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Evaluation of Reliability Indices of a Power System Based on Reactive Power Injection

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Abstract

Reliability is an important factor in planning, design, operation and maintenance of power systems. The reliability evaluation of a power system can be done using different methods. Due to complex and integrated nature of a power system, failures in any part of the system can cause interruptions. Evaluation of Reliability indices and solving of the Load flow analysis can be done using ETAP software. Newton Raphson method is adopted for the load flow analysis. The optimal capacitor placement was done using ETAP software. The reliability indices with and without capacitors is obtained from the same. As a case study the 220kV Kerala power system has been considered for the reliability and load flow analysis.

Keywords: Reliability Indices, Load flow analysis, Newton Raphson Method, Optimal Capacitor Placement.

Introduction

Power flow analysis is the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. The principal information of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. Power flow analysis is an importance tool involving numerical analysis applied to a power system. In this analysis, iterative techniques are used due to there no known analytical method to solve the problem. To finish this analysis there are methods of mathematical calculations which consist plenty of step depend on the size of system.

Power system reliability is a measure of its ability to supply electricity to all its customers continuously and economically. Electric power system is one of the largest and most complex systems. It depends on the number of outages or power failures that will occur in the service period and outage duration. A power system can be divided into three main functional regions designated as generation, transmission and distribution systems. Reliability evaluation of the power systems can be performed in each individual functional zone. Time dependent failure rates of a component are commonly represented using bath tub curve. Probabilistic methods are used for expressing reliability qualitatively.

In power systems, reliability evaluation can be defined as analyzing the ability of the system to satisfy the load demands. The basic function of a composite power system is to generate and deliver a required electrical energy to the load centers. The Reliability computation of the whole system depends on the reliability of each component included in that system. Each component has two states, an operating state and a failed state. By specifying whether the component is operating or failed we can discern the status of the system. In power systems, reliability analysis and assessment are essential factors for the continuous operation of the system. It is necessary to verify what kind of outages may occur in a practical system. In this paper the load flow analysis and reliability evaluation of a five bus system are considered. The ETAP software is used for the reliability evaluation, load flow analysis and optimal capacitor placement.

Reliability Evaluation

The term reliability means the ability of the system to perform its intended function, where the past analysis helps to estimate future performance of the system. Reliability is the probability of a device or system performing its function adequately, for the period of time intend, under the specified operating conditions.

System reliability can be computed from the failure probability of the composite power system due to outage of lines, transformers and generators. There may be more than one failure condition for outage of a line, transformer or generator. The failure probability of line, transformer or generator will be the failure probability of the system in that condition. The summation of all these failure probabilities will be the total failure probability of the composite power system.

Several indices representing the measures of reliability are defined and some of these indices are later calculated for quantitative reliability analysis. All the measures of the reliability quantify the future behavior of the units. This intended future depends on the application. It can be some seconds as in a missile example or can be some ten years as in electric power systems. It is obvious that the behavior in the future is probabilistic and it can only be held by probabilistic methods. On the other hand, reliability indices and analysis depends on the applications, operating conditions, failure types etc.

Reliability evaluation techniques have been well developed. A system component such as a generator, a transmission line, or a reactive power compensator can be represented using the two-state reliability model as shown in Figure. 1. The concepts of availability and unavailability are associated with the simple two-state model and this model is directly applicable to a base load generating unit which is either operating or forced out of service. When failure rate λ and repair rate μ are time invariant the system can be considered as a Markov process.

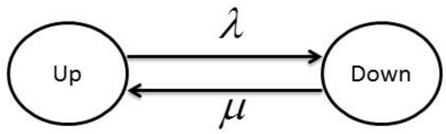

Fig.1. Two state model of a component.

The availability A and unavailability U of a component can be calculated based on its failure rate λ and repair rate μ using the following equations:

$$A = \frac{\mu}{\lambda + \mu} ; U = \frac{\lambda}{\lambda + \mu} \quad 1$$

Results from a reliability study can be expressed using different reliability indices. There are many possible reliability indices, which often are interdependent. In order to reflect the severity or significance of a system outage, reliability indices are evaluated. Depending on the application, a suitable set of indices has to be chosen, to perform the reliability evaluation. It is fairly common practice in the electric utility industry to use the standard IEEE reliability indices like CAIDI, SAIFI, SAIDI to track and benchmark reliability performance. These reliability indices include measures of outage duration, frequency of outages, system availability and response time. The standard deviation of the reliability indices provides distribution engineers with information on the expected range of the annual values. The evaluation of reliability indices for a composite system is very much computationally demanding.

System Average Interruption Frequency Index, SAIFI (f/customer.yr)

$$SAIFI = \frac{Total\ no\ of\ Customer\ Interruptions}{Total\ no\ of\ customers\ served} \quad 2$$

SAIFI is a measure of how often an average customer loses supply during one year. It is the average number of times that a system customer is interrupted during a time period.

System Average Interruption Duration Index, SAIDI (hr./customer.yr)

$$SAIDI = \frac{Total\ no\ of\ Customer\ Interruption\ duration}{Total\ no\ of\ customers\ served}$$

It is the average outage duration for each customer served.

Customer Average Interruption Duration Index, CAIDI (hr/customer interruption)

$$CAIDI = \frac{Total\ no\ of\ Customer\ Interruption\ duration}{Total\ no\ of\ Customer\ Interruption}$$

CAIDI gives the average outage duration that any given customer would experience.

Average System Availability Index, ASAI (pu)

$$ASAI = \frac{Customer\ hours\ of\ Available\ service}{Customer\ hours\ demanded}$$

Average Service Unavailability Index, ASUI

$$ASUI = 1 - ASAI$$

LOAD FLOW ANALYSIS

In a three phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide a systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system. Mainly three methods are there for load flow- Gauss Seidel, Newton Raphson and Fast Decoupled. Here Newton Raphson method is used for load flow analysis.

The most widely used power flow solution employs Newton-Raphson technique. Because of its quadratic convergence, Newton's method is mathematically superior to the Gauss-Seidel method and is less prone to divergence with ill-conditioned problems. For large power systems, the Newton-Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required for each iteration. Since in the power flow problem real power and voltage magnitude are specified for the voltage-controlled buses, the power flow equation is formulated in polar form.

The real and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^*$$

$$I_i = \frac{P_i - jQ_i}{V_i^*}$$

The above equation can be written in terms of bus admittance matrix as,

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \quad \angle\theta_{ij} + \delta_j$$

$$P_i - jQ_i = |V_i|\angle -\delta_i \sum_{j=1}^{n} |Y_{ij}||V_j|\angle \theta_{ij} + \delta_j \qquad 4$$

Separating the real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \qquad 5$$

Expanding the above equations and in Taylor's series about the initial estimate and neglecting all higher order terms results in the following set of linear equations:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{cc|cc} \frac{\partial P_2^{(k)}}{\partial \delta_2} \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & & \vdots & \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_2} & \frac{\partial P_n^{(k)}}{\partial |V_2|} \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \\ \hline \frac{\partial Q_2^{(k)}}{\partial \delta_2} \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} & \frac{\partial Q_2^{(k)}}{\partial |V_2|} \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & & \vdots & \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \frac{\partial Q_n^{(k)}}{\partial |V_2|} \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \vdots \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \qquad 6$$

In the above equation bus1 is assumed to be the slack bus. The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta|V_i^{(k)}|$ with the small changes in real and reactive power $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$.

In short form it can be written as,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \times \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \qquad 7$$

For voltage controlled buses, the voltage magnitudes are known. Therefore, if m buses of the system are voltage- controlled, m equations involving ΔV and ΔQ, corresponding columns of the Jacobian matrix are eliminated. So there are n-1 real power constraints and n-1-m reactive power constraints. Jacobian matrix is of order (2n-2-m) x (2n-2-m). J_1 is of the order (n-1) x (n-1). J_2 is of the order (n-1) x (n-1-m). J_3 is of the order (n-1-m) x (n-1) and J_4 is of the order (n-1-m) x (n-1-m).

The terms $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are the difference between the scheduled and calculated values, known as the power residuals, given by,

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{k} \qquad 8$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^k$$

The new estimates for bus voltages are

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}$$
$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \quad 9$$

The new voltage magnitudes and phase angles are computed from the equations. The process is continued until the residuals $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are less than the specified accuracy, i.e.,

$$\left|\Delta P_i^{(k)}\right| \le \varepsilon$$
$$\left|\Delta Q_i^{(k)}\right| \le \varepsilon \quad 10$$

Results

Single line diagram of the 220kv substation in Kerala was simulated using ETAP software and was modeled according to Fig. 2. The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. The various reliability indices like SAIFI, SAIDI, CAIDI, ASAI and ASUI are found out using ETAP software and are shown in Table I.

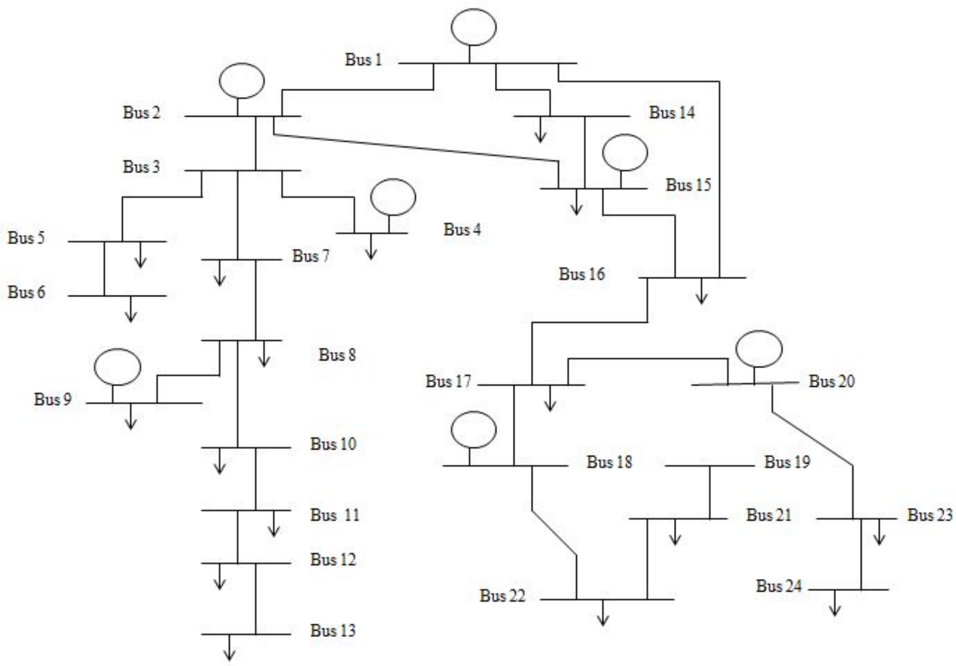

Fig.2. One line diagram of the 220KV system

Table.I. Reliability Indices

RELIABILITY INDICES	SYSTEM VALUES
SAIFI	0.2137 f / customer .yr
SAIDI	9.3003 hr / customer .yr
CAIDI	43.527 hr. / customer interruption
ASAI	0.9989 pu
ASUI	0.00106 pu
EENS	38504.74 MW hr. / yr.
AENS	2264.985 MW hr. / customer.yr

Table. II. Voltage magnitude at each bus

Bus	Voltage Magnitude without Capacitor Placement	Voltage Magnitude with Capacitor Placement
Areekode	196.6778	201.7466
Brahmapuram	212.652	213.026
Edamon	195.5756	195.7384
Edappon	193.3294	193.4922
Kalamassery	214.7552	214.9356
Kanhirode	191.3274	199.9668
Kaniampetta	206.4766	208.5314
Kundara	196.6118	196.7768
Malapparambu	206.4766	208.5314
Mylatti	189..4618	202.0788
Nallalom	195.4304	200.4662
New Pallom	211.2792	211.4574
Palakkad	206.5624	208.6172
Poovanthuruthu	202.5628	202.7344
Pothencode	193.4922	194.975
Shornur	201.5684	205.0642
Thaliparamba	190.1526	200.7456
Vadakara	193.6968	200.4992

The percentage voltage magnitude with and without capacitor placement is obtained from ETAP software and are shown in Table II. The capacitor placement have the advantages like increased voltage level at load, reduction in the line current, reduction in system losses and improvement in power factor. It has less loading on system equipment and so the investment per KW of the load is consequently reduced. For the load flow analysis bus 1 is considered as the slack bus or the reference bus. The solution for the load flow was obtained by Newton Raphson iterative method. The line data and bus data tables are the required input for the load flow analysis. The various results from load flow includes the voltage magnitudes, angles, power flows, losses in the system, power factor etc.

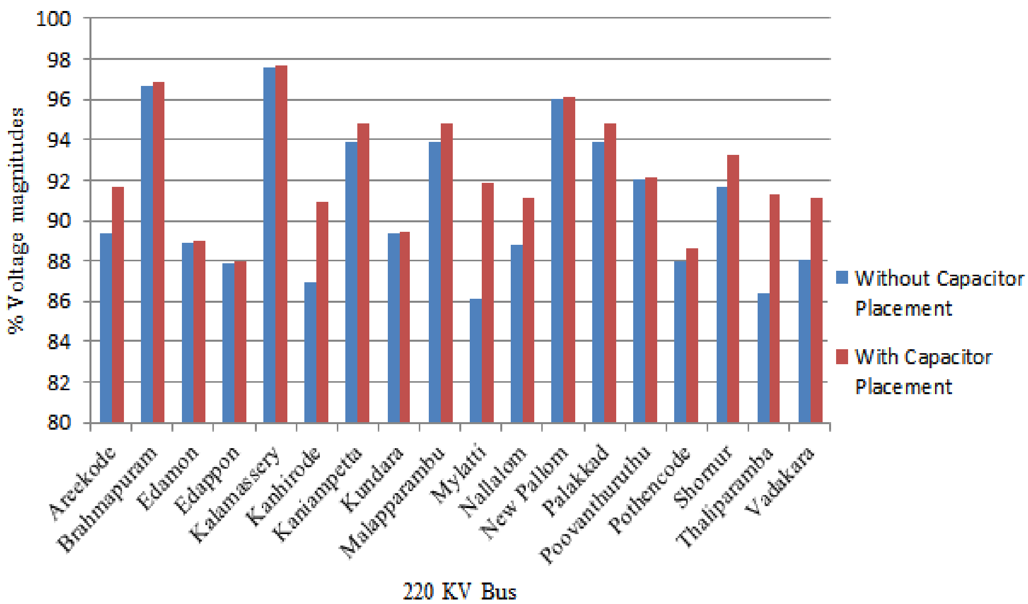

Fig.3. The % Voltage Magnitude at 220 KV substations with and without Capacitors

Conclusions

Evaluation of Reliability indices and solving of the Load flow analysis can be done using ETAP software. Newton Raphson method is adopted for the load flow analysis. The optimal capacitor placement was done using ETAP software. The reliability indices with and without capacitors is obtained from the same. As a case study the 220kV Kerala power system has been considered for the reliability and load flow analysis. Load flow analysis provides information on power system planning, design and planning. From the reliability analysis, suggestions can be made to improve the reliability.

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Prof. Abdul Jaleel. J received the Bachelor degree in Electrical Engineering from University of Kerala, India in 1994. He received the M.Tech degree in Energetics from Regional Engineering College Calicut, Kerala, India in 2002, and PhD from WIU, USA in 2006.

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