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Load Flow Analysis and Reliability Evaluation of 220kV Kerala Power system

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***Abstract*— This paper presents the load flow analysis and the reliability evaluation of 220 kV power system of Kerala. Load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems and here one of the efficient methods of Newton Raphson is used. The principal information obtained from the load flow analysis is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. Single line diagram is modeled using Electrical Transient Analyzer Program (ETAP) software. The various reliability indices are also obtained which can be used as a measure of system reliability .The optimal capacitor placement is also done using ETAP. Load flow is also carried out using MATLAB software.**

***Index Terms*—E-TAP, Load flow Analysis, MATLAB, Newton-Raphson, Reliability.**

I. INTRODUCTION

Electrical power system provides a vital service to the society. It should be operated with the goal of achieving highest reliability standards, minimum operational costs and environmental impacts. Power systems are complex, nonlinear, stochastic, dynamic systems. With the increasing network connections power systems have been growing in size and complexity.

Power flow studies commonly referred to as load flow are the back bone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. Power flow analysis finds many applications in other analyses such as transient stability and contingency studies.

The quality and reliability of a power system determined when it is operating satisfactorily is characterized by a nearly constant frequency, voltage profile at a low level of outage. Power system reliability is defined as ability of electrical power system to supply the system load with reasonable continuity and quality of supply.

The reliability of a power system is dependent on the number of outages or power failures that will occur in the service period and outage duration. Reliability of a power system is the probability of it performing its purpose adequately for the duration in which it has to operate under the conditions encountered. Major subdivisions of power system reliability are system adequacy and system security. The term adequacy relates to the existence of sufficient facilities within the system to satisfy the consumers' load demand and system operational constraints. Thus, adequacy majorly deals with static conditions and not the dynamic and transients of power system. Security is associated with system dynamics and disturbances in the system. Security is therefore related to the response of the system to perturbations it is subjected to.

In this paper the load flow analysis and reliability evaluation of the 220KV Kerala Power System is done. For the load flow Newton Raphson iterative method is utilized. Reliability indices were calculated using the ETAP Software. The sections are organized as follows. Section II describes the load flow analysis and the method used and section III briefs the reliability evaluation and the reliability indices used here. Section IV discusses about the results obtained.

II. 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 [1]. 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.

A. *Newton Raphson Method*

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 now equation is formulated in polar form [4].

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The real and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^* \qquad (1)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (2) \qquad (2)$$

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

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \quad \angle\theta_{ij} + \delta_j \qquad (3)$$

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

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

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

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, the 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 diagonal and the off- diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad j \neq i \qquad (7)$$

The diagonal and the off- diagonal elements of J_2 are

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad j \neq i$$

$$\frac{\partial |P_i|}{\partial |V_i|} = 2|V_1||Y_{ii}| \cos\theta_{ii} + \sum_{j \neq i} |V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

(8)

The diagonal and off diagonal elements of J_3 are

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq i} |V_1||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad j \neq i$$

The diagonal and the off diagonal elements of J_4 are

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ij}| \sin\theta_{ii} - \sum_{j \neq i} |V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)$$

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$$\frac{\partial Q_i}{\partial |V_j|} = -|V_i||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \qquad j \neq i \tag{8}$$

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,

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^k$$
$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^k \tag{9}$$

The new estimates for bus voltages are

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}$$

$$|V_i^{(k+1)}| = |V_i^{(k)}| + \Delta|V_i^{(k)}| \tag{12}$$

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.,

$$|\Delta P_i^{(k)}| \leq \varepsilon$$
$$|\Delta Q_i^{(k)}| \leq \varepsilon \tag{10}$$

III. RELIABILITY EVALUATION

Reliability evaluation techniques have been well developed [5]. 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.

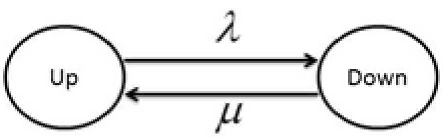

Fig. 1. Two state model of a component

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:

$$A = \frac{\mu}{\lambda + \mu}; \; U = \frac{\lambda}{\lambda + \mu} \tag{11}$$

A. Reliability Indices

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. gives the overall behavior of the system.

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

$$SAIFI = \frac{Total\ no\ of\ Customer\ Interruptions}{Total\ no\ of\ customers\ served} \tag{12}$$

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.

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

$$SAIDI = \frac{Total\ no\ of\ Customer\ Interruption\ duration}{Total\ no\ of\ customers\ served} \tag{13}$$

It is the average outage duration for each customer served.

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

$$CAIDI = \frac{Total\ no\ of\ Customer\ Interruption\ duration}{Total\ no\ of\ Customer\ Interruption} \tag{14}$$

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

4. *Average System Availability Index, ASAI (pu)*

$$ASAI = \frac{Customer\ hours\ of\ Available\ service}{Customer\ hours\ demanded} \tag{15}$$

5. *Average Service Unavailability Index, ASUI*

$$ASUI = 1 - ASAI \tag{16}$$

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IV. RESULTS

Load flow analysis is carried out in the 220KV system of Kerala. MATLAB program for finding the voltage magnitude and angles, power flows and the total losses in the system is utilized. 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.

The MATLAB program for the load flow analysis uses Newton Raphson method for the load flow analysis. The various buses are classified as slack bus, generator bus and the load bus. The line data and bus data for the 220kV Kerala power system were calculated and given as the input. The power injections in various buses were obtained for normal case, outages cases and for other contingencies.

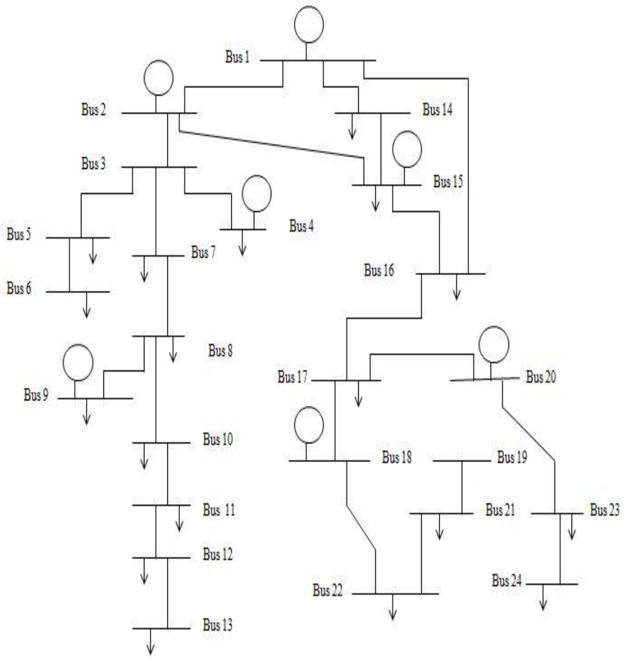

Fig.2. One line diagram of the 220KV system

For the improvement of voltage profile Capacitor placement is done. 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.

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	0.00106pu
EENS	38504.74 MW hr. / yr.
AENS	2264.985 MW hr. / customer.yr

The percentage voltage magnitude with and without capacitor placement is obtained from ETAP software and are shown in Table II.

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	195.4305	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

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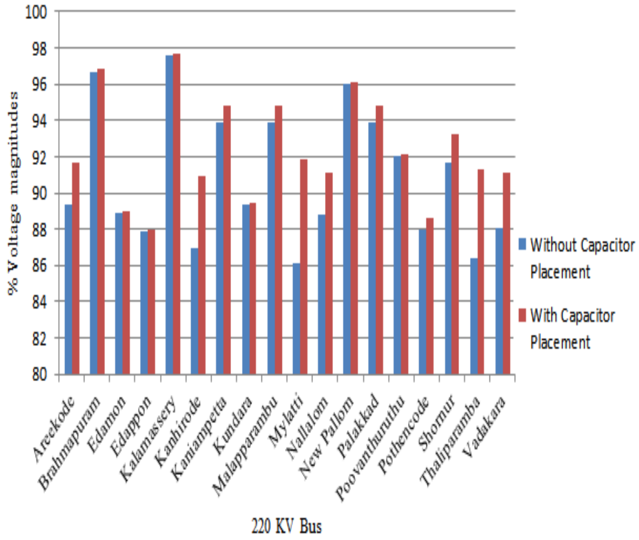

Fig.3. The % Voltage Magnitude at 220 KV substations with and without Capacitors

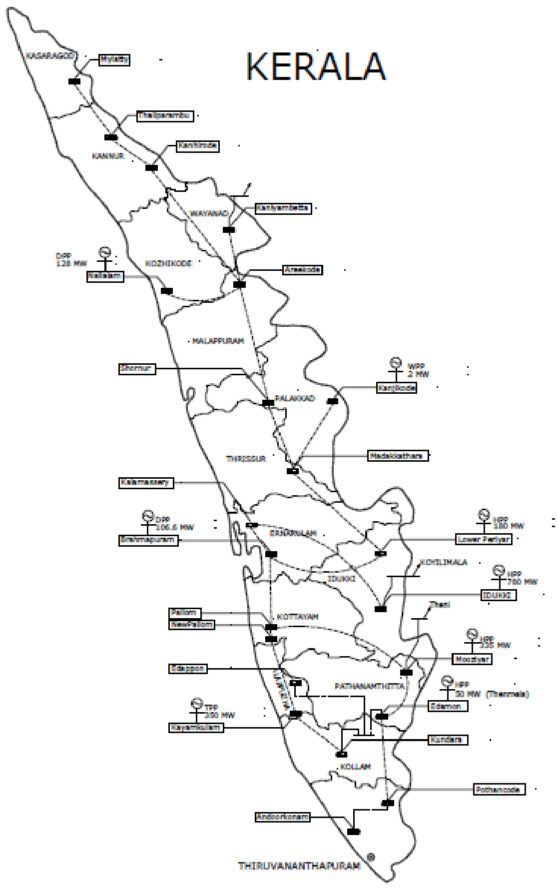

Fig.4. The 220 kV substations of Kerala

V. CONCLUSION

Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study was the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. Load flow analysis was conducted on the 220KV substations in Kerala Power System and the voltage profile was analyzed. Static capacitor banks for reactive power compensation were found to be effective in improving the voltage profiles. The load flow analysis was done using MATLAB and ETAP software. The various reliability indices were also obtained from the ETAP software.

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