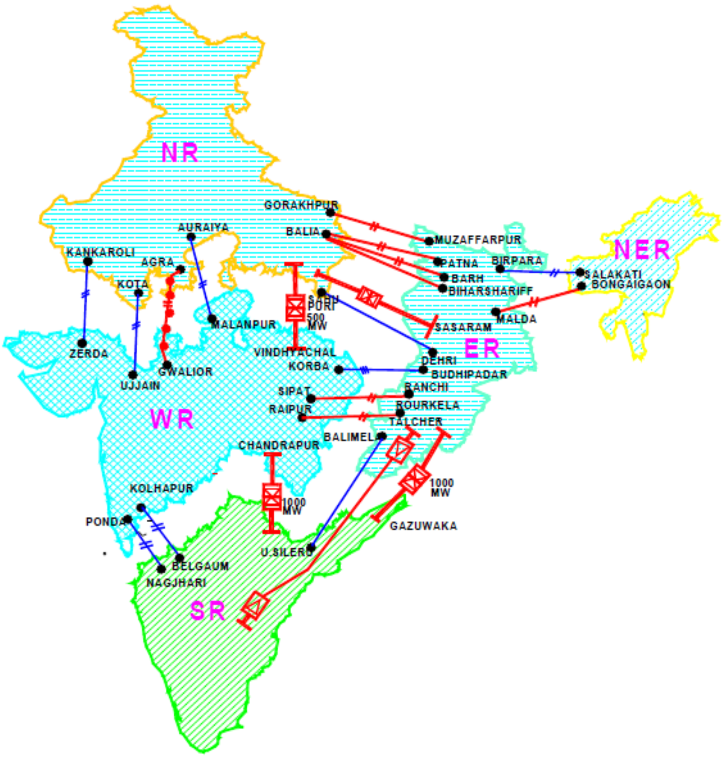

Fig. 4.2: Interconnecting Transmission Lines of India

There is approximately 90,000 circuit kilometres that is twice of route kilometres of line length transmission system in India having 400 kV AC network. This 400 kV network is mainly the bbackbone of the transmission system in India. Also there are transmission lines having 765 kV AC with line length of about 3120 circuit kilometres. Along with the HVAC System, HVDC networks are also installed which comprises of approximately 7,200 ckm of 400 kV system voltage, power of 5500 MW, +/- 500 kV long distance HVDC system. These are supported by about 1,23,000 ckm. of 220kV transmission network. As mentioned above, all the five regions are interconnected through National Grid comprising hybrid AC/HVDC system. Present inter-regional transmission capacity of the National Grid is about 20,800 MW.

4.2.5 Protection system

A relay is a logical element which takes the parameters like voltages, current, etc. as the input from the system or apparatus. Then it processes the parameters according to the conditions on which the relay is designed and then if it detects any kind of fault, it issues a trip decision. A block diagram of relay is shown in fig 4.3

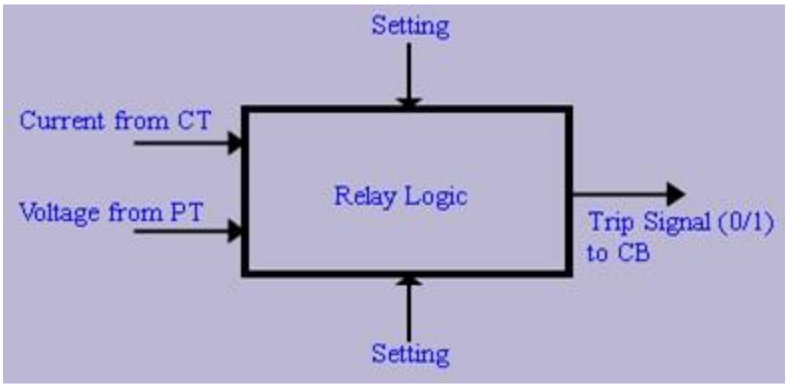

Fig. 4.3: Block Diagram of Relay

In fig 4.4, a relay R_1 is used to protect the transmission line under fault F_1. An identical system is connected at the other end of the transmission line relay R_3 to open circuit from the other ends as well.

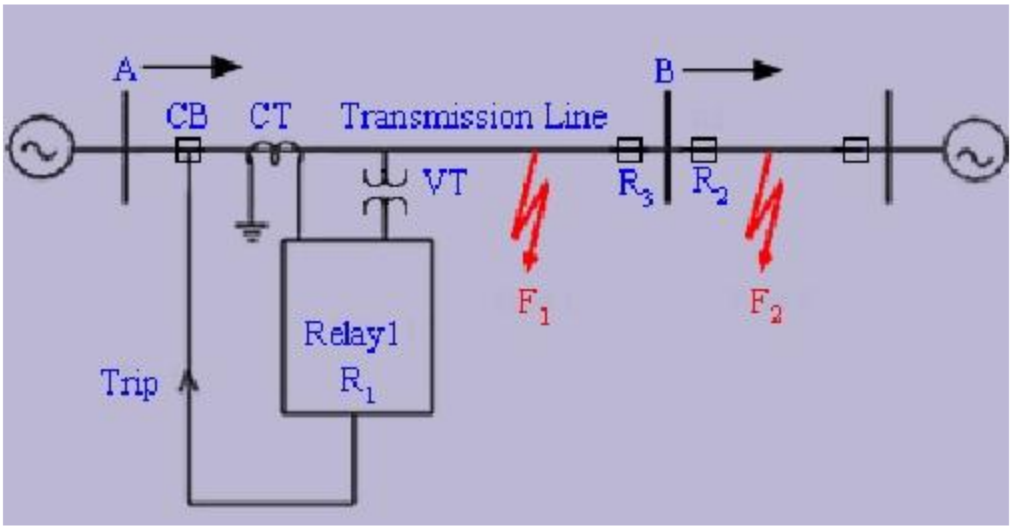

Fig. 4.4 Operation of Relay

As the real time values of the power system signals in terms of voltages and currents are very high, instrument transformers are used. A relay continuously monitors the value of voltages and currents from potential transformers (PT) and current transformers (CT) respectively. Voltage transformer (VT) is also known as Potential Transformer (PT).

The relay element processes these inputs and decides if there is an abnormal conditions or a fault, then compare it with the pre-defined values already set in the relay. If the abnormal conditions are under the prescribed one then relay does not gives any signal and if the abnormal conditions are above the prescribed values it sends a trip signal to the circuit breaker which opens the circuit, eliminating the faulty conditions and hence protecting the overall power system. By using all these equipments a grid system is prepared which represents the national grid of India which is synchronously connected that are northern, eastern, western and north-eastern. The simulation is carried out to analyse the cascading events which leads to the power outage. The simulation is performed with the help of DIgSILENT Power Factory software which is discussed briefly in next chapter.

CHAPTER 5
OVERVIEW OF SOFTWARE USED

5.1 INTRODUCTION

The software used for the simulation in this project is PowerFactory which is developed by DIgSILENT. DIgSILENT is a short form for Digital Simulation of Electrical Networks which was the first power system analysis software of the world with a single-line interface integrated graphically. Power factory software is a computer aided engineering tool which is utilized for the transmission analysis, distribution, and industrial power systems. It is basically an advanced integrated and interactive software package used in electrical power sytem and control analysis in order to achieve the main objectives of planning and operation optimization.

Following are some of the key features of the software:

1. Definition, modification and organization of the cases, core numerical routines, output and documentation functions are some of the core functions of the power factory software.
2. Data case handling and single line graphic are integrated and interactive features of this software.
3. Power system element and base case database.
4. Line and machine parameter calculation based on geometrical or nameplate information are some examples of integrated calculation functions.
5. Power system network configuration with interactive or on-line SCADA access.
6. Generic interface for computer-based mapping systems.

Analysis the power system about its equipments, stability, normal and abnormal conditions, protection, etc are done by the use of this software. In fig. 5.1 flow chart of analysis of power system is shown. The analysis can be broadly divided in system operation and system planning. Then the normal and abnormal conditions can be analysed in details with the help of this software. Therfore, this software can be used for detailed analysis of power system.

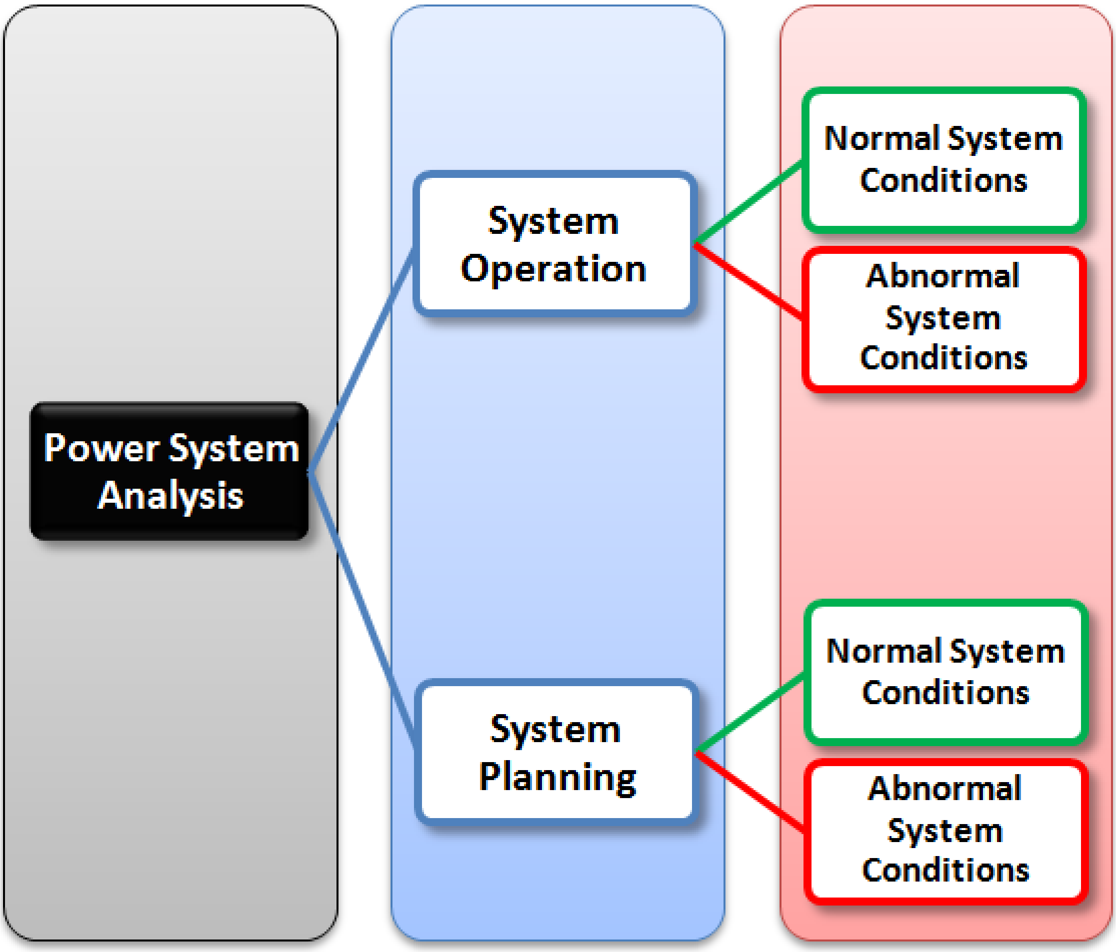

Fig. 5.1 Flow chart of Power System Analysis

To analyze power systems under steady-state non-faulted or short-circuit free conditions are carried out by the use of load flow calculation using power factory software. Where **steady-state condition** is defined as a condition in which all the variables and parameters for a particular period of observation are assumed to be constant. Basically load flow calculation is only performed in a steady state condition as it gives all the system conditions such as voltage at each bus, loading percentage of all the transmission lines, power generated by generators and absorbed by load, current values at every point, etc. for a certain point in time.

The main areas for the application of load flow calculations can be divided in normal and abnormal (Contingency) system conditions as follows:

5.2 Normal system conditions

In Normal System Conditions load flow calculation is used for the analysis of the initial conditions in steady state for stability simulations. Also complete superposition method I used for the short-circuit simulations. Optimization tasks are also performed such as to minimize the system losses, generation costs, open tie optimization in distributed networks, etc. analysis of voltage profiles, system losses and branch loading is also performed using load flow calculation.

5.3 Abnormal System Conditions

In abnormal system conditions also branch loadings, system losses and voltage profiles are calculated. Contingency analysis and network security assessment are analysed when the system is not in stable conditions. Optimization tasks, such as minimizing system losses, minimizing generation costs, open tie optimization in distributed networks, etc. are performed with the verification of system conditions during reliability calculations. Automatic determination of optimal system resupplying strategies, optimization of load shedding, calculation of steady-state initial conditions for stability simulations or short-circuit calculations using the complete superposition method (special cases) are observed during abnormal system conditions..

5.4 Simulation of normal operating conditions

The normal operating condition are the condition in which overloading is not present in the system. The generators generate active power as well as reactive power demanded by the loads. The load flow calculation basically represents the condition of system in which any branch or generator does not exceed its limit.

5.5 Simulation of abnormal operating conditions

As the whole system can't operate within the limits without any overloading, a higher degree of accuracy is desirable. The models should be selected such as the deviating conditions from the normal operating point must be correctly simulated. Hence the model must include the reactive power limits of generators and the voltage dependency. Instead, to determine the correct sharing of the active and reactive power generation, a more realistic representation of the active and reactive power control mechanisms have to be designed. Power Factory also offers an additional load flow method, named as "DC load flow (linear)", which determines the active power flows and the voltage angles within the network for the fast and reliable operation.

There are various integrating protective schemes in this software which enables the user to protect the system by selecting a suitable protection scheme in a network model. The software also allows the user to analyse the protection system characteristics by observing the graphical representation of the protection characteristics.

Models of Both generic and manufacturer specific relay models are already available in this software for the user. Graphical plots of the following characteristics are possible:

- Current Vs Time plots
- Distance Vs Time plots
- Impedance plots

5.6 RELAYS

The relays used for protection are designed in this software According to the requirements, the protecting relays are designed in this software by using following blocks:

- Relay frame
- Relay type
- Relay element

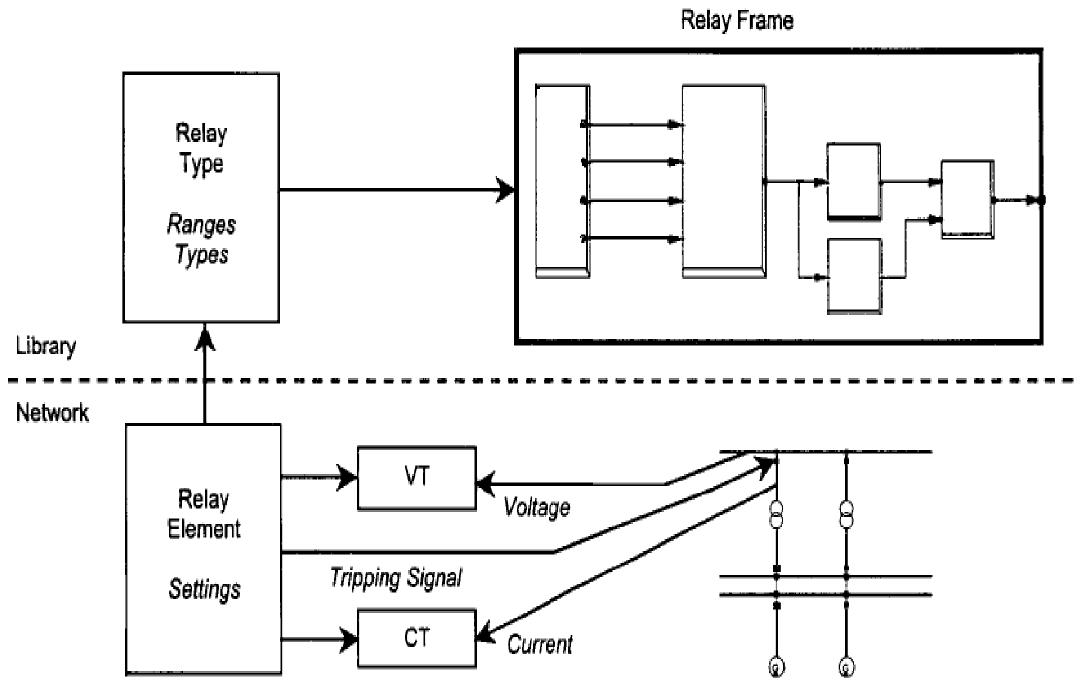

Fig. 5.2 Block diagram of relay structure

5.6.1 RELAY FRAME

The relay frame gives the specifications of the general relay functionality using a diagram in which functional blocks also known as slots are connected by signals. Slots for timers, measurement and logic elements can be defined. The number of stages that the relay consists and how these stages interact are defined by the relay frame.

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5.6.2 RELAY TYPE

There is a block definition for each slot of the frame which defines the relay type which is further associated with a specific relay frame. When a block definition is assigned to a slot, the slot is converted into a block where block definition represents a mathematical function which shows the behaviour of a physical element. In addition, the relay type specifies the ranges for the various relay settings, including finding the difference in parameters set continuously or in discrete steps.

5.6.3 RELAY ELEMENT

The relay element is also known as the actual relay in a power system as it performs the core functions of an actual relay. The relay type is referred to the library, which provides the complete structure including the setting ranges for all parameters in the relay. The relay type defines the actual settings of the relay such as reach or the pick-up settings, forms part of the relay element settings considering the range limitations.

CT and VT models are installed to step down the high values of the parameters and gives input to the relay element from the network. The output of a relay is a tripping signal which is sent directly from the relay element to the circuit breaker in the modelled system. To simulate bus bar protection, or any tele-protection schemes, a relay element can also operate more than one breaker to simulate bus-bar protection, tele-protection schemes.

5.7 OVER-CURRENT RELAY

The measurement block shown below calculates the measured signals through raw signals produced by the voltage or current transformers.

Fig. 5.3 Measurement block

The measurement block gives access to the user for setting the nominal values of current and voltage which are limited by the measurement unit type. Also the nominal voltage and/or current fields will be normally disabled if a relay does not need a nominal voltage or if there is only one nominal value to choose from, which is seen in the case of an over-current relay.

The directional block calculates the angle between a voltage or current phasor's polarization and an 'operating' current phasor. One can also select the relative angular position of the polarization current or voltage phasor.

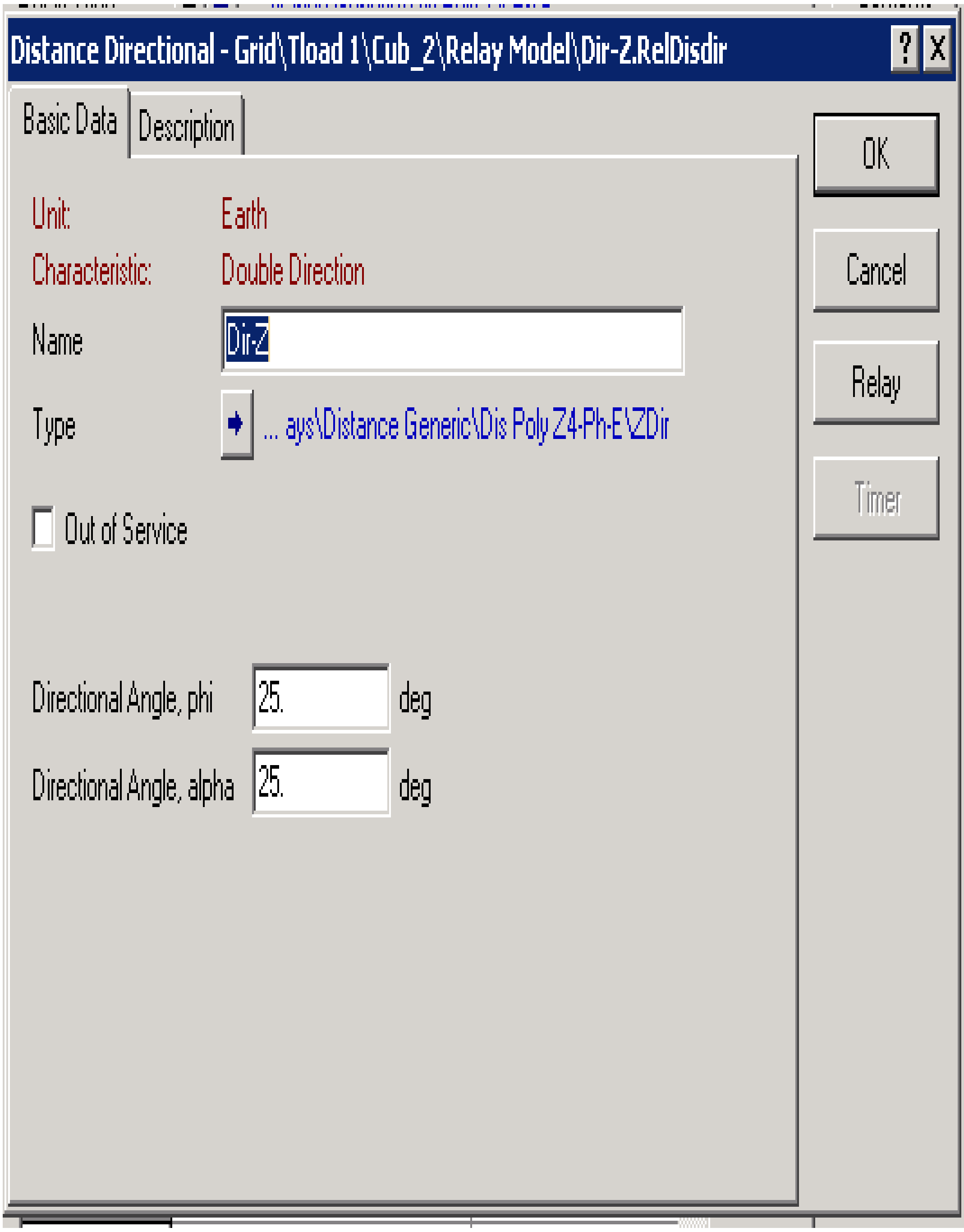

Fig. 5.4 Directional block of relay

If the angle between the operating and polarization phasor is less than 90 degrees and if the magnitude of the phasors are above the threshold setting.

The instantaneous over-current block allows for the time setting and setting of the pickup current. The setting ranges are defined by the type.

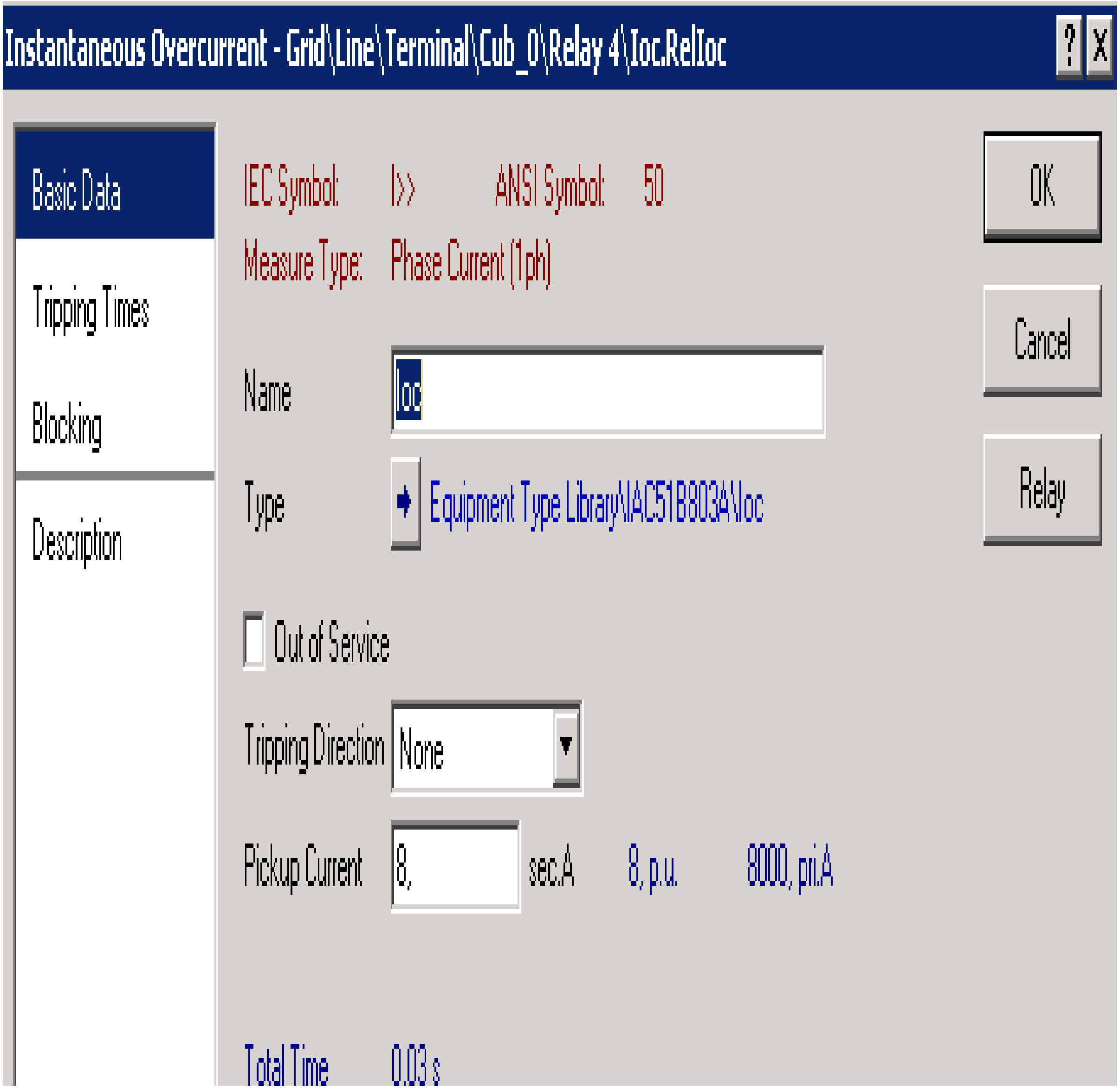

Fig. 5.5 Instantaneous over-current relay block

The instantaneous over-current block is a combination of a direct over-current relay and an optional time delay. Ts is the minimum pick-up time needed for the relay to react. Additionally, specification of Tset time dial may be given. Unless the current exceeds the pickup current Tsetr for at least Ts+Tset, block will not trip.

The time over-current block allows selection of one of the current-time characteristic which are available for the particular relay type. Furthermore, specifications of the pickup current and a time setting should be stated. Also the type of relay is specified as shown in the block below. The setting ranges are defined by the type.

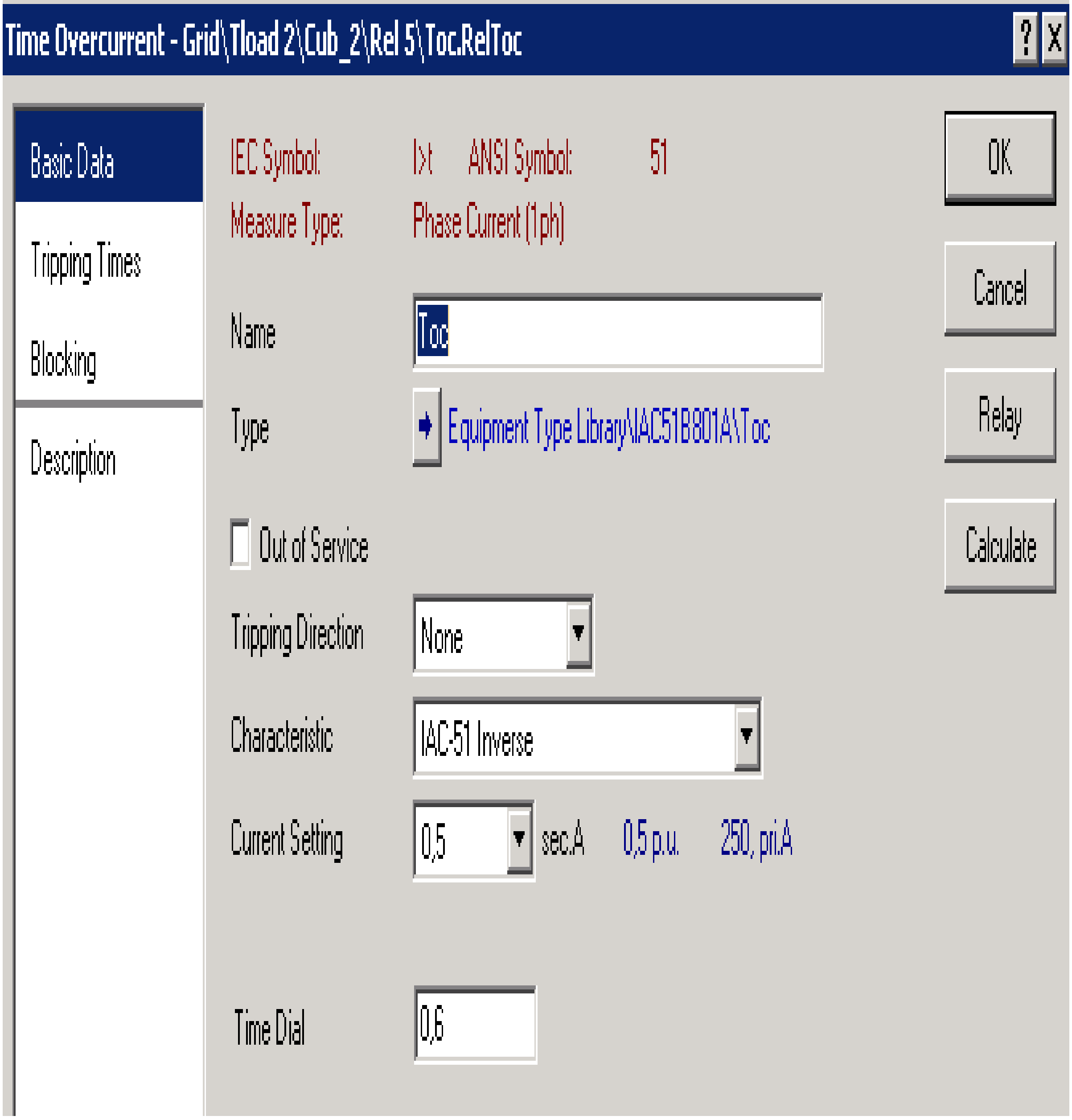

Fig. 5.6 Time Over-Current block

The logic block is the end part of a relay configuration. It processes the combination all internal trigger signals by successive AND and OR operations and then produces a single output.

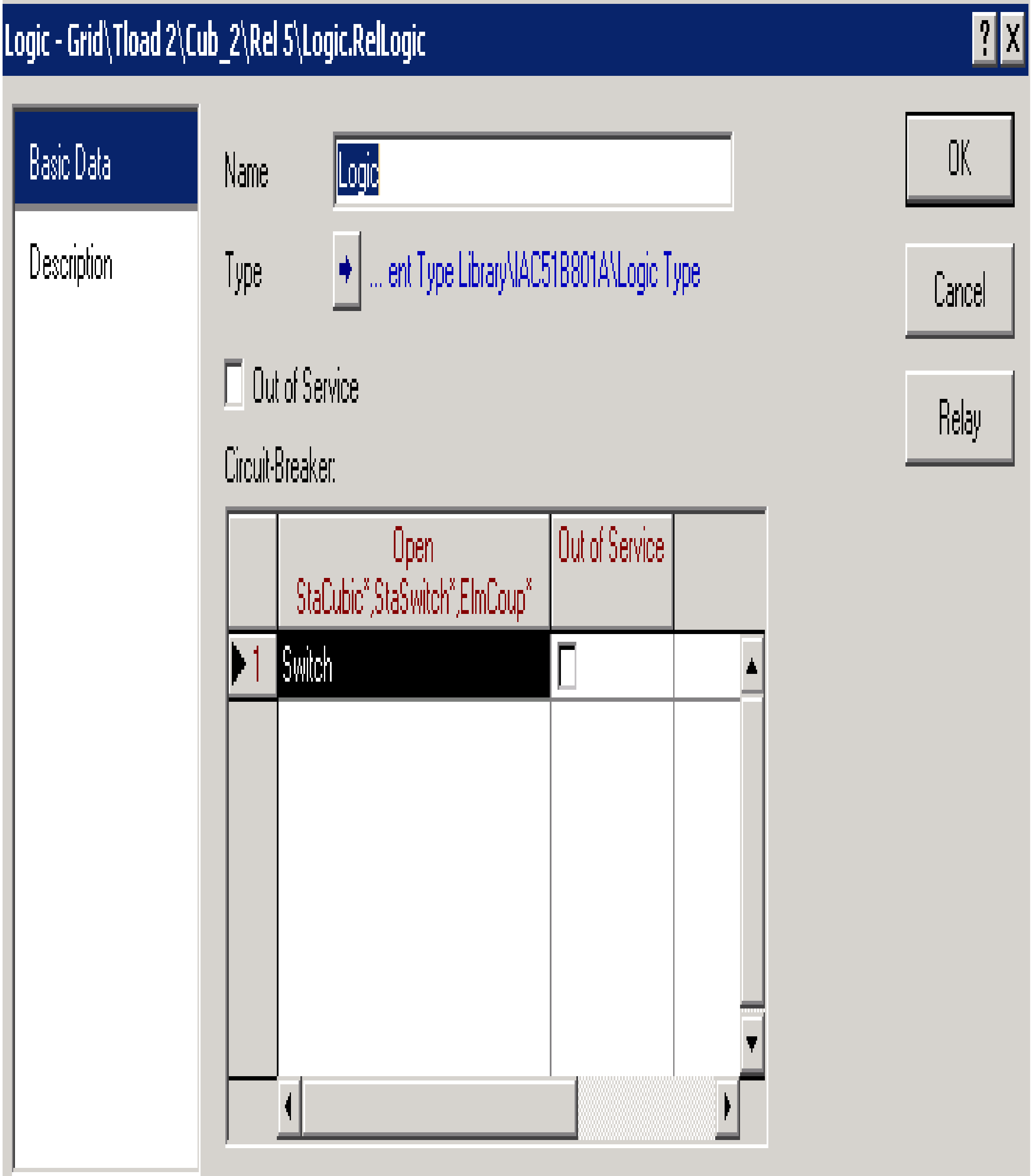

Fig. 5.7 The logic block

The logical operation is specified by the block type in which the logic block itself opens the switch if the parameter value exceeds from the threshold setting. Also if the relay is located at the cubicle and specification are not mentioned about any switch, the breaker is opened by default in the cubicle.

The overall block diagram of over-current relay is shown in figure below:

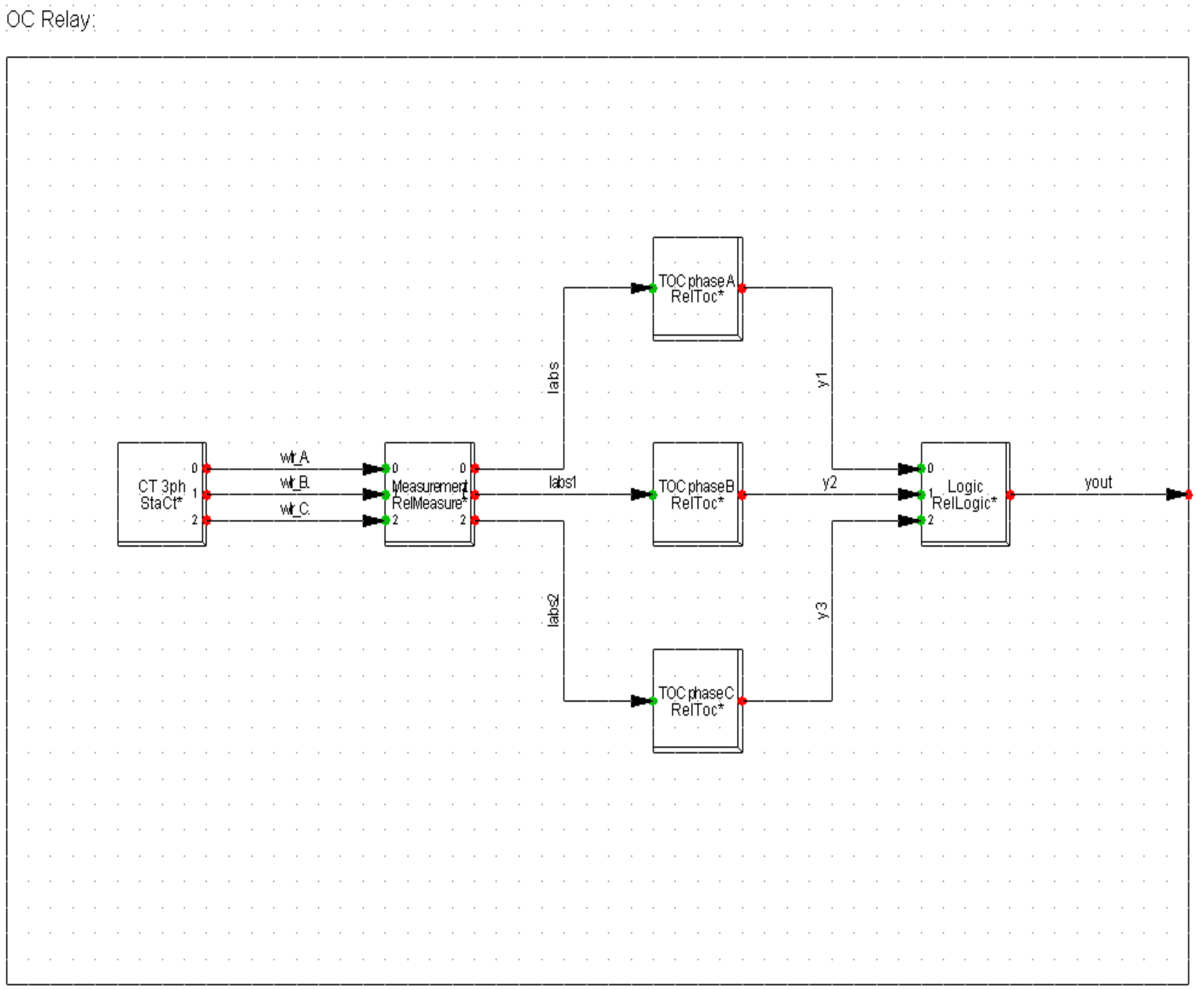

Fig. 5.8 Block diagram of over-current relay

5.8 FREQUENCY RELAY

The frequency measurement block unit is used to calculate the electrical frequency at any node for the given measured voltage. Per unit nominal voltage is required calculations in the frequency relay. The Frequency measurement time defines the time needed for calculating the frequency gradient.

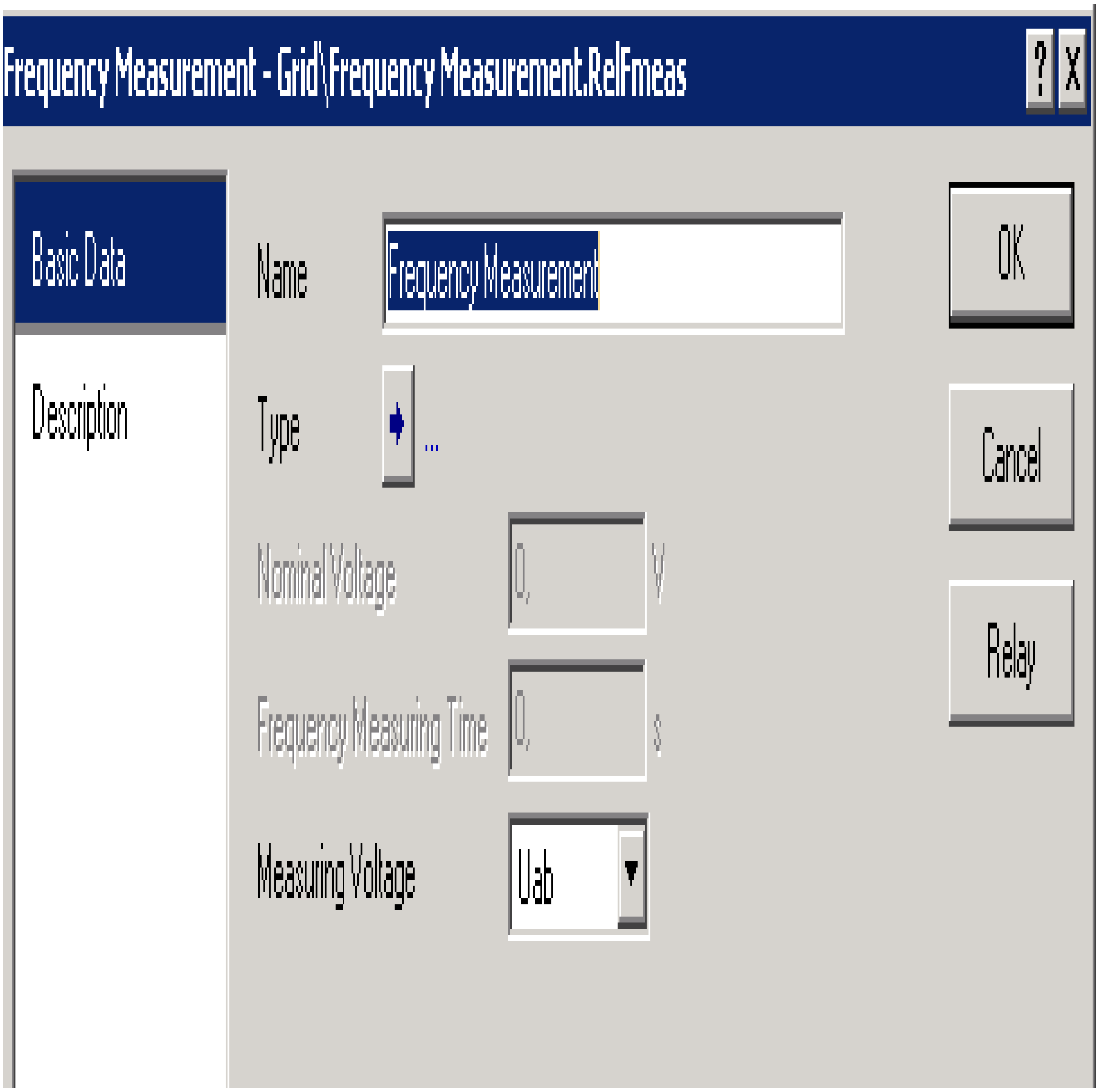

Fig. 5.9 Frequency measurement block

The frequency block has two conditions on which it trips the signal. One is for over/under frequency and another is for frequency gradient (Hz/s). The conditions are selected according to the type selected. The type also defines the reset time, during which the defined frequency conditions must also be mentioned again for the relay to reset.

The time delay set in the relay element defines the time during which the defined frequency condition must be violated for the relay to trip.

An option for out of service is also given in this block which is used if the block is not needed as per the requirement of the user.

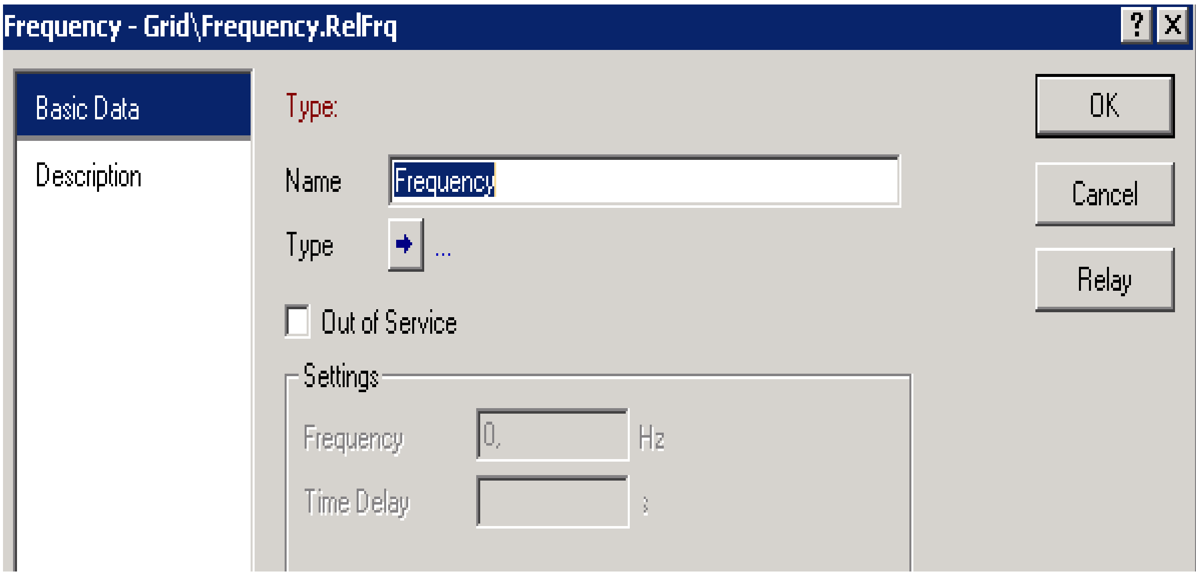

Fig. 5.10 Frequency block

The under/overvoltage block

The under/overvoltage relay type may define the block to trip on following:

• One of the three phase line to line voltages

• A particular voltage (line to line).

• The ground, positive sequence, and negative sequence voltage U0, U1, and U2 respectively.

The relay element allows only for setting of the pickup voltage and the time delay.

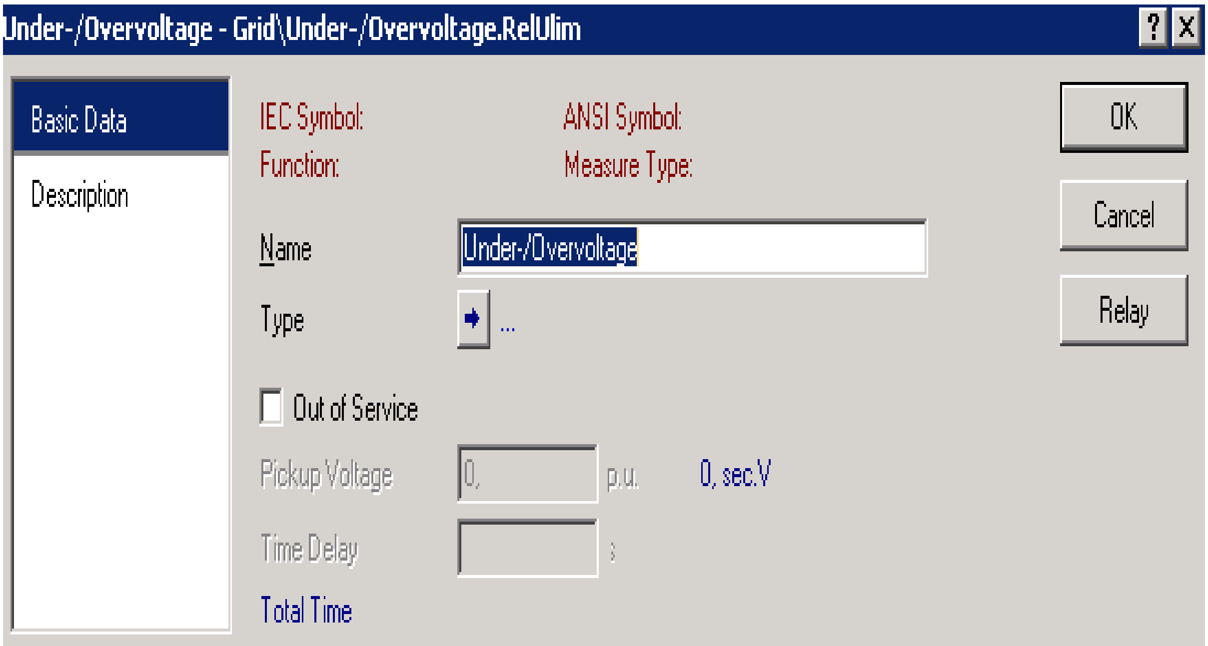

Fig. 5.11 under/overvoltage block

Using all these blocks, the frequency relay is deigned which can be used for protection from both over frequency as well as under frequency.

Similarly a directional relay is used to trip the circuit if the direction of the flow of power is changed. The power normally flows from the generating end to the load end, but if due to any fault or false operation of the system the power starts to flow from load end towards generating station. This can cause poor performance or can also even damage the equipments. For the protection, directional relay is used as a solution which trips the circuit if power flow reverses.

The over-current, frequency, directional, etc., relays are used in this model simulation as the protection system .

CHAPTER 6

SIMULATION OF BLACKOUT

6.1 Introduction

In order to simulate a grid colllaplse, the grid model described in previous chapters has been simulated using the power factory software which has been discussed briefly. Figure 6.1 shown below is the grid model simulated in DIgSILENT Power Factory software which is similar to simplfied indian grid system. The loading percentage is mentioned with all the equipments such as thermal and hydro generators, two winding transformers, transmission lines, general loads, etc.

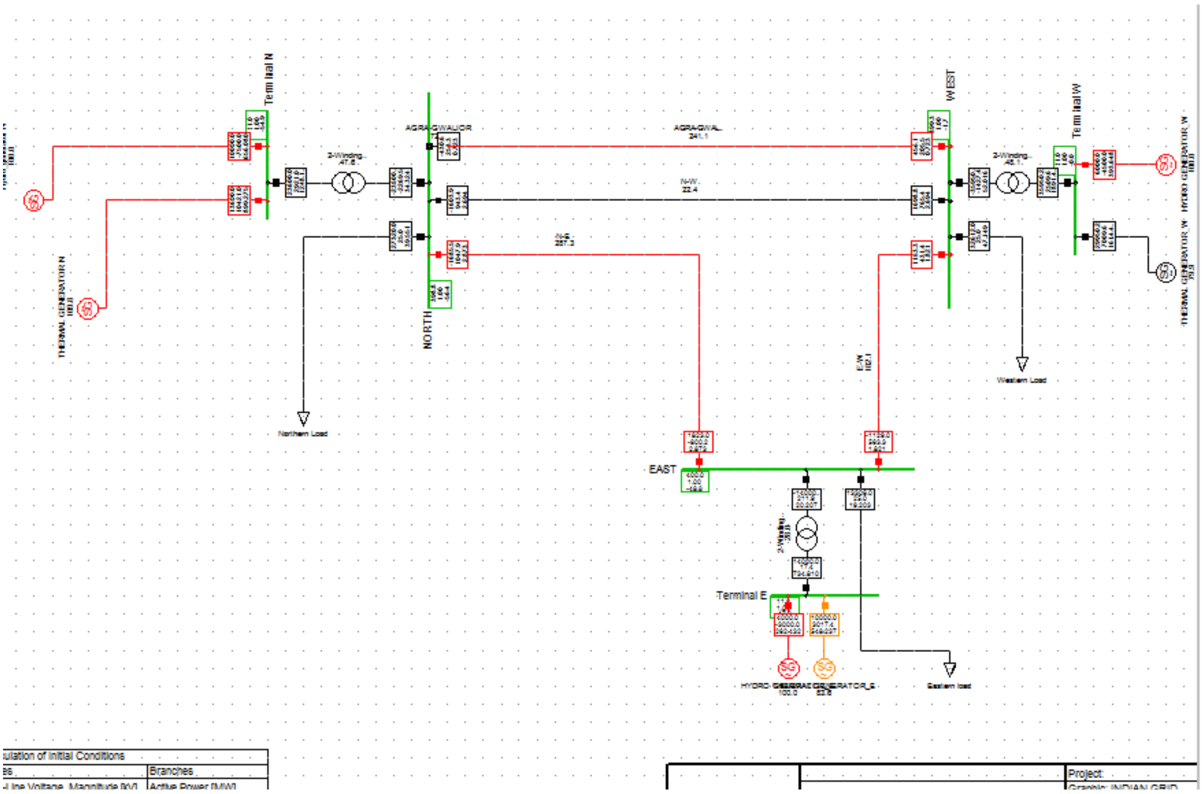

Fig. 6.1: Load flow grid model

6.2 Triggering of Grid collapse

It can be seen clearly that overloaded equipments present in the system is indicated in red colour giving information about the excess load carried which can lead to collapse of power system element.

To trigger a grid collapse an instance of first trigger has been initiated with removal of the transmission line connecting northern and western grids out for maintenance.

As soon as this line is taken off from the system, it led to various cascading events. Another line between northern and western grid becomes heavy overloaded and overcurrent relay operates which is working as a protection system for this line. This over-current relay switch off this transmission line also due to which unstable condition arises and frequency deviates from the default frequency. The frequency dips and rises in different areas due to which under-frequency and over- frequency relays operates respectively.

These frequency relays when operates trips out the generators, both hydro and thermal, due to which no demand is fulfilled and most of the areas witnesses blackout.

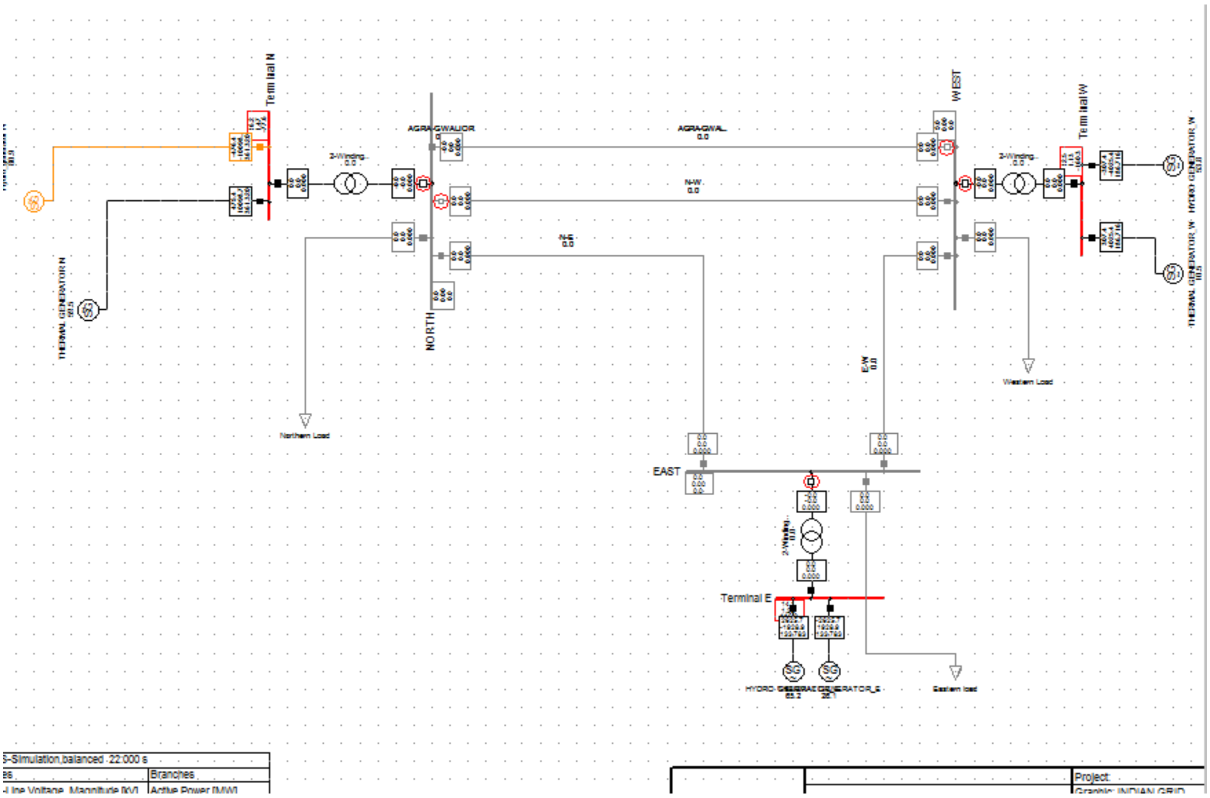

Fig. 6.2: Grid Model during Blackout

The end of simulation is shown in Figure 6.2. The small circles of red colour representing the events that took place after the Agra-Gwalior transmission line that connects northern and western grid was switched off. From the model given above it can be seen that no bus that are north, east, and west buses are neither giving any power nor it is absorbing any power. And the general loads are connected with these buses only, so they also do not absorb any power. This condition is nothing but a severe blackout due to these cascading events.

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6.3 Analysis of events

The simulation carried out in the software called DIgSILENT Power Factory gives the result in various forms such as datasheets, graphs, etc. following are some graphs plotted between some important parameters and time.
Fig. 6.3 shows that the current variation of the transmission lines interconnecting northern and western grid. For simplification, two transmission lines are considered out of which one is Agra-Gwalior line which is loaded for 400kV. It can be seen from the graph that this respective line is overloaded, so it is taken out for maintenance that is to make this line for 765kV. Due to this event, another line gets overloaded so the protective relay (over-current relay in this case) trips another lines resulting in the separation of northern and western grids.

In fig. 6.4 shows the terminal voltage variation of the transmission lines connecting northern grid to western grid. When the N-W transmission line is tripped out due to overloading by the over-current relay, at this particular instant the terminal voltage of this particular transmission line records a negative spike of voltage. After this instant the terminal voltage regarding N-W line starts increasing whereas voltage of Agra-Gwalior transmission line starts to reduce. After few seconds of separation of the northern and western grid the voltage of Agra-Gwalior transmission line turns out to be zero and after this the voltage of the N-W line also reduces to zero, indicating the bus terminal voltage to be zero representing the condition of power outage.

In fig. 6.5 shown below, the frequency (in Hz) variation with time can be analysed of all the three buses that are north, east, and west. It can be observed from the graph that initially the frequency is constant to 50 Hz. But as the Agra-Gwalior line is switched off and another N-W line is tripped out, deviation in frequency starts and it increases with time. The frequency of northern bus drops and the western grid frequency rise so that they can compensate the fault and make the deviation equals to zero. But after the separation of northern and western grid, there is a drop in frequency of both northern and eastern grid as for them the load demand is increased due to lack of power from western grid. After some time due to continuous operation of northern and eastern generators on reduced frequency, their capability is reduced due to which maximum load demand is to compensated through western grid. So the frequency of western grid is reduced and of the other two grids is increased. It is observed that as the frequency dips or rises above a certain value, it is tripped out by the under/over-frequency relay which isolated all the loads from generation. After some time when the frequency drops or rises above a certain limit that is allowed by the under/over frequency relay, the relay comes into action due to which all the general loads are separated from the generating ends.

Fig.6.6, graph is plotted between voltage(in p.u.) and time(in seconds). It can be observed from this graph that the voltage start deviating. Initially, the voltage is maintained at 1 p.u. but as the events starts after the agra-gwalior line switched off, power outage also known as blackout for long term is observed after few seconds.

In Fig.6.7, the variation of active power with time is shown. The load representing the total demand of northern, eastern, and western grids. The active power absorbed by the northern and eastern load keeps on decreasing because after the separation of northern and western grids, the load has been increased for northern and eastern grid due to which frequency reduces. Continuously operating on low frequency, their generating capability due to which maximum load demand is to be fulfilled by western load leading towards decreasing frequency for western grid and increasing frequency for northern and eastern grid. Further because of the protective frequency relays, loads are tripped out and hence the active power turned out to be zero for all the representing the blackout.

The active power absorbed by northern, eastern, western loads can be analysed with the help of this graph. The load demand of these loads represents the demand of northern region, eastern region, and western region respectively. After few seconds due to cascading events the power absorbed by the loads turned out to be zero, hence representing blackout condition as no consumer absorbs active power from the generating end.

The entire sequence of events resulting in blackout has been represented in flow chart in Figure 6.8. the events are cascading in nature and the figure itself explains that how power outage takes place only when a transmission line is removed.

6.4 Factors affecting the grid collapse

From the work carried out in this thesis, some important major factors contributing to grid collapse can be understood

a. Contribution due to Overloading
b. Contribution due to imbalance of power generation and load in the system
c. Contribution of system frequency and inertia of generators

d. Contribution due to relay setting

Overloading allows a transmission line to transfer power above its capability which degrades its performance. So, a protection system is installed for the transmission line to maintain its performance such as over-current relay.

Due to variation in load demand, power generation is also varied accordingly. Due to increase in load, generators has to supply demanded power which is above its capability which degrades the efficiency of generating systems.

Variation in load demand also varies the system frequency, which causes instability in the generators and causes degradation in the performance of the generators. A protection system is also installed for the protection such as frequency relay, directional relay, etc.

The protection system mostly comprising of the relays protects the essential equipments. Due to abnormal conditions, these protective relays operates and results in tripping and isolating the generating end from the loads.

These all factors contributes to the power outage for long duration known as Blackout.

The developed model hence can be used further for the study of individual factor causing the collapse and the rectification schemes can be tested on this system.

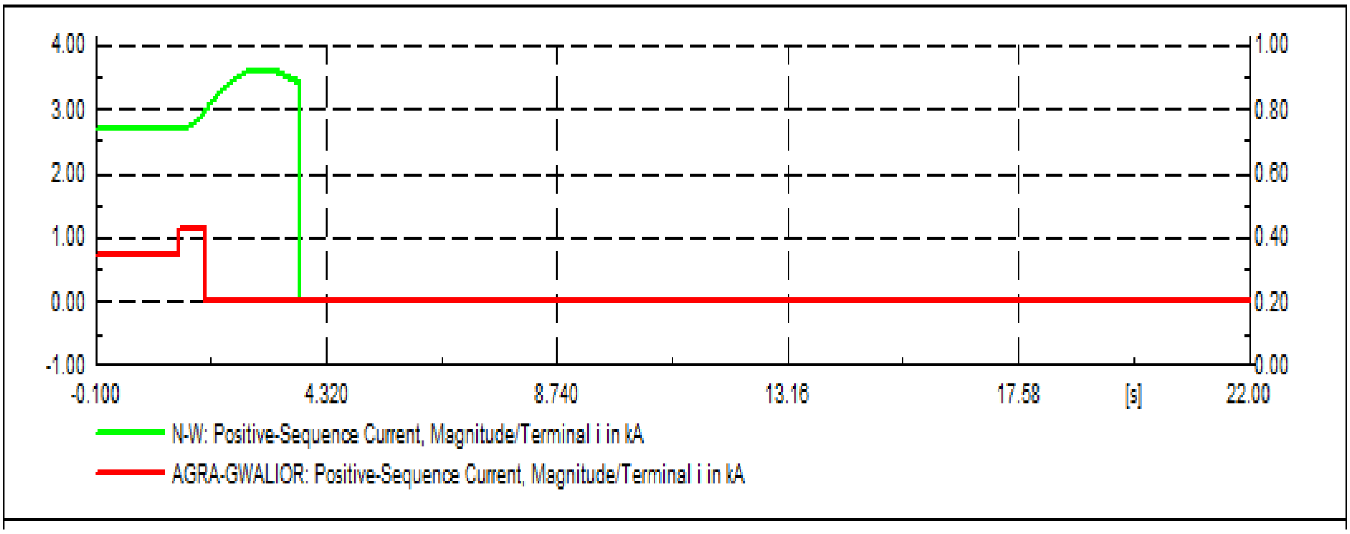

Fig. 6.3 Current variation of N-W and Agra-Gwalior transmission line

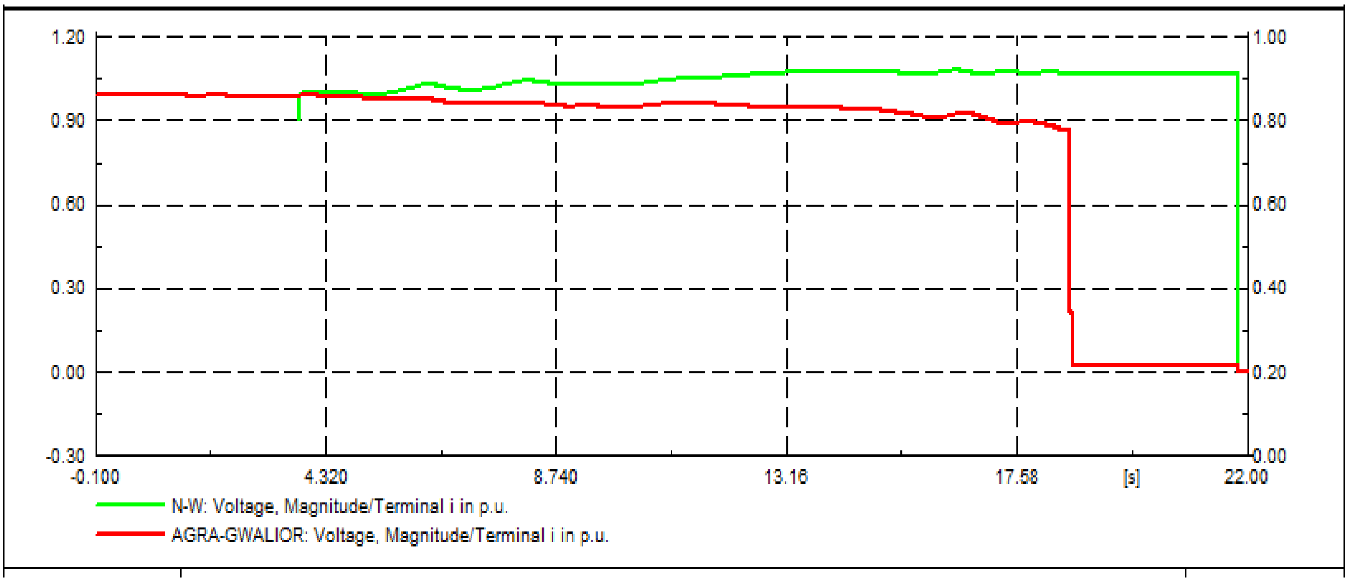

Fig. 6.4 Voltage variation of N-W and Agra-Gwalior transmission line

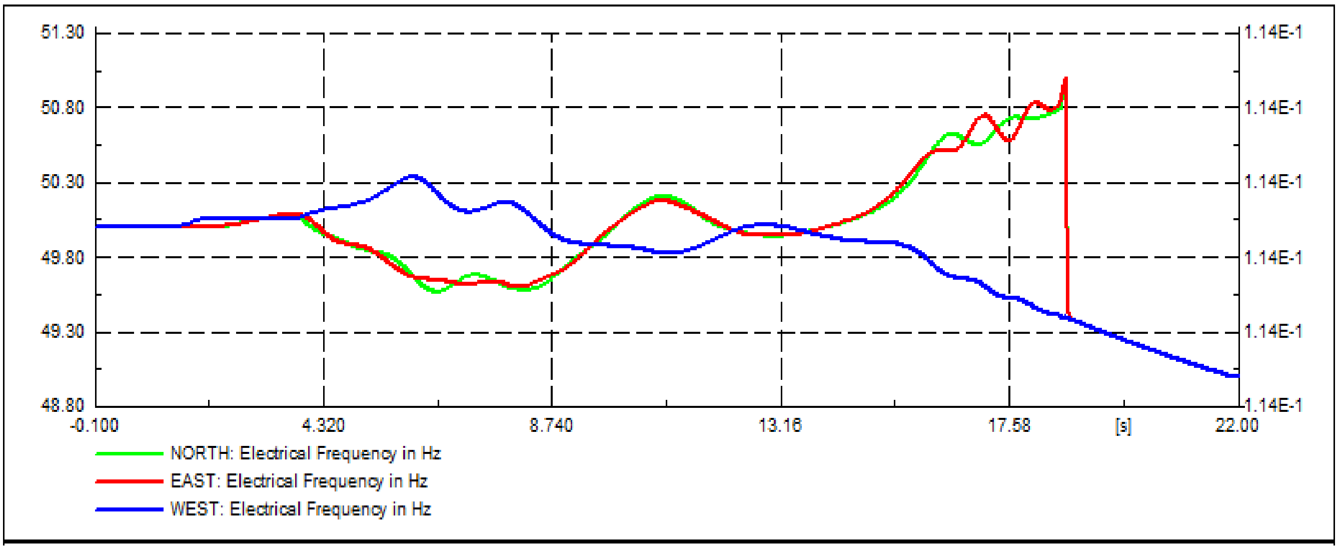

Fig. 6.5 Frequency variation North, East, and West buses

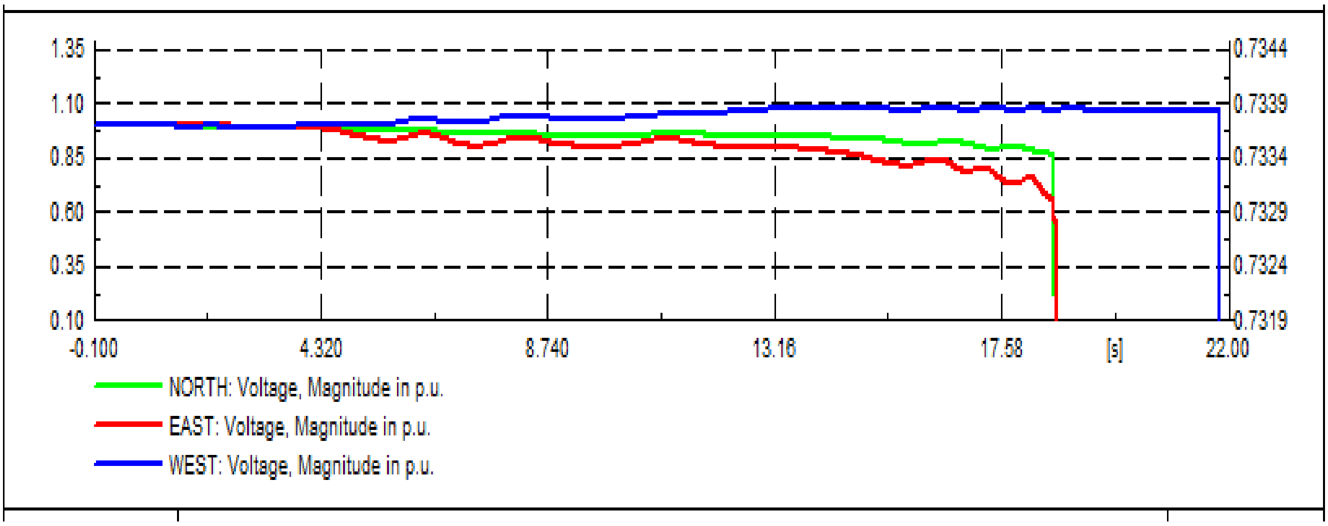

Fig. 6.6 Terminal voltage variation

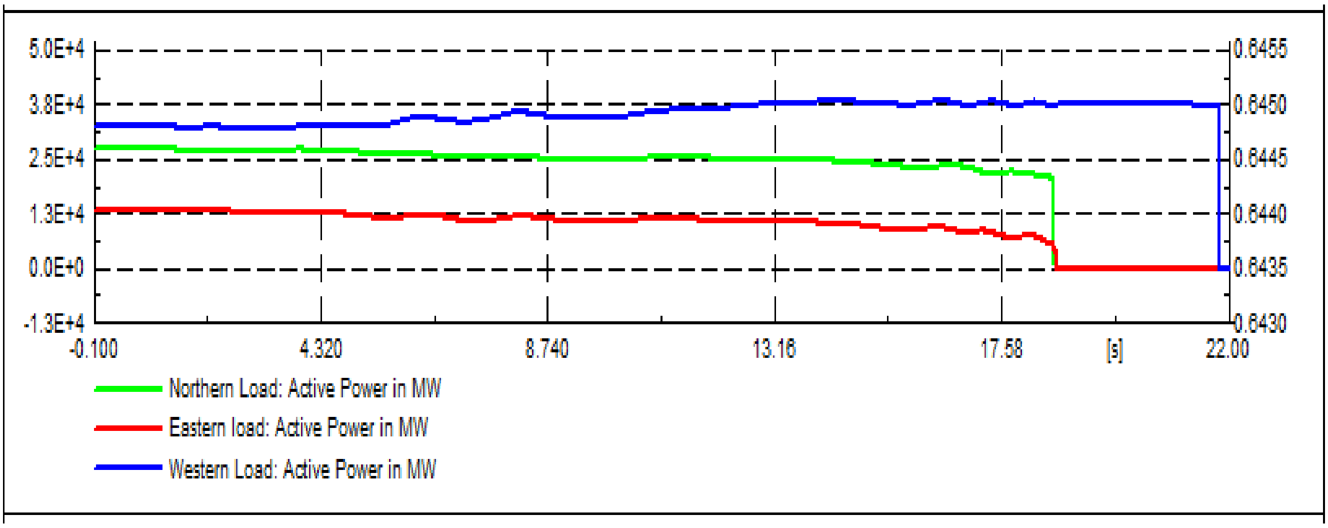

Fig. 6.7 Active Power variation of northern, eastern, and western load

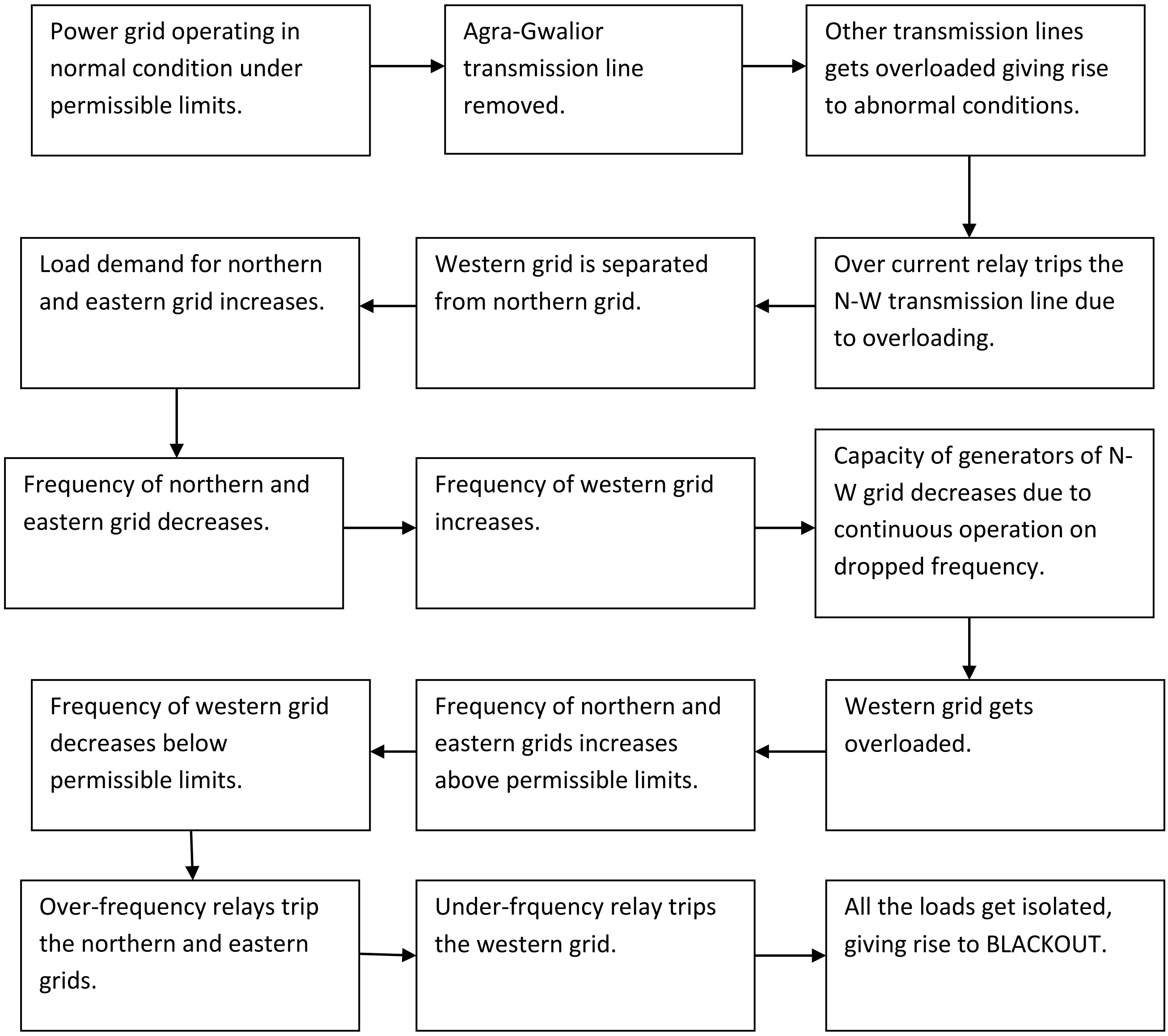

Fig. 6.8 Flow Chart Representing Sequence of Events

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

Blackouts are major catastrophic failures occurring especially in interconnected power systems. The system instability due to out-of-step condition, drop in voltage, and deviation of frequency can't be avoided. As due to any of these problems either individually or collectively may lead to the power outage, there should be necessary preventive measures installed.

In this thesis a prototype simulation model has been designed in Power factory software which simulates and analyses the blackout in detail. Detailed step by step events have been investigated with simulation of a blackout in developed model. In the developed model grid collapse has been triggered when a transmission line is switched off, resulting in overloading of other equipments and transmission lines. Overloading further results in increase of deviation in frequency, which is responsible for the abnormal conditions of the grid system which results in degradation and poor efficiency of the equipments such as generators, transformers, etc. These abnormal conditions trigger the protecting system which isolates the equipments from the grid system. Due to which grid is separated into different zones and finally isolates the loads from generation system. This is nothing but the power outage for the long-duration which is also called blackout.

This thesis work gives the step-wise description and results about the events related with the power grid system which causes power outage for long duration, also known as blackout. The reason behind these power outages has also been discussed. The detailed analysis tells about how the frequency, terminal voltages, terminal currents, and active power of the grid system behave during the cascading events that finally results in a Blackout.

FUTURE SCOPE

This model can be further extended or adopted to test mitigation techniques of grid collapse. Various preventive measures can be implied to avoid such severe conditions such as:

- Under frequency load shedding
- Under voltage load shedding
- Generation load shedding

- Rapid load shedding
- HVDC stability scheme with several functions such as Power Run-Up Function, Power Run-Back Function, Power Swing Damping Function and Frequency Limit Control Function.

This power grid model can be used as a benchmark for testing these preventive measures to avoid the severe blackouts. For example for the under-frequency load shedding method, only relay settings are to be modified by reducing the load with respect to the frequency. Also the under voltage shedding method can be analysed by monitoring the voltage waveform carefully and shedding the load accordingly. If any transmission line is tripped out due to any fault or maintenance purpose, other lines are overloaded due to which unstability arises which further results in power outage. In generator load shedding method , when a line is out of service the capacity of generators is shedded which protects the grid from further abnormal conditions. Other methods can also be studied using this model.

APPENDIX

A. GENERATION

Northern Region:

Hydro generation : 10000MW

Thermal generation : 13395MW

Eastern Region:

Hydro generation- : 3000MW

Thermal generation : 10196MW

Western Region:

Hydro generation : 6000MW

Thermal generation : 30647MW

TIE-LINE PARAMETERS

REGIONS	***WR-NR***	***WR-ER***	***NR-ER***
Voltage Level(kV)	400	400	400
Line Reactance (per km)	1.9623	0.2381	0.3333
Line Resistance (per km)	0.109	0.013	0.0185
Distance (km)	118	420	300
Surge Impedance(MW)	691	1600	1600

LOAD DEMAND

REGIONS	**DEMAND(MW)**
NORTHERN	38322
EASTERN	12213
WESTERN	28053
NORTH-EASTERN	1314

REFERENCES

[1] PowerFactory, DIgSILENT 14.1

[2] "Report of the enquiry committee on grid incident on 27th January 2007 in Northern Region".

[3] Charles Concordia, "Dynamic Performance and Security of Interconnected Systems", IEEE Power Engineering Review, Mar. 1992.

[4] Anjan Roy, P. Pentayya, and S. A. Khaparde, "Experience of Blackouts and Restoration Practices in Western Region of India", IEEE PES General Meeting, Denver, CO, USA, June 2004.

[5] An Indian Experience of Defense Against Blackouts and Restoration Mechanism followed Subrata Mukhopadhyay, Senior Member, IEEE, Sushil K Soonee, Senior Member, IEEE, Sundaram R Narasimhan, and Rajiv K Porwal, 2008 IEEE.

[6] Power System Blackouts - Literature review Arulampalam Atputharajah': 2,Tapan Kumar Saha 'School of Information Technology & Electrical Engineering, University of Queensland, Australia 2Department of Electrical and Electronic Engineering, University ofPeradeniya, Sri Lanka.

[7] Black Start in Power System - A case study in Western Region, India. U K Verma, Member, IEEE, S R Narasimhan Member, IEEE, A Gartia, Member, IEEE, P A R Bende, Aditya P Das and A K Gupta.

[8] Power System Blackouts - Literature review Arulampalam Atputharajah': 2,Tapan Kumar Saha' 'School of Information Technology & Electrical Engineering, University of Queensland, Australia 2Department of Electrical and Electronic Engineering, University of Peradeniya, Sri Lanka.

[9] A lesson learned from recent cascading outages: coupled interface and its impact on the smart-grid development- Wei Huang, Varun Perumalla, Di Wu, S. Hossein Hosseini, John N. Jiang, Senior Member, IEEE.

[10] Western Regional Load Despatch Centre Website (http://www.wrldc.com)

[11] P.M.Anderson and M. Mirheydar, "An adaptive method for setting Underfrequency Load Shedding Relays" *IEEE Transaction on Power Systems*, Vol. 7,No. 2,May 1992, pp. 720-729.

[12] P.Kundur, Power System Stability and Control, McGraw-Hill, Inc, 1993, pp. 10-12

[13] R.S.Sutton, A.G.Barto, and R.J.Williams, “Reinforcement Learning is Direct Adaptive Optimal Control,” *IEEE Control system Magazine,* April 1992, pp. 19-22.

[14] Pourbeik P.; Kundur P.S.; Taylor C.W.; The anatomy of a power grid blackout - Root causes and dynamics of recent major blackouts, IEEE Power and Energy Magazine, Vol 4, Pages: 22-19, Sept.-Oct. 2006.