Reliability Impact of Dynamic Thermal Rating System on Power System

LAI LIK CHIN

UNIVERSITI SAINS MALAYSIA

JUNE 2017

Reliability Impact of Dynamic Thermal Rating System on Power System

By

LAI LIK CHIN

Thesis submitted in partial fulfilment of the

requirement for the degree of

Bachelor of Engineering(Electrical Engineering)

JUNE 2017

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to my supervisor Dr. Teh Jia Shen for the guidance he provided. Besides, he timely involvement in criticizing my final year project has made my thesis a success.

Next, I would like to thank my examiner, Dr. Tay Lea Tien for her precious feedback on my final year project especially her insightful suggestion during my pre-viva voce.

Lastly, this thesis is dedicated to everyone who embarks on the field of future power technology.

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AC	Alternative current
AC-OPF	Alternative current optimum power flow
DC	Direct current
DC-OPF	Direct current optimum power flow
DTR	Dynamic thermal rating
ES	Energy storage
EENS	Expected energy not served
GA	Genetic algorithm
HL	Hierarchical level
TTF	Time to failure
TTR	Time to repair
MC	Monte Carlo
NERC	North American Electric Reliability Council
NSMC	Non sequential Monte Carlo
RTN	Reliability test network
SMC	Sequential Monte Carlo
STR	Static thermal rating

Kebolehpercayaan Impak *Dynamic Thermal Rating* pada Sistem Kuasa

ABSTRAK

Secara konvensional, penjanaan tenaga elektrik membawa jumlah besar pelepasan karbon dioksida. Pembinaan loji kuasa untuk memenuhi permintaan elektrik disebabkan oleh industrilization dan pembandaran akan membawa perubahan iklim. Untuk menangani krisis tersebut, teknologi elektrik mesti seiring dengan kemajuan teknologi terkink. Grid pintar boleh ditakrifkan sebagai grid kuasa yang boleh mengesan dan bertindak balas terhadap keubahan tempatan dan membolehkan komunikasi dua hala antara syarikat utiliti dan grid. Tesis ini bermula dengan menyediakan latar belakang penyelidikan yang termasuk struktur sistem kuasa, kaedah analisis sistem kuasa dan kebolehpercayaan sistem kuasa dalam bab 1. Seterusnya, IEEE standard 738, simulasi Monte Carlo dan analisis aliran kuasa Optimum telah dikaji dalam bab 2. Dalam bab 3, metodologi yang digunakan dalam tesis ini dijelaskan dengan terperinci. Contohnya simulasi Monte Carlo, kebolehpercayaan *Dynamic Thermal System* (DTR) dan analisis sensitiviti bagi sistem DTR. Selepas itu, analisis menggunakan kaedah yang dicadangkan dan membuktikan bahawa sistem DTR mampu meningkatkan kebolehpercayaan sistem kuasa dengan mengurangkan *Expected Energy Not Served* (EENS). Tambahan pula, didapati bahawa ujian *Reliability Test Network* (RTN) indeks kebolehpercayaan biasanya tidak sensitif terhadap kebolehpercayaan sistem DTR. Akhir sekali, kesimpulan dibuat dan kerja masa depan dicadangkan dalam bab 5.

Reliability Impact of Dynamic Thermal Rating System on Power System

ABSTRACT

Conventionally, generation of electrical energy comes with a large amount of carbon dioxide emission. The unceasing construction of power plant to meet the demand due to industrialization and urbanization will inexorably lead to climate change. To mitigate the crisis, the current electrical technology has to keep pace with the advancement of smart grid technology.Smart grid technology can be defined as the power grid that can detect and react to local changes and allow two-way communication between the utility company and the grid. This thesis begins by providing the research background that includes structural of the power system, the method of power system analysis and power system reliability in chapter 1. Next, IEEE 738 standard, Monte Carlo simulation and Optimum power flow analysis have been reviewed in chapter 2. In chapter 3, the methodology used in this thesis is explained in detail such as sequential Monte Carlo simulation, reliability impact of Dynamic Thermal Rating system(DTR) and sensitivity analysis for DTR system. Thereafter, the analyses are performed by using the proposed methodology and proved that DTR system is able to improve the reliability of power system by reducing Expected Energy Not Served (EENS). Furthermore, it was found that Reliability Test Network(RTN) reliability indices are normally not sensitive toward the reliability of the DTR system. Lastly, a conclusion is made and future work is suggested in chapter 5

CHAPTER 1

INTRODUCTION

1.1 Research Background

Electric power systems are evolving into more complex, higher reliability and more efficient over a few decades to meet the escalating demand due to increase in population, constructions of new industry and many others[1],[2].

In order to achieve adequacy and continuity power supply in the event of failure or outages and regular maintenance of power plants, there are some preventive methods such as preparation of spare or redundant capacities. However, the degree of redundancy abide in economy constraint is often a knotty problem for the power system planner as overinvestment will lead to excessive operating cost. Underinvestment, on the other hand, will lead to an inadequate reliability of the power system [3].

1.1.1 Method of Power System Analysis

There are two methods of power system assessment. There is analytical and simulation. An Analytical method is accepted widely in the industry because it provides sufficient data for planners and designers. However, some significant data or information may be lost due to assumption making for analytical method. Additionally, a realistic complex power system is impossible to be assessed. Because of that, the probabilistic method has to be considered, that is Monte Carlo simulation. One of the main reasons to use simulation method to assess the reliability indices of the power system is that actual behavior and mechanism of the power system are taken into account. Therefore, a clear picture of deficiency of the system may face will be obtained. Moreover, the behavior of power system is stochastic in nature. Therefore, the probabilistic technique is used to respond this characteristic.[4]

For the probabilistic method, there are two types of the simulation process, namely non-sequential Monte Carlo and sequential Monte Carlo simulation. In this research, sequential Monte Carlo simulation is used because the ambient conditions such as wind speed, wind angle to the transmission line, temperature are changing time from time to time and the thermal rating of the transmission lines are influenced by all these ambient conditions[5].

1.1.2 Structural of Power System

A modern power system is often large and complex. Thus, the power system is divided into few main functional zones. There are generation facilities, transmission facilities, and distribution facilities.These functional zones can be grouped into three hierarchical level(HL). HL 1 refers to generation facilities. It is not included transmission problem since it only concerns about the ability of generation system to satisfy the power demand.

The second level HL2 refers to the composite generation and transmission system. This level unlike the previous one, it concerns about the ability to deliver energy to the bulk supply points. For this reason, optimum power flow is used to calculate the load flow. There are two types of OPF, alternating-current optimum power flow, and direct-current optimum power flow. The difference between AC-OPF and DC-OPF is that AC-OPF calculates the reactive power flows which have an effect on the voltage levels while DC-OPF only concern with real power flows.

HL3 refers to the complete system including distribution system. Satisfaction of the capacity and energy demands of individual consumers is taken into account at this level [3]. However, analysis HL3 is unnecessary because it is too complex and it takes too much time be simulated. In this project, HL2 is used to simulate and direct-current optimum power flows(DC-OPF) is performed.

1.1.3 Power System Reliability

The main purpose of the power system is to provide power to customers with an acceptable level of reliability and quality[6]. Providing high reliability and quality of power is essential as the demand for power is getting more with time. Beside population factor, several inventions like the electric car, air-conditioner, heater are the main source of power consumption. Therefore, it can clearly be seen that society today highly rely on power, increasing the reliability of power system is one of the main concerns of engineering design today. The reliability of power system can be defined as the ability of power system meet the demand with a satisfactory amount of electricity continuously. In other words, the more reliable of a power system, the less outage will be.

According to North American Electricity Reliability Council(NERC), system balance, thermal balance, system resiliency and system reliability are the objectives included in the reliable designs of power system[7].

1.2 Problem Statement

The necessity to compare several methods for power system reliability evaluation has been continuing and increasing. Therefore, IEEE 24 Bus Reliability Test System(24 bus RTN) is to provide the basic data needed for the evaluation. The reliability and transmission capacity of a modern power system can increase through dynamic thermal rating system(DTR system) and this evaluation can be done by the 24 Bus RTN. On top of that, the degree of reliability of a power system can be obtained by Monte Carlo simulation. However, there are few problems can be arisen in DTR system and the method to get the reliability.

1. The solve large and complex power system problem which analytical method can not provide.
2. To improve the reliability of power system by using DTR system.

1.3 Objective of Research

The main objectives of this project are:

1. To investigate the impact of implementing Dynamic Thermal Rating using IEEE 24-bus Reliability Test System
2. To conduct sensitivity analysis of DTR reliability indices on power system using IEEE 24 Bus Reliability Test System

Dynamic Thermal Rating System technology is getting important as the demand for energy is escalating. The scarcity of land is one of the factors that urge to develop an alternative way to solve the problem stated previously. In this project, the high reliability and feasibility of DTR will the .

1.4 Scope of Research

In this research, Monte Carlo Simulation is used to get the reliability of a power system. IEEE 24 Bus Reliability Test Network is utilized in this research. The optimum DC power flow is obtained by using MATPOWER While the thermal rating of a transmission line is determined by IEEE Standard 738-2006.

1.5 Thesis Outline

Chapter 2 is a literature review. This chapter includes the related researches carried out by other experts. The advantages of using Monte Carlo simulation is also included.

Chapter 3 is the methodology which describes overall flow of work of the project. This chapter included IEEE 24 bus Reliability Test Network (RTN) used in this research.

The steps of implementing Monte Carlo simulation will also be discussed. Besides that, IEEE Standard 738-2006 will be used to be the standard to calculate the thermal rating of transmission lines.

Chapter 4 will study the results and problems of the research. The discussions for the results and analysis will also be given in this chapter.

The last chapter is the conclusion. In this chapter, the results and discussions will be concluded and some future improvements and advice will be proposed in the chapter.

1.6 Summary

This chapter gives an overview of this project. The current power grid is transforming into smart grid system to provide higher reliability and quality to the society. Nevertheless, smart grid system can not be fully implemented nowadays due to current technology limitation. Despite that, there are still many research interests in the electrical industry to enhance the transmission system. Among the employed methodologies, the dynamic thermal rating (DTR) of transmission lines will be focused on this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this project, IEEE 24 Bus Reliability Test Network serves as a large realistic power system and it is to be simulated by using Monte Carlo Simulation. The main purpose of the simulation is to imitate the stochastic behavior of power system. Theoretically, by considering all the states like transmission statues, generation statues, DTR sensor statues, the simulation can describe the actual reliability of the power system but it is impossible to study all of them due to the massive amount of the states involved.

For complex realistic power system, many failure state selection techniques such as cut-set, fault-tree, Markov state selection and analytical are not feasible for large complicated system analysis. The common method to simulate a large complicated power system is Monte Carlo technique. Therefore, Monte Carlo method is utilized in this project and it is discussed next.

In a DTR system, the weather conditions are periodically updated to calculate the maximum thermal rating. This is different from Static thermal rating(STR) which only give a fixed rating based on conservative weather assumptions. Because of that, the full utilization of line capacity has been limited. As a result, by implementing the DTR technology, power congestion can be eased or even solved. Besides that, the needs to construct new power stations or new transmission system can be avoided or reduced [8]. In this chapter, DTR technology will be reviewed in detail including the method to conduct the research.

2.2 Line Thermal Rating

Conventionally, the line rating of a power system is static thermal system due to its unsophistication implementation. It is determined by weather data of a region and the electrical properties of a conductor. Then, based on the risk level that power utility company is willing to accept, a low probability of exceeding the conductor maximum thermal rating are chosen to be the static thermal rating of the conductor.

Despite the simplicity of implementing the static thermal rating system, there is still a small probability of exceeding the maximum rating of the conductor as the weather can be worse than conservative weather assumption occasionally. It could damage the conductor in this case. Furthermore, the static thermal rating system has another weakness, that is underutilization of the line capacity since its rating is determined by a set of conservative weather condition which weather condition is not that worse most of the time.

To implement the dynamic thermal rating system, sensors to collect weather data must be installed. The weather data collected will be used to calculate the real-time line rating of the conductor by using IEEE 738 standard. The sensors to collect those data can be divided into two types, direct method devices, and indirect method device. The direct device like weather monitoring sensor gets all the necessary data that stated in IEEE 738 standard. On the other hand, weather conditions are not measured in the indirect method. Some devices are used like sag monitoring devices and line tension monitoring devices get the data by measuring the line sag and line tension respectively. The conductor's sagging and tension values reflect the weather conditions. However, special formulas are needed to calculate the line rating.

2.2.1 Dynamic Thermal Rating System

The DTR used in this project is according to IEEE Standard 738-2006. The purpose of the standard is to disclose the approach of calculating the current-temperature relationship of bare overhead conductors. The conductor surface temperature is the main concern in this topic and it is a function of conductor material properties, conductor diameter, conductor surface condition, ambient weather condition and conductor electrical current. The equation can be used in either way that is to calculate the conductor temperature when the electrical current is known or to calculate the current to gain the maximum allowable conductor temperature [9].

Conventionally, the calculation for static thermal rating uses the worst case situation. For example, low wind speed (2ft/s) and high ambient temperature(40-degree Celsius) are used to determine the STR for overhead cable. For power transformer, a whole day high temperature (40 degree Celsius) is assumed. While underground cable, low soil thermal resistivity (90°C-cm/watt) is the [10]. Consequently, the line capacity is actually can carry much more current than this since it is not all the time in the worst case condition, Figure 2.1 depicts that DTR is higher than STR most of the time, Therefore, full utilization of line capacity is ensured [11]. Moreover, DTR can increase the reliability of power system also since it is the real-time monitoring system. If the weather condition is worse than the condition assumed for determining the thermal rating of the transmission line, thermal overloading can be avoided from overheating by lowering the current transmission. The weather condition data can be obtained by installing sensor mounted on transmission line tower or using weather model.[11]

2.2.2 Line Thermal Rating Calculation

There are two mainstream standards, IEEE standard 738 and CIGRE, they both use the heat balance concept which is supported by the first law of thermodynamics. However, the calculated result may be slightly different between the two standards because their method to the problem are not the same although the same set of data is used. In this project, IEEE Standard 738 is used and it will be discussed below.

Thermal behaviour of a bare overhead line can be described under steady-state condition using (2.1).

$$Q_c(T_c,T_a,V_w,\phi) + Q_r(T_c,T_a) = Q_s(\theta) + I^2R(T_c) \qquad (2.1)$$

Where,

Q_c	Convective heat loss
Q_r	Radiative heat loss
Q_s	Solar heat gain
I	Conductor ampacity
R	Conductor resistance
T_c	Conductor temperature
T_a	Ambient temperature
V_w	Wind speed
ϕ	Wind angle
θ	Solar angle

Joule Heating

The joule heat gain of a bare stranded conductor is given by Equation 2.2

$$Q_j = I_{ac}^2 R(T_c) \tag{2.2}$$

Convective cooling

$$Q_{c1} = \left[1.01 + 0.0372(\frac{D\rho_f V_w}{\mu_f})^{\wedge}0.52\right] k_f K_{angle}(T_c - T_a) \tag{2.3}$$

$$Q_{c2} = 0.0119(\frac{D\rho_f V_w}{\mu_f})^{\wedge}0.6 k_f K_{angle}(T_c - T_a) \tag{2.4}$$

Where,

D	Conductor diameter
ρ_f	Density of air
V_w	Wind velocity
k_f	Thermal conductivity of air at temperature T_{film}
μ_f	Dynamic viscosity of air
K_{angle}	Wind direction factor
T_{film}	Average temperature between T_c, T_a

The_K_{angle} is determined using the one of the equations below. The angles ϕ and β are complements of each other. ϕ is the angle between the wind direction and conductor axis. While β is the angle between wind direction perpendicular to the conductor axis.

$$K_{angle} = 1.194 - \cos(\phi) + 0.194\cos(2\phi) + 0.368\sin 2\phi \tag{2.5}$$

$$K_{angle} = 1.194 - \sin(\beta) - 0.194\cos(2\beta) + 0.368\sin(2\beta) \qquad (2.6)$$

When there is no wind speed, natural convection equation used and it is given in Equation 2.7

$$Q_{cn} = 0.0205\rho_f^{0.5}D^{0.75}(T_c - T_a)^{1.25} \qquad (2.7)$$

Radiative Cooling

The equation of radiative cooling is given by Equation 2.8 as shown below, ε is the emissivity of the conductor.

$$Q_r = 0.0178D\varepsilon\left[\left(\frac{T_c+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right] \qquad (2.8)$$

Solar Heating

The solar radiation heat gain is given in Equation 2.9

$$Q_s = \alpha Q_{se}\sin(\theta)\,A' \qquad (2.9)$$

Q_{se} is calculated by the Equation 2.10 below

$$Q_{se} = K_{solar}q_s \qquad (2.10)$$

Where,

K_{solar}	Solar altitude correction factor
q_s	Total solar and sky radiated heat flux rate

The value of q_s is based on the clarity of the atmosphere. In IEEE 738 standard, only clear and industrial atmosphere condition are taken into account. It is calculated as in Equation 2.11

$$q_s = A + BH_c + CH_c^2 + DH_c^3 + EH_c^4 + FH_c^5 + GH_c^6 \qquad (2.11)$$

A,B,C,D,E,F and G	Constant
H_c	Altitude of the sun

H_c is calculated base on the Equation 2.12

$$H_c = \arcsin[\cos(Lat)\cos(\delta)\cos(\varpi) + \sin(Lat)\sin(\delta)] \quad (2.12)$$

Lat	Latitude
δ	Solar declination
ϖ	Number of hours from the local sun noon times, 15^0C

δ and θ are obtained from the Equation 2.13 and 2.14 respectively

$$\delta = 23.4583\sin\left[\frac{284+N}{365}360\right] \quad (2.13)$$

$$\theta = \arccos[(H_c)\cos(Z_c - Z_1)] \quad (2.14)$$

Z_c	Azimuth of the sun
Z_1	Azimuth of the line(constant)

The azimuth of the sun can be calculated by Equation 2.15

$$Z_c = C + \arctan(\chi) \quad (2.15)$$

C	Constant(can be obtained from the IEEE 738 standard)
χ	Solar azimuth variable

Solar azimuth can be obtained by Equation 2.16

$$\chi = \frac{\sin(\varpi)}{\sin(Lat)\cos(\varpi) - \cos(Lat)\tan(\delta)} \quad (2.16)$$

Once all the variables are known, the maximum allowable current capacity of the conductor under steady-state can be calculated as follow:

$$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R(T_c)}} \tag{2.17}$$

Since the transmission lines consist of many spans and their conditions are different from place to place. Therefore, the lowest value of allowable currents calculated is used as the line rating. Figure 2.1 shows the difference between DTR and STR in term of line rating over 200 hours.

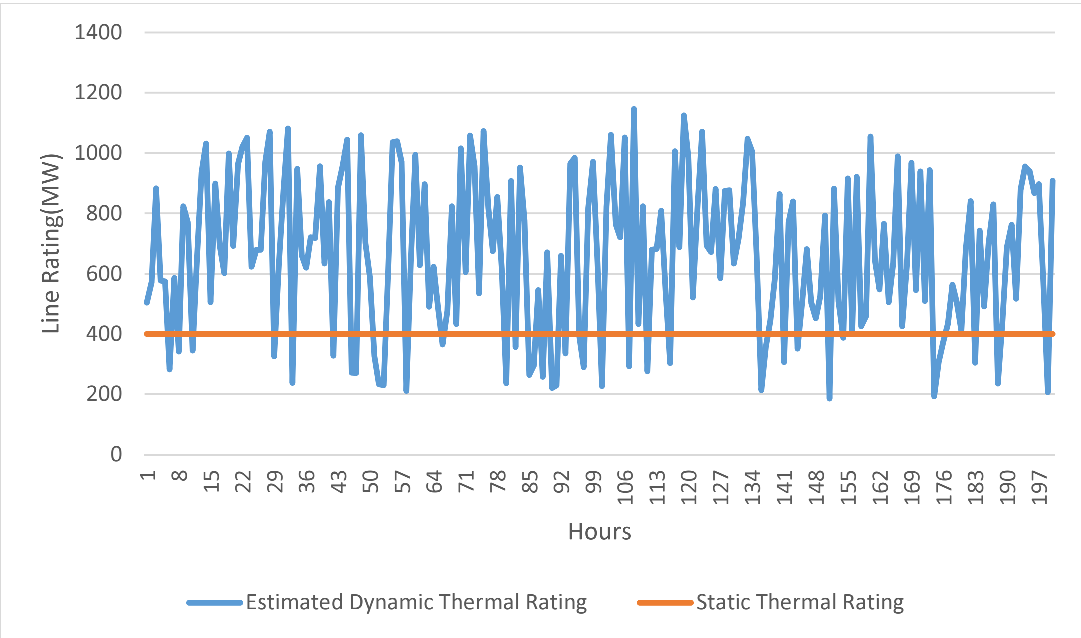

Figure 2.1:Line Rating

2.3 Monte Carlo Simulation on Power System

Monte Carlo simulation is a very popular method because of its flexibility. It provides several reliability indices like frequency and duration of the outage. Besides, it can be the benchmarks against other method and to be compared [12].

In this research, a probabilistic method named Monte Carlo Simulation will be used to examine the impact of the reliability of power system. By using this Monte Carlo

Simulation, it provides several advantages over analytical method such as the graph. This ensures the opportunity to study the whole system more precisely [13].

2.3.1 Non-Sequential Monte Carlo

In chapter 1, types of Monte Carlo simulation are mentioned. There are non-sequential and sequential simulation. The Non-sequential method is for the simulation which basic intervals of the system lifetime is not its concern. Hence, some critical events like the loss of loads are not being sampled. However, Non-sequential Monte Carlo simulation required shorter computing time and it is sometimes preferred when chronological events and the development of state transitions time are not necessary.

2.3.2 Sequential Monte Carlo

For the sequential method, basic intervals in chronological order are taken into account. For instance, hydro generation and wind farm, which can have a significant effect on the next interval and impact on the reliability indices being evaluated, all chronological events are considered from the beginning until the end. The main advantages of SMC are mentioned as below:

1) Frequency index of power system can be obtained
2) More details like weather data can be incorporated in the simulation process

Conversely, the disadvantages are:

1) More computational time are needed for SMC due to the generation of random variate for each component and chronological behavior of the components are stored throughout the simulation process.
2) Some detailed information like chronological load data is available as it is flowchart recorded in the past. Despite that, due to the technology advancement, detailed information are started to be given attention.

2.3.3 Implementation of the Monte Carlo Simulation

A power system is stochastic in nature, its behavior pattern of in real time will be different to a certain extent. Due to this characteristic, Monte Carlo can generate this kind of pattern to suit the nature of power system. This concept can further be explained by considering the toss of a coin.

$$P(\text{head})=\lim_{N\to\infty}\frac{H}{N} \tag{2.18}$$

From (4), it is known that a small number of tosses produce very poor probability. Theoretical, the probability of getting head is 0.5, but if the number of tosses is small, it might get that probability much greater or much Real-time than 0.5 which is not true. The value of probability of getting head will oscillate. However, it tends to converge to the true value.

Same goes to the investigation of a real power system, random numbers are generated to be used to represent the stochastic nature of a real power system. Each simulation will produce an estimation of a real power system behavior according to the random numbers generated. This procedure is repeated until a big clear picture is obtained. There are many ways to study the information obtained including plots of the distributions for example density function or frequency histograms.

Moreover, means, modes, minima, maxima and percentiles can be obtained also. One of the advantages of Monte Carlo Simulation is that estimates from the simulation can be plot. While analytical method does not offer this advantage. Nevertheless, SMC simulation requires a large amount of computing time to obtain those reliability indices with acceptable confidence. Variance reduction technique can be utilized to increase the efficiency of the simulation. Better precision will be obtained for the same amount of simulation time given that the variance of an output random variable can be reduced without changing its expected value. In other words, fewer number simulations are required to run to get a precise result. There are several variance reduction techniques for instance importance sampling, correlated sampling, antithetic variates. The antithetic variates techniques have been deployed in [12] to decrease the number of simulation runs.

2.3.4 Rate of Convergence

In order to obtain an acceptable level of convergence confidence, the high number of Monte Carlo Simulations are required. Generally speaking, the higher the number of simulations, the lower the coefficient of variation will be, thus, the accuracy of the Monte Carlo simulation is more accurate. In a power system reliability analysis, the speed of convergence varies with different reliability indices. It is common to take the rate of convergence of expected energy not served (EENS) as the stopping criterion as it has the slowest rate of convergence among all the reliability indices. Commonly, a 5% confidence level is considered acceptable. The coefficient of variation is given by Equation 2.19

$$\alpha = \sqrt{\frac{\frac{V(X)}{N}}{E(L)}} \tag{2.19}$$

α: Coefficient of variation

$V(X)$: $Variation\ of\ the\ indices$

N: $Number\ of\ simulations$

$E(L)$: $Average\ of\ the\ indices$

2.3.5 Other Simulation Method

Beside Monte Carlo Simulation method, the Fuzzy method is also employed in the reliability of DTR research. [14] shows that the result from fuzzy DTR method is consistent with the result of the probabilistic method in shorter computational time because it does not need to do multiple simulations as it uses the fuzzy number to estimate the distribution of transmission line ampacity.

2.4 DC Optimal Power Flow

In this project, DC Optimal Power Flow is used as it satisfy typical optimal power flow constraint. For example, generator, voltage or branch flow limits. Due to this, DC OPF analysis is chosen rather than solely DC power flow analysis because it is closer to the real situation.

MATPOWER is a package of MATLAB for solving power flow and optimal power flow problems. It is used to solve DC power flow of the system. The input data that relevant to the system parameters has to be prepared by the user as well as calling the function to execute the simulation and printing or viewing the results. The results can be saved in output data structures or files [15].

For AC power flow, the power balance equations are shown below. Assuming that the load injections are constant.

$$g_p(\theta, V_m, P_g) = P_{bus}(\theta, V_m) + P_d - C_g P_g = 0 \qquad (2.20)$$

$$g_Q(\theta, V_m, Q_g) = Q_{bus}(\theta, V_m) + Q_d - C_g Q_g = 0 \qquad (2.21)$$

Θ : voltage angle; V_m: voltage magnitude; P_g,Q_g: generator injections

C_g: generator constraint

In DC power flow analysis, the equation is simplified to a quadratic program. The voltage magnitudes and reactive powers are ignored. The real power flow is modelled as linear function of the voltage angle.

The vector x is the standard DC OPF, x is matrix.

$$X=\begin{bmatrix} \theta \\ P_g \end{bmatrix} \tag{2.22}$$

There are four different algorithms to solve AC power flow problem. The first one is using standard Newton's method. Some AC power flow problem is solved by standard Newton's method which uses polar form to solve the problem and a full Jacobian will be updated at each iteration.

Fast-Decoupled method is also included in MATPOWER, the advantage of using Fast-decoupled method is that computational time will be shortened by updating the voltage magnitude and angles separately according to fixed estimated Jacobians which are factored in the early stage of the solution process. The fourth algorithm is from Glimm and Stagg, it is the standard Gauss-Seidel method. However, several disadvantages have been found in this method compare to the Newton method.

Basically, the process of AC power flow is the same as optimal AC power flow analysis except that constraints are considered in optimal AC power flow analysis.

2.5 Summary

In this chapter, the literature review of Monte Carlo simulation, DTR, DC optimum power flow and line thermal rating have been provided and discussed in detail. There are three purposes of this chapter.

Firstly, DTR is introduced and IEEE 738 is used to calculate the line rating. The advantages of implementing DTR is also discussed. For example, the full utilization of line capacity is possible. Besides that, line overheating can be prevented because sometimes line thermal limits are lower than the STR.

Secondly, the theory behind of Monte Carlo simulation is explained. There are two types of Monte Carlo simulations, NSMC and SMC. The both advantages and disadvantages of NSCM and SCM are discussed. For instance, strong computational power and longer simulation time are required by SCM. On the other hand, some important chronological events such as loss of load are not recognized by NSMC. The simulation will eventually converge to a value, and the when to stop is determined by the rate of convergence. Less than 5% of the rate of convergence is widely accepted that the simulation can be stopped.

Lastly, a brief power flow analysis of MATPOWER is introduced. For instance, AC-OPF and DC-OPF. Compare with AC-OPF, voltage magnitude and reactive power are ignored in DC-OPF. Hence, the power analysis is simplified into a quadratic program. DC-OPF analysis is preferred than DC power flow analysis in this project because branch flow constraint, generation constraint are considered in DC-OPF which is closer to the realistic power system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology used in this project. All the procedures of the objectives such as the reliability impact of DTR and sensitivity analysis of DTR will be discussed in detail. The flow of the project is explained. The usage of the diagrams and flow chart to make the flow of work clearer and understandable.

3.2 Reliability Test Network(RTN)

IEEE 24 bus RTN is a virtual power network that is often used for reliability analysis of power system. Figure 3.1 shows IEEE 24-bus RTN and its load model and generation details will be discussed in this section.

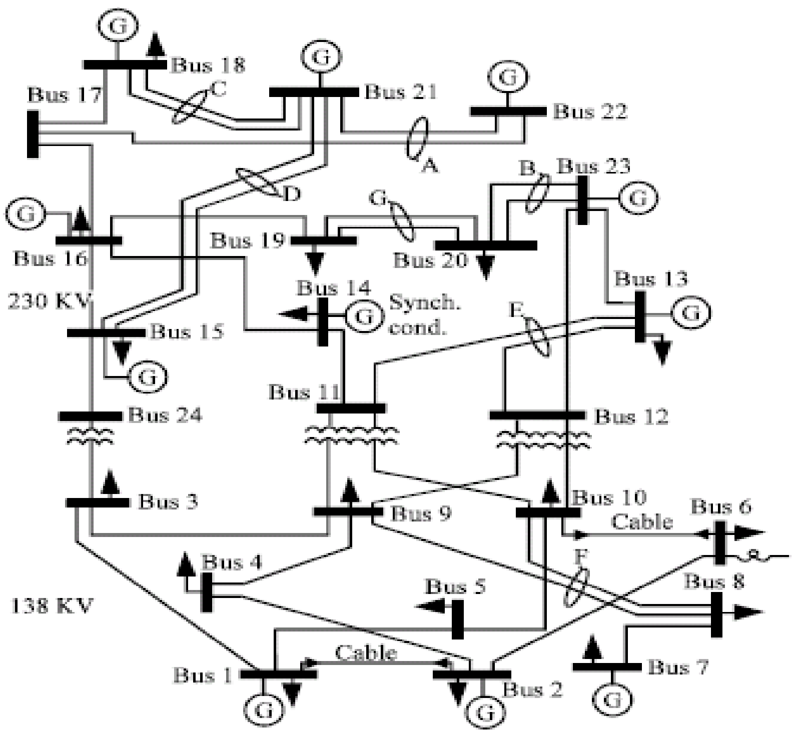

Figure 3.1:IEEE 24-bus RTN[15]

Figure 3.1 shows the connection of the RTS. IEEE 24 bus Reliability Test network is used in this project. There are 32 generators commissioned and 14 loads. The generators are in bus 1,2,7,13,15,16,18,21,22,23. While bus 14 is a synchronous condenser. For loads, there are in bus 1,2,3,4,5,6,7,8,9,10,13,14,15,16,18,19,20. In order to study a complex modern power system, a power system is often divided into three hierarchical level. Level 1 is about generation facility, transmission facilities are added in level 2. While level 3, it is the most complicated, distribution facilities is included in this level. In this project, HL 2 is used to perform system analysis that refers to the composite generation and transmission system. The ability to deliver energy to the bulk supply points is the main concern in this project.

3.2.1 Load Model

The annual peak load of 24-bus RTN is 2850MW. The load model is hourly loads for one year on per unit basis. After converting the loads value from the unit basis, the load values will be superimposed into the IEEE 24 bus RTN every hour until 8736 hours which is the total hours of one year.

3.2.2 Generating System

Table 3.1 is the model of generating system. The generating unit rating and reliability data is included in the Table 3.1.

Table 3.1: Reliability of Generating Unit

Unit Size(MW)	Number of Units	Forced Outage Rate	MTTF	MTTR	Scheduled Maintenance (weeks/year)
12	5	0.02	2940	60	2
20	4	0.10	450	50	2
50	6	0.01	1980	20	2
76	4	0.02	1960	40	3
100	3	0.04	1200	50	3
155	4	0.04	960	40	4
197	3	0.05	950	50	4
350	1	0.08	1150	100	5
400	2	0.12	1100	150	6

Where,

MTTF Mean time to failure

MTTR Mean time to repair

$$\text{Forced outage rate} = \frac{MTTR}{MTTF + MTTR}$$

Partial outage for generating is possible in real case. However, to simplify the case, the partial outage for generating unit is not included in this thesis.

3.3 Transmission Line Status

The reliability data is provided by the RTN itself. An uniform random number between 0 and 1 will be generated to get random value of time-to-failure(TTF) and time-to-repair(TTR) when perform SMC simulation. The equations below show TTF and TTR

$$TTF = -\frac{1}{\lambda} lnU \quad (3.1)$$

$$TTR = -\frac{1}{\mu} lnU \quad (3.2)$$

Where U is the uniform random number, λ and μ are the failure rate and repair rate respectively. λ and μ are given in IEEE 24-bus RTN report [16]. The TTF and TTR will be rounded to round number. The "Up" duration depends on the U random number. If U is large, the "Up" status for transmission line will be longer. Therefore, the statues for transmission lines will be different for every cycle of simulation.

3.4 Calculation of Line Thermal Rating

Static thermal rating is determined from a set a dynamic thermal rating. The main difference between these two is that STR will be fixed to a certain rating based on the weather condition. The line ratings of STR are not updated periodically as DTR does. DTR system gets data from its sensors to periodically update the parameters that affect the conductor thermal rating. The parameters are given prior to the calculation of the thermal rating of transmission lines. The determination of line ratings is discussed in chapter 2.

Once the thermal rating is determined, it will be updated hourly with the RTN transmission lines.

3.5 Simulation of Sequential Monte Carlo

The steps below show the procedure of a sequential Monte Carlo simulation. In this thesis, IEEE 24-bus RTN is selected to demonstrate the simulation.

Step 1) Initialize $N = 0$ (N is the number of years sampled)

Step 2) Consider $N = N + 1$

Step 3) Generate an up and down sequence in sample year by using Equation 3.1 and 3.2

Step 4) Superimpose the up and down sequence on the load model

Step 5) Conduct DC-OPF to determine the energy not served for every hour

Step 6) Update the energy not served for every year

Step 7) Repeat Step 2) to Step 6) until the coefficient of EENS reaches the acceptable level.

Figure 3.2 shows an example of sequential Monte Carlo simulation

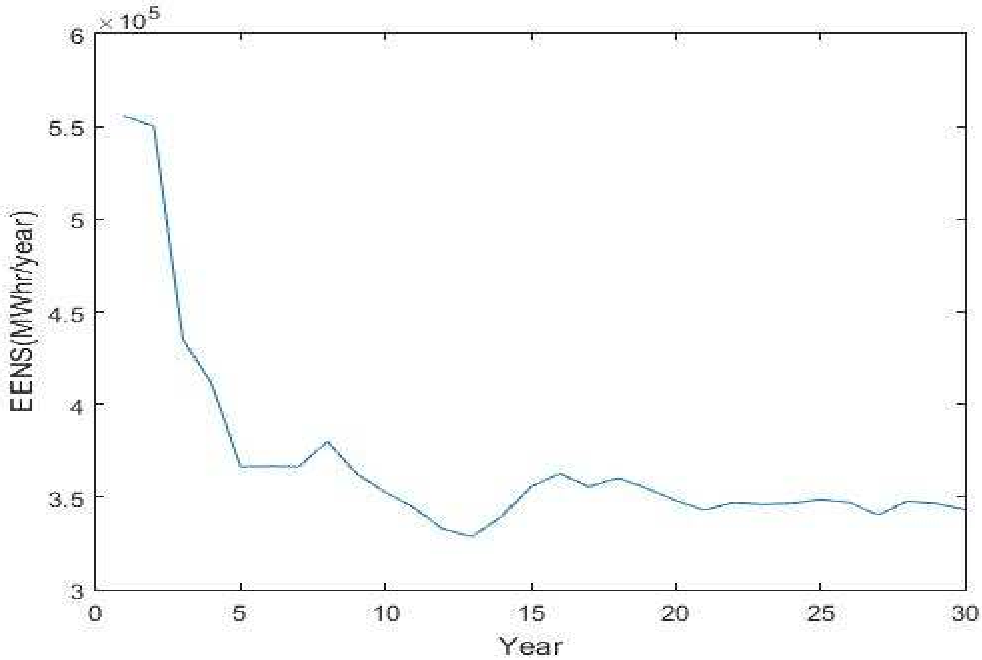

Figure 3.2: Example of Monte Carlo Simulation

From the Figure 3.2, it can be seen that EENS gradually converges to a value and the fluctuation of EENS in Figure 3.2 is getting less. This means that large numbers of