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Power System Reliability Index Assessment by Chronological Model with FACTS Devices

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Abstract. Providing quality and reliable power supply to the customers is the vital role in the power system. To deliver the economic and uninterrupted supply to the customers, the concept of restructuring the power system is an efficient notion to evaluate. The reliability of the power system can be checked by the reliability index. The chronological load model is introduced to evaluate reliability index in the vertical and restructured power system. There are many compensators, reactors and capacitor banks employed to control the power flow, but FACTS plays a superior role to control the power flow parameters. To examine the improvement in the reliability index, FACTS devices can be located at the optimal location. The ideal location to install the FACTS can be identified from the power flow analysis with required constraints and the corresponding reliability index will be calculated using chronological load model. Economic operation of transmission and the distribution was also achieved by using FACTS devices. The proposed assessment reveals that the objectives of power system reliability parameters in the deregulated power system can be achieved by the chronological load model.

INTRODUCTION

The power industry worldwide is experiencing a radical change in its business as well as in operation wherein, the vertically integrated utilities are being unbundled and opened up for competition with private players [1]. Planning, Operation and control of electric power was administered by a single entity or utility and as there was vertical integration of all tasks, they were referred to as vertically integrated utility. The restructuring process of power system involves unbundling of the originally vertically integrated utility. This leads to separate the activities involved in an integrated power system leading to creation of functional partition amongst them. Thus, three mutually exclusive functions are created and there are separate entities or companies that control these functions. Then, the competition can be introduced in the generation activity by allowing other private participants in their segment [2]. Restructured power system is the assortment of Generation Companies, Transmission Companies and Distribution Companies.

The role of system study is to verify the precision of power system parameters throughout the power system. Electricity is an essential commodity that can be bought and sold in the market place, where anybody can choose their required supply in the competitive electricity markets [3]. Privatisation leads to more flexible and reliable supply to the customers. Competition in the electricity markets may lead to many innovations in the power transmission and distribution which also initiates efficient and economic power delivery. There will be remarkable competitions in the power generation which enable the uninterrupted power delivery to the customers at reasonable price. The disaggregation of electricity from the vertical integrated system overcome the monopoly [4]. The competition in the generation, transmission and distribution sectors leads to quality and economic power delivery. The term reliability is defined as the ability of the component or equipment performed as designed. In power system, the term reliability depends on adequacy and security. If the output produced by a system is sufficient to cater to all demands in the power system, the system is said to be adequate [5].

Flexible Alternating Current Transmission System (FACTS), devices can be used in the power system as a compensator or regulator to increase the system reliability. FACTS devices are well suited for series and shunt recompense in the power system network [6]. The following devices are analysed to verify the power system

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reliability. Static Var Compensator and Static Condensers are used for shunt recompense. Thyristor Controlled Switched Capacitor and Static Synchronous Series Capacitor are used for Series recompense. UPFC is used for both series and shunt recompense. Installation of FACTS will improve the economic feasibility which will reduce Remedial Action Cost and Expected Energy Not Supplied [7]. The implications of FACTS can be correlated with the reliability index to check the enhancement of power system reliability [8].

RELIABILITY ASSESSMENT

The reliability management materialized in the centralised policy of vertical integrated system is converted into the decentralised policies which materialize the deregulated power system. The reliability assessment involved in the restructured power system should concentrate the generator rescheduling and load curtailment, which are the pillars of system reliability[9]. The contingency management in the real time system is a big challenge due to the fluctuations in the frequency, voltage and imbalance power. The network violations during the contingency analysis need to be monitored to enhance system reliability[10].

MATHEMATICAL REPRESENTATION

The mathematical reliability model for a Chronological load is expressed as follows

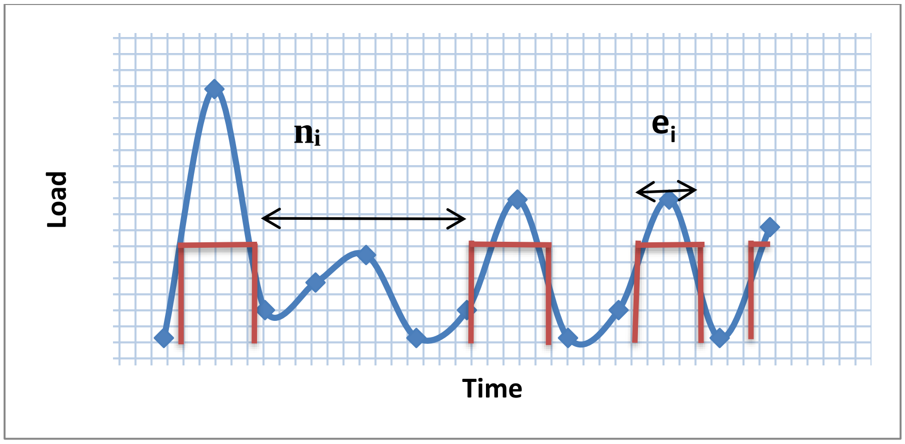

FIGURE 1. Chronological Load Model

n_i – normal load pattern
e_i – extreme load pattern
N – average duration of normal load
A – average duration of extremis load
λ_{avg} – average component failure
λ – failure rate at normal condition
λ^1 – failure rate at extremis condition

Consider two components are operating at normal and extremis state associated with the failure and repair rate

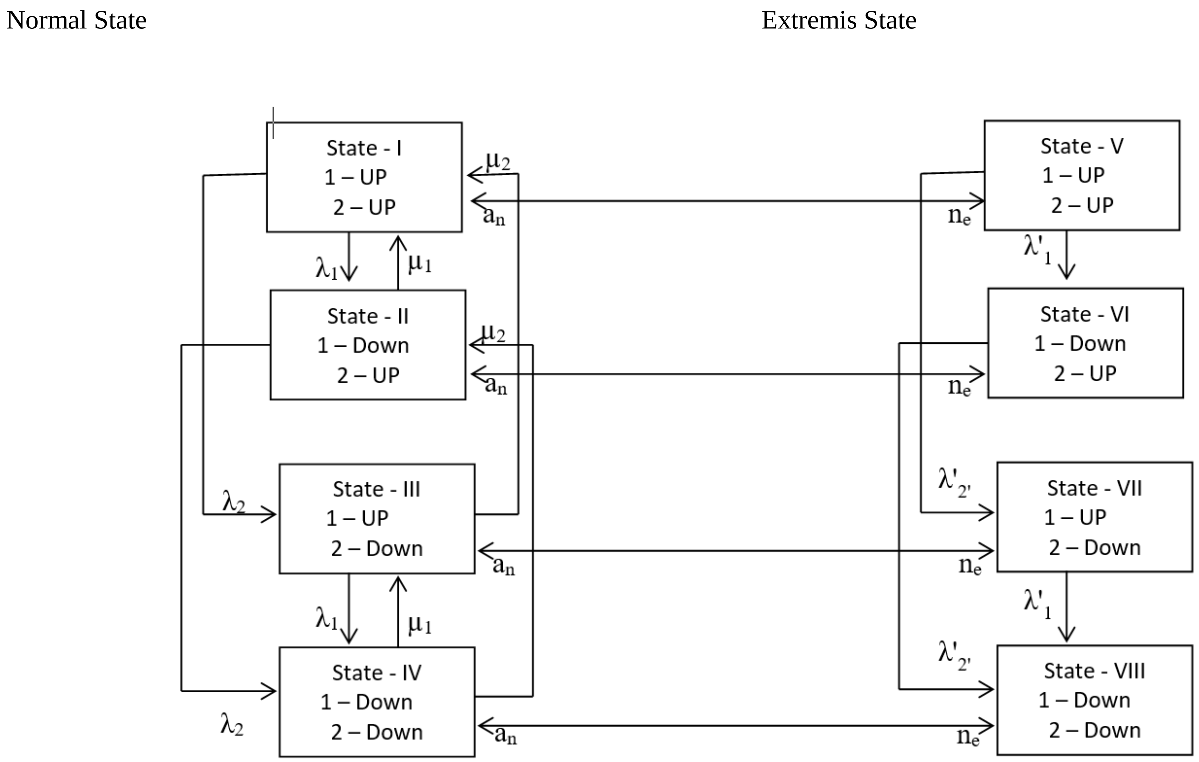

FIGURE 2. State Space Diagram of 2-Component, 2-State System

From the above state space diagram,

$$(\lambda_1 + \lambda_2 + n_e)P_I - \mu_1 P_{II} - \mu_2 P_{III} - a_n P_V = 0 \tag{1}$$

$$(\lambda_2 + \mu_1 + n_e)P_{II} - \lambda_1 P_I - \mu_2 P_{IV} - a_n P_{VI} = 0 \tag{2}$$

$$(\lambda_1 + \mu_2 + n_e)P_{III} - \lambda_2 P_I - \mu_1 P_{IV} - a_n P_{VII} = 0 \tag{3}$$

$$(\mu_1 + \mu_2 + n_e)P_{IV} - \lambda_2 P_{II} - \lambda_1 P_{III} - a_n P_{VIII} = 0 \tag{4}$$

$$(\lambda'_1 + \lambda'_2 + a_n)P_V - n_e P_I = 0 \tag{5}$$

$$(\lambda'_2 + a_n)P_{VI} - \lambda'_1 P_V - n_e P_{II} = 0 \tag{6}$$

$$(\lambda'_1 + a_n)P_{VII} - \lambda'_2 P_V - n_e P_{III} = 0 \tag{7}$$

$$a_n P_{VIII} - \lambda'_1 P_{VII} - \lambda'_2 P_{VI} - n_e P_{IV} = 0 \tag{8}$$

The dependent simultaneous equations are solved by

$$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 = 1 \tag{9}$$

The above linear equations can be expressed in matrix form

$$[D][P] = 0 \tag{10}$$

Where [D] is the matrix obtained from state-space diagram and [P] is the matrix from transpose of independent equation. The matrix [P] gives the probability of failure rate of the assessed components. The Expected energy not supplied can be obtained from the probability of failure rate.

[D] =

$$\begin{bmatrix} \lambda1+\lambda2+\mathrm{ne} & -\mu1 & -\mu2 & 0 & -\mathrm{an} & 0 & 0 & 0 \\ -\lambda1 & \lambda2+\mu1+\mathrm{ne} & 0 & -\mu2 & 0 & -\mathrm{an} & 0 & 0 \\ -\lambda2 & 0 & \lambda1+\mu2+\mathrm{ne} & -\mu1 & 0 & 0 & -\mathrm{an} & 0 \\ 0 & -\lambda2 & -\lambda1 & \mu1+\mu2+\mathrm{ne} & 0 & 0 & 0 & -\mathrm{an} \\ -\mathrm{ne} & 0 & 0 & 0 & \lambda'1+\lambda'2+\mathrm{an} & 0 & 0 & 0 \\ 0 & -\mathrm{ne} & 0 & 0 & -\lambda'1 & \lambda'2+\mathrm{an} & 0 & 0 \\ 0 & 0 & -\mathrm{ne} & 0 & -\lambda'2 & 0 & \lambda'1+\mathrm{an} & 0 \\ 0 & 0 & 0 & -\mathrm{ne} & 0 & -\lambda'2 & -\lambda'1 & \mathrm{an} \end{bmatrix}$$

$$[\mathrm{P}] = [P_I \quad P_{II} \quad P_{III} \quad P_{IV} \quad P_V \quad P_{VI} \quad P_{VII} \quad P_{VIII}]^{\mathrm{T}}$$

The Expected Energy Not Supplied (EENS) is calculated from the load curtailments and the associated average frequency and duration index and it is given in Equation (11)

$$EENS = \sum_i^n CL_i F_i D_i \quad \text{MWhr/Yr} \qquad (11)$$

IEEE proposed many reliability indices for the complex system, which is declared as bulk reliability indices. The bulk Expected Energy Not Supplied is modified with the annual peak load and it is given in equation (12)

$$BEENS = \frac{EENS}{P_L} \quad \text{MWhr/MWYr} \qquad (12)$$

Reliability of bulk system with respect to the availability of supply is given as

$$R_B = 1 - \text{Loss of Load Probability} \qquad (13)$$

The reliability index for the bulk system with the variation of demand with respect to the time is given in the equation (14).

$$R_B = \frac{1}{\sum_{i=1}^N T_i} \sum_{i=1}^N P_i (1 - LOLP) T_i \qquad (14)$$

Here T represents the time interval of ith Component in the reliability test system.
P_i represents the probability of failure rate of ith Component in the reliability test system
Loss of Load Probability can be estimated with the variations in supply and demand and the variation of load pattern [11,12]. The un-served energy shows that the generating capacity is not correlated with the load pattern. The load pattern varies with the time interval of demand.

Therefore, the Loss of Load probability can be identified from the generating units and it is given in the equation (15)

$$\text{LOLP} = \sum_i^N P_{C_i} > L_i \qquad (15)$$

P_{C_i} Stands for the probability of load curtailment with respect to the load pattern correlated with the capacity of generating units.
But the independent generating units which are required to reduce the forced outage rate and the probability of the failure rate [13]. It can be estimated with the unavailability index and it can be written as

$$P_{C_i} = U_i (1 - U_i) \qquad (16)$$

Where U_i represents the Unavailability index in the bulk reliability system with the independent generator units.
The availability function of the bulk reliability system is denoted as A_i with the ith component and system can be represented as in equation (17)

$$A_i(L_i, T_i) = \frac{1}{\sum_i^N T_i} \sum_i^N A(L_i) T_i \qquad (17)$$

The availability index can be calculated with the variations of outage rate in the load pattern. Therefore, the Loss of Load probability can be easily computed with the availability index and it is given in equation (18) and equation (19)

$$\text{LOLE} = 1 - A_i \tag{18}$$

Or

$$A_i = 1 - \text{LOLE} \tag{19}$$

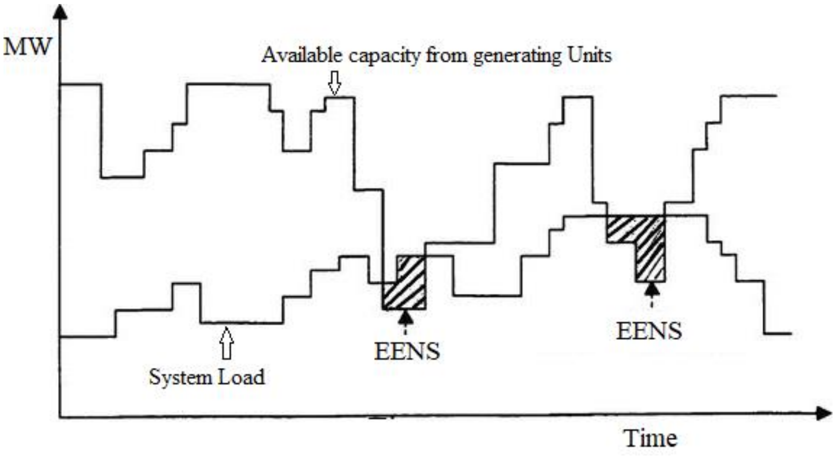

FIGURE 3. Correlation of System Load and Available Capacity

The Severity Index also calculated from the above bulk index and it is given in Equation (20)

$$SI = \frac{EENS}{P_L}\, x\, 60 \ \text{ System Min/Yr} \tag{20}$$

The performance of the restructured network will be indicated by the enactment pointers which includes capacity weighted and customer weighted indices[14].

CONCLUSION

The contingencies present at each location were addressed by the Chronological load model in the bulk system. The steady state analysis proposed by the chronological load model gives the adequacy and the security of the bulk system through the corresponding reliability indices. The accuracy of the frequency index and the duration index will be very high because the bulk reliability indices are synthesised by the probability distribution function. Since the accuracy is at the optimal in the sequential simulation, it can be used as a benchmark for the real time system. The results can be used for the expansion of power system and power system planning. Reliability of the system also increased with decrease in EENS. The electrical interruptions can be isolated with the proper placements of DGs and the adequacy of system can be maintained

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