TSS based Composite Power System Reliability Evaluation Considering Demand Response

VenkataSatheesh Babu.K[1], V.Madhusudan[2], V.Ganesh[3]

[1] *Research Scholar, Dept. of EEE, JNTUA, Ananthapuramu, India*
[2] *Professor, Dept. of EEE, VNRVJIT, Hyderabad, India*
[3] *Professor, Dept. of EEE, JNTUACEP, Pulivendula, India*

***Abstract*— Electrical Power Systems are large & complex systems in the world. Reliability is inherent characteristic of power system that describes the ability to perform an intended objective. By properly investing on planning and operational stages the likelihood of customer interruptions can be reduced. With the increased interconnections and ever growing demand for electricity reliability assessment of large electrical systems is gaining attention in the recent times. This paper proposes Truncated State Space (TSS) based reliability evaluation by considering demand response. In Reliability assessment, large numbers of system states have to be evaluated for computation of indices which is computationally cumbersome. To overcome this, state space can be condensed by eliminating the states with insignificant probabilities. The state space is further reduced by considering demand response characteristics. Reliability indices like ELC, EENS are used to demonstrate the effectiveness of the proposed method. With the combination of demand response characteristics and TSS the reliability of the system is significantly improved. Reliability test systems like RBTS-6 bus system and IEEE-24 bus reliability test systems are used to implement the proposed method.**

***Keywords*— Truncated State Space (TSS), Demand Response, Composite Power System, Reliability, RBTS, State Enumeration, EENS**

I. INTRODUCTION

Worldwide Electrical Power Systems are becoming more complex and highly interconnected. The basic functional zones of a power system are generation, transmission and distribution. It is very difficult or perhaps impossible to analyze the whole power system as a single entity using a completely realistic and exhaustive procedure. A power system is, therefore, usually divided in to segments which can be analyzed separately as in [1]. These segments are referred to as generation, transmission and distribution functional zones as shown in below Fig.1 The primary objective of a power system is to supply electricity to consumers with high degree of continuity and low cost. Reliability is very important parameter considered in power system planning and operation. Economically viable reliability solution is required for modern competitive electricity markets. Due to over investment operating cost increases and under investment may lower the degree of reliability. So the economic trade-off of these two aspects is quite challenging for power system planner. Several techniques were proposed in the literature [2]-[5] for resolving the dilemma between reliability and economy. The computational effort required for the implementation of those techniques was large and did not consider customer response characteristics. This paper proposes a truncated state space (TSS) based reliability evaluation under the influence of customer demand characteristics.

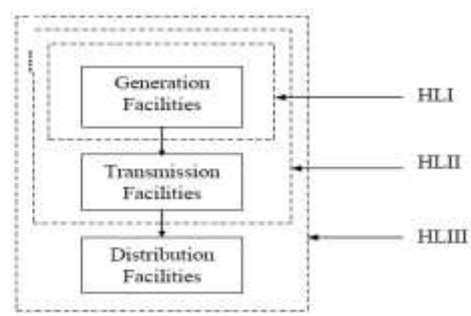

Fig.1 Power system Hierarchical Levels

A. Objective of the Paper

This paper is focused on the examination of the ability to conduct TSS based composite system reliability evaluation using Demand Response. The studies described in this paper were conducted using a MATLAB Software.

The main objective of this work is to enhance the System Reliability. This includes the following steps:

1. Development of complete independent computer model, using MATLAB programming
2. Test the computer model using RBTS-3 bus system and compare with the theoretical calculations.
3. Test the computer model using RBTS-6 bus system, IEEE-24 systems.
4. Compare the results for both cases i.e., with and without considering response.

B. Demand Response

For any commodity as the price increases the demand gets decreased. This is considered as price-demand elasticity [7]. The slope of price-demand curve as shown in Fig.2 is called as price-demand elasticity. Where Δd and $\Delta \rho$ are changes in demand and price; and d_o and ρ_o are base demand and price of a given equilibrium point respectively.

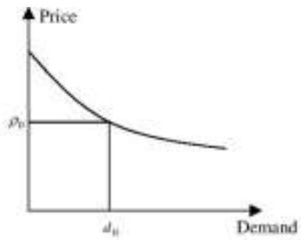

Fig.2 Demand-Price Curve

The change in price of a commodity results in the change in demand. In practice the changes in demand result from change in both price and time. So there are two coefficients self-elasticity coefficients and cross-elasticity coefficients as proposed in [2]. The self-elasticity coefficient ξ_{ii} shows the effect of price on load in the same time slot *i*. The cross elasticity coefficient ξ_{ij} relates load at time slot *i* to price at time slot *j*. Broadly the self-elastic coefficient is the change in demand for change in price both considered in same time interval. The cross-elastic coefficient is the change in demand for change in price both considered in different time interval. The coefficients of elasticity can be modelled as a matrix as in [6] for a time period of 24 hours. The self-elasticities are placed as diagonal elements and cross elasticities are placed as off-diagonal elements of a matrix. Any column of such matrix explains the change in demand for the respective change in the price.

In electricity markets demand response may result in significant dynamic changes in consumer demand according to the price scenario. Demand response is quite different from energy efficiency measures, which causes reduction in power usage for doing the same task. Whereas the demand response just stagger the consumption of electricity.

C. How it works

Demand response is mechanism to perpetrate consumer to decrease demand and hence reducing the peak load for electricity. As the generating stations and transmission lines are sized based on the peak demand plus errors in forecast, unforeseen events the reduction in peak will reduce the capital cost. The beauty of demand response is that it may also be used to increase the demand as and when required.

The demand response characteristics are modelled in the MATLAB program and are taken as input for calculating the reliability indices. Probability of load curtailed, frequency of load curtailed, expected load curtailed & expected energy not supplied are computed for different reliability test systems and the effect of demand response on these parameters are studied. Comparison of these indices for different test systems is also shown.

D. Methods for Composite System Reliability Evaluation

There are two methods available for computing the reliability of Hierarchical Level II systems.

1. Monte Carlo Simulation Techniques.
2. Analytical Methods.

Monte Carlo methods of simulation compute the reliability indices by considering the random characteristic of the system. These methods consider the problem as a sequence of experiments.

In analytical methods a mathematical model is used to represent the system and the reliability indices are computed from this model. In this paper state space enumeration approach is used. Analytical methods and Monte Carlo methods have their own advantages and disadvantages as shown in [9], [11].

The computational time required for obtaining the indices is relatively less in analytical techniques. Particular simplifying assumptions are needed when the system is complex and large. On the other hand the simulation methods may need long time for the computation.

E. State Space Enumeration Method

A system state in state space enumeration method is described by the present state and the transition that can occur between states. The system state is the present working condition of working, failed, maintenance etc. The change in state causes the transition from one state to another. Such possible combination of all states makeup the system state space. The state space method has the advantage of applying the markov model for the transition of system states.

One of the main applications of state space method is it can be applied to systems which are repairable and also replaceable. By using probability, frequency of failure and other indices the reliability of repairable systems can be found. As these approach uses calculation of indices by considering state by state it is called as state enumeration method.

F. Truncating the State Space

In state space enumeration method the number of system states to be computed is numerous. For example if the system has ‘n’ independent components then we have to evaluate 2^n states. To lessen the effort of the task, numerous approximations and other devices that decrease the required calculations have been developed.

One such rough calculation is Truncation of State-Space (TSS). By the truncation of the state space, the exclusion is meant of the states with insignificant probabilities from among those that are to be evaluated in the state enumeration procedure. In its modest form, the truncation is carried out on the supposition that the probabilities of the states representing a large number of overlapping failures are negligible in comparison with the probabilities of states with a lower number of failures; the number of states to be evaluated is then greatly reduced, and it is possible to assess a large variety of systems with the aid of suitable computer program

G. Reliability indices

The following reliability indices are used in the paper to test and validate the proposed method.

1. Probability of Load Curtailment

(PLC) = $\sum P_j P_{kj}$

2. Frequency of Load Curtailment

FLC (Occ/Yr) = $\sum F_j P_{kj}$

Where *j* is an outage condition in the network

P_j is the probability of existence of outage *j*

F_j is the frequency of existence of outage *j*

P_{kj} is the probability of the load at bus *K* exceeding the maximum load that can be supplied at that bus during the outage *j*

3. Expected Load Curtailed

ELC (Mw/Yr) = $\sum L_{kj} F_j$

Where L_{kj} is the load curtailment at bus *K* to alleviate line overloads arising due to contingency *j*

4. Expected Energy Not Supplied

EENS (Mwh/Yr) = $\sum L_{Kj} P_j * 8760$

These indices when computed for a single load level over a period of one year are denoted to as "annualized indices ". In practical systems, the load does not keep constant throughout the period and the effect of a variable load level can be encompassed to produce more representative "annual indices". The elementary values for the annual indices will be different from the annualized indices got using the peak load levels.

The load point indices are very beneficial in system design and in relating another system configuration and system replacements. The overall system indices specify the sufficiency of the composite system to meet its total load demand and energy requirements and therefore quite useful to the system planner and to the system manager.

H. Reliability Test Systems

Three test systems are used in this paper. They are an educational test system designated as the Roy Billiton Test System(RBTS) [8], IEEE-24 bus system [10] and another one is small 3 bus system which is an example taken from the reference [1].

The RBTS is a small educational test system developed as part of the graduate program in power system reliability evaluation at the University of Saskatchewan. The RBTS is a 6 bus system [8] it has 2 generator (PV) buses, 4 load (PQ) buses, 9 transmission lines and 11 generating units. The minimum and the maximum ratings of the generating units are 5MW and 40MW respectively. The voltage level of the transmission system is 230kv and the voltage limits for the system buses are assumed to be 1.05 p.u and 0.97 p.u. The system peak load is load is 185 MW and the total installed generating capacity is 240 MW. The transmission system contains single lines. The lengths are shown in proportion to their actual lengths. The geographic representation of the system gives the configuration a more physical appeal and can be used to consider various segments of the system in terms of the actual customer classes connected to those regions.

The IEEE 24 Bus Reliability Test System [10] was established in 1979 by an IEEE Task Force as a reference network which can be used to test (or) compare methods for system reliability studies. The System has 10 generator buses, 17 load buses, 38 transmission lines. The total number of generating units is 32. The minimum and maximum rating of the generating units is 12 MW and 400 MW respectively. The total system peak load is 2850 MW and the total generation is 3405 MW.

I. Simulation Results for Different Test systems

The proposed methodology is implemented using MATLAB program. The MATLAB simulation results for different reliability test systems are presented here. The comparison of reliability indices Probability of Load Curtailed (PLC), Frequency of Load Curtailed (FLC), Expected Load curtailed (ELC) & Expected Energy Not Supplied (EENS) are computed using computer program for different test systems.

The comparison of indices for Roy Billinton Test System RBTS-3 bus system is show in Table 1.

Table.1 Comparison of indices for RBTS-3 Bus system

System Reliability Indices			
Before Demand Response		After Demand Response	
PLC	0.10490	PLC	0.09125
FLC (fail/Year)	16.44	FLC (fail/Year)	8.02
ELC (MW/Year)	274.44	ELC (MW/Year)	56.12
EENS (MWh/Year)	7310.65	EENS (MWh/Year)	4153.96

The results show that by using TSS method and considering demand response apart from probability, frequency of failures the Expected Load Curtailed (ELC) and Expected Energy Not Supplied (EENS) are significantly reduced. As the size of the system increase this reduction is more pronounced.

The comparison of indices for Roy Billinton Test System RBTS-6 bus system is show in Table 2.

Table.2 Comparison of indices for RBTS-6 Bus system

System Reliability Indices			
Before Demand Response		After Demand Response	
PLC	0.20125	PLC	0.18962
FLC (fail/Year)	71.57	FLC (fail/Year)	54.92
ELC (MW/Year)	1556.70	ELC (MW/Year)	1038.10
EENS (MWh/Year)	115.40	EENS (MWh/Year)	78.54

As the size of the system is further increased this reduction is more prominent.

The comparison of indices for IEEE-24 bus test system is show in Table 3.

Table.3 Comparison of indices for IEEE-24 Bus system

System Reliability Indices			
Before Demand Response		After Demand Response	
PLC	0.08097	PLC	0.07154
FLC (fail/Year)	53.76	FLC (fail/Year)	32.54
ELC (MW/Year)	9404.01	ELC (MW/Year)	6250.17
EENS (MWh/Year)	124114.90	EENS (MWh/Year)	98291.20

From the comparison of indices shown in Tbale.3 the reduction in the indices like Expected Load Curtailed (ELC) and Expected Energy Not Supplied (EENS) it is apparent that the reliability of the system is greatly enhanced. As the number of states to be evaluated is reduced enormously the computational burden is reduced and the simulation is converged.

The four Reliability Indices are compared graphically in the following section for different test systems to understand the impact of improvement for large size systems.

J. Graphical Comparison of Indices for Different Test systems

The comparison of PLC for different test systems is shown in Fig.3 & FLC in Fig.4

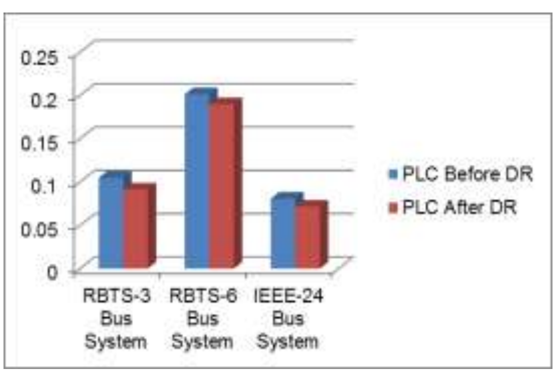

Fig.3 Comparison of PLC for different test systems

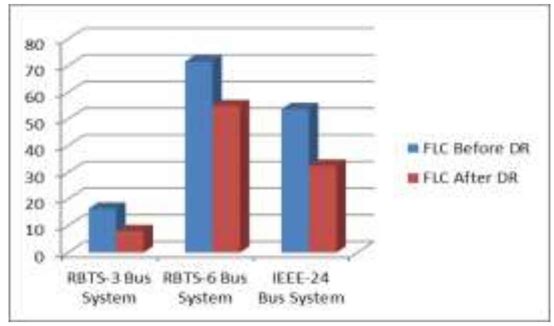

Fig.4 Comparison of FLC for different test systems

The comparison of ELC for different test systems is shown in Fig.5 & EENS in Fig.6

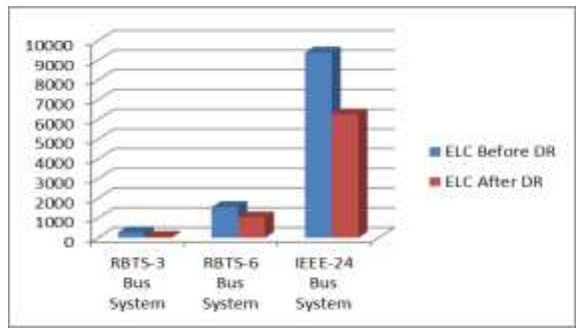

Fig.5 Comparison of ELC for different test systems

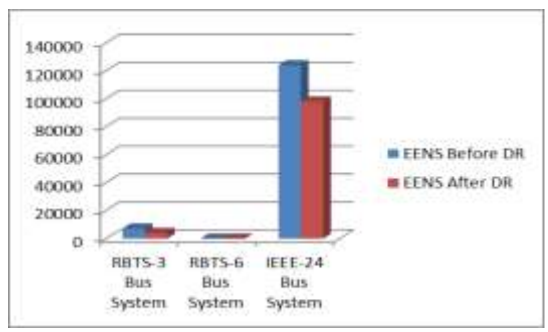

Fig.6 Comparison of EENS for different test systems

Comparisons of reliability indices for different test systems reveal some interesting points. Though the probabilities, frequencies are not greatly changed in terms on numerical values their impact on system operation cannot be neglected. But the Expected Load Curtailed (ELC) and Expected Energy Not Supplied (EENS) show substantial improvement. Especially their reduction is more noticeable for larger systems as seen from the results. Hence the results suggest the reliability evaluation procedure with the proposed methodology is more convincing when the network under consideration is large and interconnected.

II. CONCLUSIONS

The purpose of composite system Reliability evaluation is to estimate the ability of the system to produce electrical energy at the generation sources and then move this energy to the major load points. Composite System Reliability evaluation involves analysis of the combined generation and transmission system in regard to its ability to serve the system load. A brief introduction to the importance of Reliability in power system is introduced. Overview of composite system reliability evaluation and computational methods is highlighted.

A series of study on Composite System Reliability evaluation using State Space Enumeration method is described in this paper. Some of the basic concepts associated with state space method are introduced. Basic indices, generation model, transmission model, are briefly described.

The Truncated State Space (TSS) based state space enumeration method is applied in the MATLAB program for evaluating the reliability of composite generation and transmission system; it can be utilized to conduct a wide variety of composite system studies. The three test systems, i.e. the RBTS-3 bus, RBTS-6 bus and IEEE-24 bus are used extensively in this paper. TSS method together with the Demand Response (DR) load curtailment philosophy plays a major role in the variations in the system and the load point indices due to changes in the generating unit and transmission lines un-availabilities.

The number of states to be evaluated for any large system is greatly reduced by using TSS based Enumeration method. It is possible to assess a large variety of systems with the aid of suitable computer program. From the simulated results we can conclude that the proposed method effectively improves the System Reliability. The reliability study of the composite power system considering the distributed generating sources may be carried out as future work.

REFERENCES

[1]. Billinton R., Allan R.N.: ‘Reliability evaluation of Power systems’ Plenum Press, New York, London, 1996

[2]. L. Goel, Qiuwei Wu and Peng Wang, “Reliability Enhancement of a Deregulated Power System Considering Demand Response”, IEEE proceedings, pp. 1-6, 2006.

[3]. A.K. David and Y.C. Lee, “Dynamic Tariffs: Theory of Utility-Consumer Interaction”, IEEE Transactions on Power Systems, Vol. 4, No. 3, pp. 904-911, Aug. 1989.

[4]. A.K. David and Y.Z. Li, “Consumer Rationality assumptions in the Real-Time Pricing of Electricity”, IEE Proceedings, Vol. 139, No. 4, pp. 315-322, 1992.

[5]. J.He,Y.Sun,D.S.Kirschen, C.Singh, “State space partitioning method for composite power system reliability assessment”, IET Generation, Transmission & Distribution, 780-792, 2010

[6]. F.C.Scheweppe, M.C.Caramins, “R.D.Tabors and R.E.Bohn, “Spot pricing of electricity”, MA: Kluwer, 1998

[7]. R.Rajaraman,et.al, “ The effect of demand elasticity on security prices for the poolco and multi-lateral contract models”,IEEE Transaction on power systems,Vol.12, No.13,Aug.1997.

[8]. R.Billinton, L.Goel, “ A Reliability test system for educational purposes-Basic data”, IEEE Transaction on power systems,Vol.1,No.3, Aug., 1989

[9]. Singh C., Mitra j.: ‘Composite system reliability evaluation using state space pruning’, IEEE Trans. Power Syst., 1997, 12, (1), pp. 471 – 479

[10]. Reliability Test System Task Force: ‘IEEE reliability test system’, IEEE Trans. Power Appar. Syst., 1979, 98, (6), pp. 2047 – 2054

[11]. Billinton R., Khan E.: ‘A security based approach to composite power system reliability evaluation’, IEEE Trans. Power Syst., 1992, 7, (1), pp. 65 – 72

[12]. Allan.R.N, Billinton R., “Probabilistic assessment of power systems, Proc. IEEE, 2000, 88, (2), pp. 140 – 162