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SOME ASPECT OF RELIABILITY EVALUATION OF COMPOSITE POWER SYSTEM

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Abstract: Reliability evaluation has been broadly used for power system planning and operations [1], since they are capable of incorporating various system uncertainties such as equipment failures as well as random variations in generation capacity or load demand. Meanwhile, power systems are becoming more complicated, which leads to highly nonlinear problems in their reliability evaluation. The purpose of assigning the reliability of a composite power system is to estimate the ability of the system to perform its function of transporting the energy provided to the bulk supply points. This paper gives an introduction to reliability evaluation of composite power system. The paper also includes a description of reliability evaluation parameters at different levels and different methods for reliability evaluation of a power system.

Keywords: Reliability, Power System, Monto Carlo Simulation

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INTRODUCTION

For system analyzers, system planners and designers the system reliability is a very crucial key point for analysis. It is significant to evaluate reliability because of increasing complexity of systems, cost competitiveness, to have alternate designs of the system, cost benefit. As in today's scenario the power system is getting more complex either due to grid connections or because of smart grids for improved systems, but it is more complex to evaluate reliability. The level of satisfactory reliability or unsatisfactory reliability of the system is may be due to the effect of individual component or it may be the contribution of the whole system. The function or performance of individual component and of the whole system and its failure frequency decides the reliability of the system. The basic definition of reliability also says that "*Reliability is the characteristic of any device which shows its capability to perform its adequate function under given conditions".* From the definition again it is clear that reliability is a function of performance characteristic of a device. The failure of even a single device may affect the reliability. So, there are two main factors which affect the reliability as shown in fig.1.

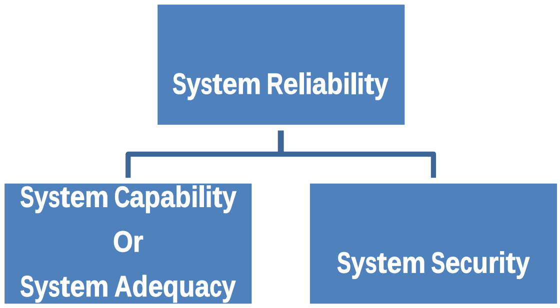

Figure1 Factor of reliability

System capability is about to satisfy the load demand and to do this it is required to have presence of sufficient resource at generating stations. For this the generating capacity of the station is always maintained above peak load demand and is done by forecasting the load by system designers. The system adequacy also must include the planned or unplanned outages of generating units or other equipments which form the system.

The system security is also a function of system reliability. Here the security term stands for the capability to survive under any condition. The variation in normal operating condition may be there because of variation in loading conditions, either it may be due to overloading or under loading. There may be other parameters which can affect the reliability of system viz. Current variation, frequency variation etc.. In a secure system all these parameters must remain within permissible limits.

The time period is also one of the criteria to measure the reliability. Reliability decreases as time move towards t = ∞ i.e. reliability is a decreasing function of time as shown in fig.2. It is because after a time period the aging effect after dominating over the performance of the device.

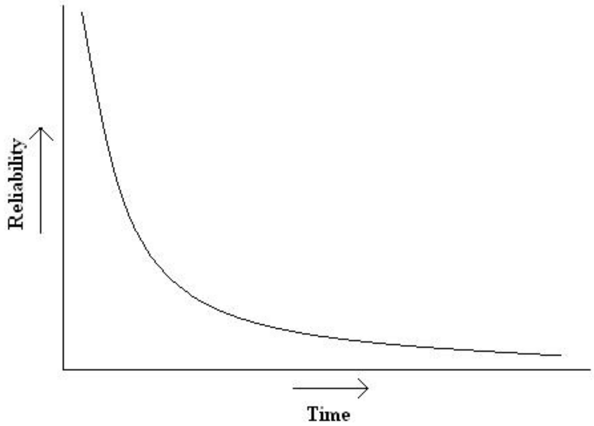

Figure 2 Reliability Vs Time characteristic

As we all know that the complete power system consist of three main divisions i.e. generation, transmission and distribution. For reliability evaluation of system it's quite difficult to evaluate reliability of each and every device (as reliability is related to adequate performance of the device) individually. To avoid this complication, reliability evaluation is done for complete system by several methods. Now days the reliability evaluation is started on large scale i.e. for composite power system. In this method the reliability evaluation of each division i.e. generation transmission, and distribution is performed commonly in complete system.

Reliability Evaluation of Generating Stations

The reliability at generating station can be the effect of the independent outage of device/ generating unit or may be the effect of variation or unavailability of resources. The reliability of the generating station varies according to mechanism applied for electricity generation. The approach to to generate electricity can be thermal, hydel, wind, solar, nuclear or it may be a hybrid approach to generate electricity. The reliability evaluation for a hybrid generating station by applying Monte Carlo simulation (MCS) has been already done. In this the reliability was evaluated using IEEE RTS & as a hybrid combination, combination of wind and hydro power station was used. Genetic algorithm is one of the competent methods to evaluate reliability which gives out the optimal reliability result. Wang et al. [37] find out the most common reason for failure and hence evaluates reliability. The work was carried out by applying Genetic Algorithm technology. Another fact associated with variation in reliability is system economics. The less reliable system affects more on the economics of the system as well as on the consumer also. R. Billinton, W. Zhang [40] discussed about reliability indices which was having relation to cost so as to improve the economics of the system with maximum optimized reliability results. As discussed earlier that aging effect is also one of the major reason which is involved in varying the reliability of the system. Wenyuan Li [19] and Hagkwen Kim, Chanan Singh [20] has discussed the effect of aging criteria of reliability. In this paper later there are few more reliability evaluation indices are enlisted. One of which is the probability of failure and in this reliability index the participation of the failure protective devices are considered. The same was done by Xingbin Yu [22]. In this the system reliability was evaluated by considering the failure of the protection system which is considered to be one of the biggest reasons for failure of the system.

A proper executing system may get deviates and losses reliability even because of the failure of a single device. A component or device is considered to be an outage when it is unavailable to perform its proposed function. A component outage, however, may or may not cause load interruption. Independent outage events including the outage of two or more components are referred to as overlapping outages. The basic component model used in these applications is the two-state representation shown in Figure 3, in which the component is assumed to be either up or down. The rate of departure from the component up state to its down state is the component failure rate λ. The restoration of the component to its operational state is denoted by another transition rate, termed as the component repair rate μ.. The two parameters, λ and μ can be expressed in terms of Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR) respectively, where, MTTF is the reciprocal of λ and MTTR is the reciprocal of μ.

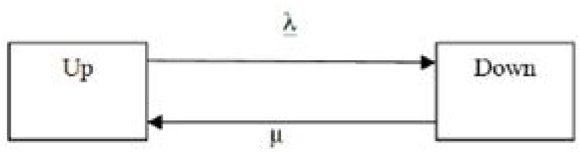

Figure 3 Two State Model for a single component

Reliability Evaluation of Transmission System

The industry for transmitting the electrical energy also plays an important role in achieving he reliability of the system. In this particular part the quality of equipment like conductors, insulators, and their withstanding capacities for disturbance decides the reliability of the system. Sometimes weather or natural disasters also are a few parameters which may affect the reliability. An important factor which can affect the reliability is loadability which shows the maximum permissible line loading in terms of percent SIL i.e. surge impedance loading.

There are different criteria which decides maximum permissible loading of line. This criterion varies according to the type of transmission line. For short transmission line thermal limit or temperature rise is in consideration for line loading. In medium transmission line voltage drop is the criteria for deciding the line loading and for long transmission this criteria are changed to angle stability. Tarek A. M. sharaf and Gunnar J berg [41] took this parameter for reliability evaluation they determine loadability using AC load flow model and optimization procedure but instead of linear optimization procedure they use non linear optimization procedure. X Yu and C Singh [42] also consider the same parameter that is loadability to evaluate reliability but they used Monte Carlo simulation to evaluate loadability as reliability evaluating parameter.

As very commonly multiple circuit transmission lines are used over worldwide for transmission of electrical energy. Lie et al. [38] evaluated reliability for same structure using analytical method followed by MCS. Choudhary et al. [39] has done a quantitative reliability assessment of the transmission system. It's a necessary pre step of system planning. Another technique to determine reliability is deterministic criteria but it lacks behind quantitative criteria in terms of accuracy. Apart from this, sometimes reliability also effect on the reactive power . The reactive power is also necessary in power system. Failure or mis-operation of reactive power source may lead to either excess or shortage of reactive power which directly affects the reliability of the power system. The result variation in reliability may not be in the form of a power outage but may be in the form of excess losses or poor power factor or poor power rating. Peng Wang and et al [21] discussed about new reliability indices which are used to calculate reactive power shortage.

So, in a nut shell manner we can say that in today's time lots of steps are taken to make the system capable with an increased rate of the security. One of the methods to improve reliability is grid connection and as a advancement in this the latest technique is smart grid. Other than this although there are many techniques to evaluate the reliability (few of them are discussed soon after this) but in all the methods on the basic side we need to calculate the reliability indices. There are many reliability indices which can be evaluated for reliability evaluation. For example these are like loss of load probability i.e. [LOLP] loss of load expectation (LOLE) & expected energy not supplied (EENS) etc.

II. RELIABILITY INDICES

Under broad segment the reliability indices can be classified under two categories: [24]

i) Deterministic indices

ii) Probabilistic indices

Deterministic indices show the postulated conditions. They do not show the system reliability and are also not responsible for system reliability. Hence for planning these systems are having a very limited use.

Different deterministic reliability indices are:

i. Percent reserve margin: This shows the excess of installed generating capacity over annual peak load.

ii. Reserve margin in terms of the larger unit.

These parameters do not reflect the data like unit size and outage rate etc.

Probabilistic indices show the reliability of the system and are necessary part of reliability evaluation. These parameters can also impact the system reliability.

Different probabilistic indices are:

i. Loss of load probability (LOLP) : This LOLP may be defined as probability of loss of load exceeding the available generation capacity.

For LOLP = P [L>C].

Where

L = Load

C = Available capacity of generation.

ii. Loss of load expectation (LOLE): This reliability index shows the time when insufficient generating capacity is there to serve peak load.

iii. Expected unserved energy or Expected energy not supplied (EENS): This index measures the expected amount of energy which is failed to serve or supply to consumer because of shortage in basic energy supply.

For composite power system reliability indices are categorized into a system based indices and load point indices. These reliability indices find out their application at unlike places. A system based indices provide an appreciation of global system adequacy and can be used by planners and managers for comparing the adequacies of different systems. However, these indices cannot be used to assess the adequacy of particular system load points. Therefore, load point indices are required to assess the reliability of load points, which is useful for benchmarking load points and identifying weak areas in the system. Load point indices can be used to identify the contribution of each load point to bulk system unreliability.

The system based reliability indices are:

i) Bulk power interruption index

ii) Average number of load curtailment

iii) Average energy curtailment

iv) Average number of voltage violation

v) Maximum system load curtailed under contingency condition

vi) Maximum energy not supplied under contingency condition.

The load point indices include the evaluation of:

i) Probability of failure

ii) Failure frequency

iii) Average of voltage violation

iv) Average load curtailed

v) Expected energy not supplied

vi) Average duration of load curtailment

With the help of above available reliability indices the reliability of the composite power system is calculated, this calculation will be done with the help of any one of the methods of reliability evaluation. To evaluate reliability there are few more reliability indices that are used to weigh up reliability. These reliability indices are:

(i) **SAIFI (System Average Interruption Frequency Index)**: This particular index informs about the typical average frequency of interruptions per customer by having a ratio of total interruptions to customer to the number of customers in the system.

(ii) **SAIDI (System Average Interruption Duration Index)** : This index informs about the average time that all customers are interrupted by having a ratio of customer interruption total period to the total number of customers in systems.

(iii) **CAIDI (Customer Average Interruption Duration Index)** : This index conveys the average time required to restore service

(iv) **CAIFI (Customer Average Interruption Frequency Index)**: It is the average number of interruptions considered to have a duration, experienced by customers who had at least one interruption during the period.

(v) **MAIFI (Momentary Average Interruption Frequency Index)**: This particular index gives out the data about the average frequency of momentary interruptions, typically defined as less than five minutes.

The above discussed last five indices give information about the duration and frequency of the system.

III. RELIABILITY EVALUATION OF COMPOSITE POWER SYSTEM

As the topic of the paper suggests we are focusing on the reliability evaluation of composite power system So a composite power system can be divided into many operating states in terms of the capacity available to fulfil demand subject to the satisfaction of security limits (line flows and voltage limit). Hence, the evaluation of a reliability index for a composite system is very much computationally demanding. The three basic functional zones are those of generation, transmission and distribution as shown in figure-4.

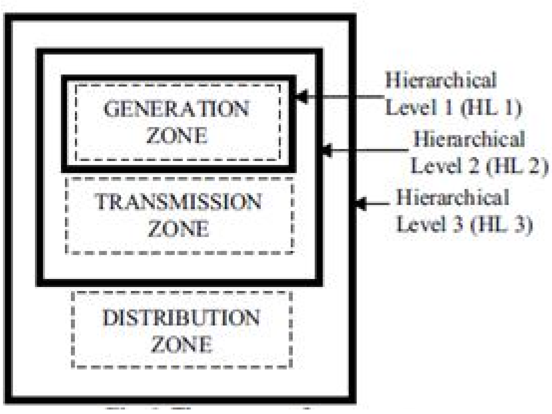

Figure 4 Three Zones of power system

These functional zones can be combined to form hierarchical levels (HL) for conducting system reliability analysis [4]. Reliability assessment at HL I is concerned with the generation facilities [6]. Reliability assessment at HL II considers the generation and transmission as a composite system. The effect of load growth, configuration changes and facility additions can be studied and reliability indices can be evaluated for the overall system, as well as for the individual buses [7-10]. All three of the functional zones are involved in an HL III assessment. The main objective of an HL III study is to conduct an adequacy assessment at consumer load points [4].

IV. COMPOSITE SYSTEM RELIABILITY EVALUATION METHODOLOGY

There are two main methods which are widely used for reliability evaluation i.e.

1. Analytical Methods
2. Computational or Simulation Methods

Both approaches are able to calculate reliability indices. Both methods use the adequacy & security of a system state using a power flow method for calculating reliability. AC load flow or DC load flow [8-9] may be used depending upon the needs of the study.

1. Analytical Methods can be divided into Contingency Enumeration Methods (CEM), State Enumeration Methods (SEM) and Markov Cut Set method. Few more fault analysis method is fault tree analysis method and minimal cut set method. The minimal cut sure method is one of the steps of fault tree analysis or we can say it's the first step of the fault tree analysis method to evaluate reliability. Based on the mathematical analysis in all analytical methods a mathematical model is prepared and generally all models are based on Markov models. Yong Liu & Singh [23] proposed a method to evaluate reliability of composite power system. In that they used Markov cut set method which was based on DC optimal power flow. The minimal cut set is analyzed using this DC optimal power flow which was limited up to a particular order and then they used Markov cut set method to calculate reliability indices. Yong Liu & Singh [26] again use minimal cut set method approach as the analytical methodology to evaluate reliability of composite power system but for a short duration of time. Cost outage is also one of effect of reliability. Choi, J.S. et al [32] use an analytical approach to determine the outage cost in a composite power system as an effect of reliability. To evaluate this cost outage they use the analytical method using effective load duration curve.

2. Computational Methods This method can be divided into

Monte Carlo Simulation (MCS) & Artificial Intelligence (AI) based on the iteration technique. The Monte Carlo method can be applied on time varying load to evaluate reliability. For showing the time varying load load duration curve can be used. Monte Carlo itself consist of sequential technique and non sequential methods such as state sampling and state transition sampling.

Monte Carlo simulation methods estimate the indices by simulating the actual process and random behavior of the system. The method, therefore, treats the problem as a series of experiments. In general, if complex operating conditions are not considered and/or the failure probabilities of components are small (ie., the system is very reliable), then analytical techniques are usually more efficient. When complex operating conditions are concerned and/or the number of severe events is relatively large, Monte Carlo methods are often preferable [5]. The basic sampling procedure can be conducted by assuming that the behavior of each component can be categorized by a uniform distribution under {0, 1}. In the case of a two-state component representation, the probability of outage is the component forced unavailability. It is also assumed that component outages are independent events. The basic information obtained by this component outage is the only unavailability of components. The other information by this type of model is availability of components. This gives only average data information. If we increase the information by increasing the number of states then it will be quite complex. To remove this complexity S. A. Khaparde, K. Bhattacharyya [30] gives the combination of fuzzy logic and neural network to evaluate reliability with more accurate power system model and more accurate reliability indices. A. R. Abdelaziz [31] also evaluate the reliability of fuzzy based power system. Jaeseok Choi et al [27] presents a concept of composite power system effective load duration curves using Monte Carlo method. This effective load duration curve is important for both generation and transmission . The reliability indices for a composite power system are calculated using this effective load duration curve with a Monte Carlo method. Sometimes the load is completely uncertain and for such type of problems fuzzy logic can be used. J. Tome Saraiva et al [28] consider the uncertainty in load and define it by fuzzy numbers using a Monte Carlo algorithm. This fuzzy technology is specially used for long term planning where there is uncertainty in load in future. J. He, Y. Sun, L. Cheng et al used a hybrid method to evaluate reliability. They use the combinational advantage of state enumeration method and mounted Carlo simulation. The advantage of this combination is that SEM is used to solve lower order contingencies and MCS for higher order contingencies. As such there are lots of computational methods but out of those computational methods genetic algorithm is again one of the best computational methods which makes the reliability evaluation easier and reduces the efforts as compared to analytical methodology. Samaan, N.; Singh, C. [33] used genetic algorithm method to evaluate reliability. A genetic algorithm is a computational method which gives the result having resemblance to the actual system results. To improve the accuracy we can increase the number of algorithm generations. In this the actual reliability indices for complete system are calculated using reliability indice data for each load separately. The GA method takes the failure status of each load separately and then combined it to get the annual result. Lingfeng Wang; Singh, C.[34] used this GA method in parallel to speed up the computation process. All of the above described methods for reliability evaluation are used in different test systems. Most of them are used on the IEEE reliability test system. The IEEE reliability test system (RTS) is of two versions.RTS-79 which was the first test system of IEEE. RTS-96 has introduced as an advanced version of reliability test system from the IEEE. In this there are some changes with respect to evaluation methodologies [35]. R. Billinton also developed a reliability test system which is known as RBTS i.e. Roy Billinton test system. This test system is also used in many research works to evaluate the reliability of the system.

V. CONCLUSION

This paper summarizes the various aspects for the reliability evaluation of composite power system. This introduces the various reliability indices used to evaluate reliability of composite power system. The methods for reliability evaluation are Simulation and analytical methods and out of these two methods Simulation method is considered to be superior because it reduces the computational time as compared to analytical methods as well as it gives more accurate and real results.

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