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LOAD FLOW BASED RELIABILITY ASSESSMENT OF A REAL TIME RADIAL DISTRIBUTION SYSTEM - CASE STUDY

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Abstract— In this paper mainly describe about the Distribution system reliability is evaluated in two ways. One by placing capacitor at weak voltage nodes for improvement of voltage profiles, reducing the total losses. Second way by improving reliability indices by placing protective equipment (isolators)in the feeder. This paper present an effective approach for real time evaluation of distribution power flow solutions with an objective of determining the voltage profiles and total losses, and to improve the voltage profiles and reducing losses by placing capacitors at weak voltage profile nodes using Particle Swarm Optimization (PSO) technique. The Distribution System Reliability Indices are also calculated for the existing radial distribution system before and after placement of isolator. The paper presents a topological characteristic of distribution networks have been fully utilized to make the direct load flow solution is possible for a real time system. Two matrices the bus-injection to branch-current matrix and the branch-current to bus voltage matrix and a simple matrix multiplication are used to obtain power flow solutions. This paper also presents an approach that determines optimal location and size of capacitors on existing radial distribution systems to improve the voltage profiles and reduce the active power loss. Capacitor sizing was done by using Particle Swarm Optimization. In this paper we have considered the load diversity factor for analysis of load data for real time system. The performance of the method was investigated on a real time distribution system as case study. For load data of real time distribution system the average power factor for feeder was considered and distributed depending on the connected load. The load flow results obtained are compared with power summation method.

***Keywords*— BIBC, BCBV, Diversity Factor, Reliability Indices, Distribution Load Flows, PSO.**

I. .INTRODUCTION

The demand for electrical energy is ever increasing. Today over 21% (theft apart!!) of the total electrical energy generated in India is lost in Transmission (5-7%) and Distribution (15-18%). The electrical power deficit in the country is currently about 35%. Clearly, reduction in losses can reduces this deficit significantly. It is possible to bring

down the distribution losses to 6-8% level in India with the help of newer technological options (including information technology) in the Electrical Power Distribution Sector which will enable better monitoring and control. The electric utility system is usually divided into three subsystems which are Generation, Transmission, and Distribution. A fourth division, which sometimes made is Sub-Transmission. However, the latter can really be considered as a subset of transmission since the voltage levels and protection practices are quite similar. Electricity distribution is the final stage in the delivery of electricity to end users. A Distribution Network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (less than 50 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 1000 V) distribution wiring and sometimes electricity meters.

Electric power is normally generated at 11-25kV in a power station. To transmit over long distances, it is then stepped-up to 400kV, 220kV or 132kV as necessary. Power is carried through a transmission network of high voltage lines. Usually, these lines run into hundreds of kilometers and deliver the power into a common power pool called the grid. The grid is connected to load centers through a sub-transmission network of normally 33kV (or sometimes 66kV) lines. These lines terminate into a 33kV (or 66kV) substation, where the voltage is stepped-down to 11kV for power distribution to load points through a distribution network of lines at 11kV and lower.

The power network, which generally concerns the common man is the distribution network of 11kV lines or feeders downstream of the 33kV substation. Each 11kV feeder which emanates from the 33kV substation branches further into several subsidiary 11kV feeders to carry power close to the load points (localities, industrial areas, villages, etc.,). At these load points, a transformer further reduces the voltage from 11kV to 415V to provide the last-mile connection through 415V feeders (Low Tension (LT) feeders) to individual customers, either at 240V (as single-phase supply) or at 415V (as three-phase supply). A feeder could be either an overhead line or an underground cable. In urban areas, owing to the density of customers, the length of an 11kV feeder is generally up to 3 km. On the other hand, in rural areas, the feeder length is much larger (up to 20 km). A 415V feeder should normally be restricted to about 0.5 - 1.0 km. unduly long feeders lead to low voltage at the consumer end.

II. DIVERSITY FACTOR

The probability that a particular piece of equipment will come on at the time of the facility's peak load. It is the ratio of the sum of the individual non-coincident maximum demands of various subdivisions of the system to the maximum demand of the complete system. The diversity factor is always greater than 1. The (unofficial) term *diversity*, as distinguished from *diversity factor* refers to the percent of time available that a machine, piece of equipment, or facility has its maximum or nominal load or demand (a 70% diversity means that the device in question operates at its nominal or maximum load level 70% of the time that it is connected and turned on). This diversity factor is used to estimate the load of a particular node in the system.

III. LOAD FLOW STUDIES

The load-flow study in a power system has great importance because it is the only system which shows the electrical performance and power flow of the system operating under steady state. Load-Flow studies are performed to determine the steady-state operation of an electric power system. A load-flow study calculates the voltage drop on each feeder, the voltage at each bus, and the power flow in all branch and feeder circuits. Losses in each branch and total system power losses are also calculated. Load-Flow studies are used to determine the remain within specified limits, under various contingency conditions only.

Load-flow studies are often used to identify the need for additional Generation, Capacitive/Inductive VAR support or the **placement of capacitors** and/or reactors to maintain system voltages within specified limits. An efficient load-flow study plays vital role during planning of the system and also for the stability analysis of the system. Distribution networks have high R/X ratio whereas the transmission networks have high X/R ratio. Hence, the distribution networks are ill-conditioned in nature. Therefore, the variables for the load-flow analysis of distribution systems are different from those of transmission systems. The Transmission load flows Newton Raphson Method; Gauss method fails due to high X/R ratio. Many modified versions of the conventional load-flow methods have been suggested for solving power networks with high *R/X* ratio. The following are the effective load flow techniques used in the distribution networks:

1. Single-Line Equivalent Method
2. Very Fast Decoupled Method
3. Ladder Technique
4. Power Summation Method
5. Backward and Forward Sweeping Method

The proposed algorithm is tested on a Real Time system. The remaining part of the paper is organized as follows: Section 4 gives the formulation of load flow model, Section 5 discusses the load flow algorithm, Section 5develops the test system and Real Time Systems results and discussions and Section 6discusses the conclusions.

IV. FORMULATION OF LOAD FLOW MODEL

(a) Algorithm Development:

The technique is based on two derived matrices, the bus-injection to branch-current matrix and the branch current to bus-voltage matrix, and equivalent current injections. In this section, the development procedure will be described in detail. For distribution networks, the equivalent current-injection based model is more practical [5-13]. For bus , the complex load S is expressed by

$$Si = P_i + jQi \quad \text{----------- (1)}$$

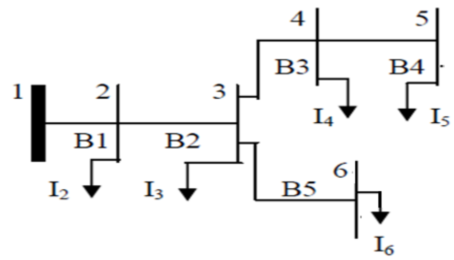
Where I = 1, 2, ... *N*

And the corresponding equivalent current injection at the –kth iteration of solution is

$$I_i^k = (P_i + jQ_i / V_i^k)^* \quad \text{--------- (2)}$$

Where Vi^k and $Ii^k$are the bus voltages and equivalent current injection of bus i at kth iteration respectively.

(b) Relationship Matrix Development



A simple distribution network shown in fig.1 is used as an example the current equations are obtained from the equation (2) .The relationship between bus currents and branch currents can be obtained by applying Kirchhoff's current law (KCL) to the distribution network. Using the algorithm of finding the nodes beyond all branches proposed by Gosh et al. The branch currents then are formulated as functions of equivalent current injections for example branch currents B1, B3 and B5 can be expressed as

$$\left.\begin{aligned} B1 &= I2+I3+I4+I5+I6 \\ B3 &= I4+I5 \\ B5 &= I6 \end{aligned}\right\} \quad \text{------------ (3)}$$

Therefore the relationship between the bus current injections and branch currents can be expressed as

$$\begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2 \\ I3 \\ I4 \\ I5 \\ I6 \end{bmatrix} \quad \text{------}$$

(4a)

Eq (4a) can be expressed in general form as

$$[B] = [BIBC]\,[I] \quad \text{-------------------- (4b)}$$

Where BIBC is a bus injection to branch current matrix, the BIBC matrix is a upper triangular matrix and contains values of 0 and 1 only.

The constant BIBC matrix is an upper triangular matrix and contains values of 0 and 1 only.

The relationship between branch currents and bus voltages as shown in Fig. 1. For example, the voltages of bus 2, 3, and 4 are

$$V_2 = V_1 - B_1 Z_{12} \quad \text{------------ (5a)}$$

$$V_3 = V_2 - B_2 Z_{23} \quad \text{------------ (5b)}$$

$$V_4 = V_3 - B_3 Z_{34} \quad \text{------------- (5c)}$$

where V_i is the voltage of bus i, and Z_{ij} is the line impedance between bus i and bus j. Substituting (5a) and (5b) into (5c), (5c) can be rewritten as

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad \text{----------- (6)}$$

From (6), it can be seen that the bus voltage can be expressed as a function of branch currents, line parameters, and the substation voltage. Similar procedures can be performed on other buses; therefore, the relationship between branch currents and bus voltages can be expressed as

$$\begin{bmatrix} V1 \\ V1 \\ V1 \\ V1 \\ V1 \end{bmatrix} - \begin{bmatrix} V2 \\ V3 \\ V4 \\ V5 \\ V6 \end{bmatrix} = \begin{bmatrix} Z12 & 0 & 0 & 0 & 0 \\ Z12 & Z23 & 0 & 0 & 0 \\ Z12 & Z23 & Z34 & 0 & 0 \\ Z12 & Z23 & Z34 & Z45 & 0 \\ Z12 & Z23 & 0 & 0 & Z56 \end{bmatrix} \begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \end{bmatrix} \text{---}$$

(7a)

Equation can be rewritten in general form as:

$[\Delta V]= [BCBV]\ [B]$ ------------- (7b)

Where BCBV is the *branch –current to bus voltage matrix.*

(C) Building Formulation Development:

Observing (4), a building algorithm for BBIBC matrix can be developed as follows:

Step 1) For a distribution system with m-branch section and n bus, The dimension of the BIBC matrix is m× (n-1).

Step2) If a line section (B) is located between bus i and bus j, copy the column of the I^{th} bus of the BIBC matrix to the column of the j^{th} bus and fill a 1 to the position of the k^{th} row and the j^{th} bus column.

Step 3) Repeat Step (2) until all line sections is included in the BIBC matrix. From (7), a building algorithm for BCBV matrix can be developed as follows.

Step 4) For a distribution system with m-branch section and n-k bus, the dimension of the BCBV matrix is m x (n-1).

Step 5) If a line section is located between bus i and bus j ,copy the row of the i^{th} bus of the BCBV matrix to the row of the j^{th} bus and fill the line impedance (Z) to the position of the j^{th} bus row and the k^{th} column.

Step 6) Repeat procedure (5) until all line sections is included in the BCBV matrix. The algorithm can easily be expanded to a multiphase line section or bus.

For example, if the line section between bus and bus is a three-phase line section, the corresponding branch current B will be a 3×1 vector and the in the BIBC matrix will be a 3×3 identity matrix. Similarly, if the line section between bus i and bus j is a three-phase line section, the ZI in the BCBV matrix is a 3×3 impedance matrix.It can also be seen that the building algorithms of the BIBC and BCBV matrices are similar. In fact, these two matrices were built in the same subroutine of our test program. Therefore, the computation resources needed can be saved. In addition, the building algorithms are developed based on the traditional bus-branch oriented database; thus, the data preparation time can be reduced and the proposed method can be easily integrated into the existent DA.

D. Solution Technique Developments

The BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injections, can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch currents and bus voltages. The corresponding variations at bus voltages, generated by the variations at branch currents, can be calculated directly by the BCBV matrix. Combining (4b) and (7a), the relationship between bus current injections and bus voltages can be expressed as

$[\Delta V]=[BCBV][BIBC][I]=[DLF][I]$ ------(8)

And the solution for distribution power flow can be obtained by solving (12) iteratively

$I_i^k=I_i^r(V_i^k)+jI_i^i(V_i^k)=((P_i+jQ_i)/V_i^k)^*$ --------------(9a)

$[\Delta V^{k+1}]=[DLF][I^k]$ -------------(9b)

$[V^{k+1}] = [V°] + [\Delta V^{k+1}]$ ----------- (9c)

According to the research, the arithmetic operation number of LU factorization is approximately proportional to N^3. For a large value of N, the LU factorization will occupy a large portion of the computational time. Therefore, if the LU factorization can be avoided, the power flow method can save tremendous computational resource. From the solution techniques described before, the LU decomposition and forward/backward substitution of the Jacobian matrix or the Y admittance matrix are no longer necessary for the proposed method. Only the DLF matrix is necessary in solving power flow problem. Therefore, the proposed method can save considerable computation resources and this feature makes the proposed method suitable for online operation.

D. Losses Calculation

The Real power loss of the line section connecting between buses i and i+1is computed as

$$P_{RLOSS}(i,i+1) = R_{i,i+1}\frac{P^2{}_i + Q^2{}_i}{\|V_i\|^2} \text{ ------------ (10)}$$

The Reactive power loss of the line section connecting between buses i and i+1is computed as

$$P_{XLOSS}(i,i+1) = X_{i,i+1}\frac{P^2{}_i + Q^2{}_i}{\|V_i\|^2} \text{ ----------- (11)}$$

The total Real and Reactive power loss of the feeder P_{FRLOSS} is determined by summing up the losses of all sections of the feeder, which is given by:

$$P_{FRLOSS}(i,i+1) = \sum_{i=1}^{N-1} P_{RLOSS}(i,i+1) \text{ --------- (12)}$$

$$P_{FXLOSS}(i,i+1) = \sum_{i=1}^{N-1} P_{X\,LOSS}(i,i+1) \text{ -------- (13)}$$

V. PARTICLE SWARM OPTIMIZATION & RELIABILITY INDICES

Particle Swarm Optimization (PSO) is a Meta heuristic parallel search technique used for optimization of continues nonlinear problems. The method was discovered through simulation of a simplified social model. PSO has roots in two main component methodologies perhaps more obvious are ties to artificial life in general, and to bird flocking, fish schooling and swarming theory in particular.It is also related, however to evolutionary computation and has ties to both genetic algorithms and evolutionary programming. It requires only primitive mathematical operators, and is computationally inexpensive in terms of both memory requirements and speed.

It conducts searches using a population of particles, corresponding to individuals. Each particle represents a Candidate solution to the capacitor sizing problem. In a PSO system, particles change their positions by flying around a multi-dimensional search space until a relatively unchanged position has been encountered, or until computational limits are exceeded. In social science context, a PSO system combines a social and cognition models. The general elements of the PSO are briefly explained as follows:

Particle X(t): It is a k-dimensional real valued vector which represents the candidate solution. For an ith particle at a time t, the particle is described as $X_i(t)=\{X_i,1(t), X_i,2(t),... X_i,k(t)\}$.

Population: It is a set of 'n' number of particles at a time t described as $\{X_1(t), X_2(t)… X_n(t)\}$.

Swarm: It is an apparently disorganized population of moving particles that tend to cluster together while each particle seems to be moving in random direction.

Particle Velocity V(t): It is the velocity of the moving particle represented by a k-dimensional real valued vector $V_i(t)= \{v_i,1(t), v_i,2(t)…… v_i,k(t)\}$.

Inertia weight W(t): It is a control parameter that is used to control the impact of the previous velocity on the current velocity.

Particle Best (pbest): Conceptually pbest resembles autobiographical memory, as each particle remembers its own experience. When a particle moves through the search space, it compares its fitness value at the current position to the best value it has ever attained at any time up to the current time. The best position that is associated with the best fitness arrived so far is termed as individual best or Particle best. For each Particle in the swarm its pbest can be determined and updated during the search.

Global Best (gbest): It is the best position among all the individual pbest of the particles achieved so far.

Velocity Updation: Using the global best and individual best, the ith particle velocity in kth dimension is updated according to the following equation.

V[i][j]=K*(w*v[i][j]+c1*rand1*(pbestX[i][j]-X[i][j])+c2*rand2*(gbestX[j]-X[i][j])).

where, K constriction factor, c1, c2 weight factors
w Inertia weight parameter , i particle number
j control variable ,
rand1, rand2 random numbers between 0 and 1

Stopping criteria: This is the condition to terminate the search process. It can be achieved either of the two following methods:

i. The number of the iterations since the last change of the best solution is greater than a pre-specified number.

ii. The number of iterations reaches a prespecified maximum value.

VI. ALGORITHM FOR PARTICLE SWARM OPTIMIZATION:

Step1: Run the base case distribution load flow and determine the active power loss.
Step2: Identify the candidate buses for placement capacitor.
Step 3: Generate randomly 'n' number of particles where each particle is represented as
particle[i] ={Qc1,Qc2,Qc3,……Qcj}
Step 4: Run the load flow by placing a particle 'i' at the candidate bus for reactive power compensation and store the active power loss(TLP).
Step 5: Evaluate the fitness value. If the current fitness value is greater than the its pbest value, then assign the pbest value to the current value.
Step6:Determine the current global best (g_best_particles) minimum among the particles individual best(pbest) values.
Step 7: Compare the global position with previous. If the current position is greater than the previous, then set the global position to the current global position.
Step 8: update the particle velocity by using
V[i][j]=K*(w*v[i][j]+c1*rand1*(pbestX[i][j]-X[i][j])+c2*rand2*(gbestX[j]-X[i][j])).
Step 9: Update the position of particle by adding the velocity v[i][j].
Step 10: Now run the load flow and determine the active power loss(pl) with the updated particle.
Step 11: Repeat step 5 to 7
Step 12: Repeat the same procedure for each particle from step 4 to step 7.

VII. RELIABILITY INDICES:

System Average Interruption Duration Index (SAIDI)

The most often used performance measurement for a sustained interruption is the System Average Interruption Duration Index (SAIDI). This index measures the total duration of an interruption for the average customer during a given period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other period.

To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-minutes of interruption. The customer-minutes of all interruptions are then summed to determine the total customer-minutes. To find the SAIDI value, the customer-minutes are divided by the total customers. The formula is,

$$SAIDI = \frac{Sum of customer\ interruption duration}{Total\ number of customers} \frac{\sum U_i * N_i}{\sum N_i} \quad (14)$$

Where
U_i=Annual outage time, Minutes
N_i=Total Number of customers of load point i.

SAIDI is measured in units of time, often minutes or hours. It is usually measured over the course of a year, and according to IEEE Standard 1366-1998 the median value for North American utilities is approximately 1.50 hours.

Customer Average Interruption Duration Index (CAIDI)

Once an outage occurs the average time to restore service is found from the Customer Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers. CAIDI is,

$$SAIDI = \frac{Sumofcustomer\ interruptionduration}{Tota\ln umberofcustomer\ interruptions} \frac{\sum U_i * N_i}{\sum \lambda_i * N_i} \quad (15)$$

Where

U_i=Annual outage time, Minutes

N_i= Total Number of customers of load point i.

λ_i=Failure Rate.

CAIDI is measured in units of time, often minutes or hours. It is usually measured over the course of a year, and according to IEEE Standard 1366-1998 the median value for North American utilities is approximately 1.36 hours

System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of time that a system customer experiences an outage during the year (or time period under study). The SAIFI is found by divided the total number of customers interrupted by the total number of customers served. SAIFI, which is dimensionless number, is

$$SAIDI = \frac{Tota\ln umberofcustomer\ interruptions}{Tota\ln umberofcustomersserved} \frac{\sum \lambda_i * N_i}{\sum N_i} \quad (16)$$

$$SAIFI = \frac{SAIDI}{CAIDI} \quad \text{………. (17)}$$

Where

N_i=Total Number of customers interrupted.

λ_i=Failure Rate.

SAIFI is measured in units of interruptions per customer. It is usually measured over the course of a year, and according to IEEE Standard 1366-1998 the median value for North American utilities is approximately 1.10 interruptions per customer.

Average Service Availability Index (ASAI)

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service was available during a given period of the total customer hours demanded. This is sometimes called the service reliability index. The ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. The ASAI is found as,

$$ASAI = [1 - (\frac{\sum (r_i * N_i)}{(N_T * T)})]*100 \quad \text{………. (18)}$$

$$ASUI = 1 - ASAI \quad \text{………. (19)}$$

Where

T= Time period under study, hours.

r_i=Restoration Time, Minutes

N_i=Total Number of customers interrupted.

N_T=Total Customers served.

Average Energy Not Supplied (AENS)

This is also called as Average System Curtailment Index **(ASCI)**

$$AENS = \frac{Totalenergynot\sup plied}{Tota\ln umberofcustomersserved} = \frac{\sum L_{a(i)} * U(i)}{\sum N_i} \quad . (20)$$

VIII. INVESTIGATED REAL TIME SYSTEM &RESULTS

The real time system considered in this paper is an Eramitta (urban feeder) feeder located at mangalam substation in Tirupati,Chittoor(Dt),Andhra Pradesh,India.This feeder is not installed by any capacitor banks. It is an fast growing residential area. In future if the demand increases in this feeder then this feeder must be installed by capacitor banks by using PSO technique.

Real time radial feeder system data

The radial distribution systems have following characteristics

Base Voltage = 11KV. Base MVA=100.

Conductor type = All Aluminum Alloy Conductor (AAAC)

Resistance = 0.55 ohm/KM.,

Reactance = 0.351 ohm/KM.

MATLAB program was developed for Load flow, PSO for placement of capacitor to analyzing the results for Radial Distribution feeder. To demonstrate the effectives of the proposed concept, a 20-node 11kv Eramitta urban distribution feeder is selected. Line data for this feeder is shown in Table I.

Load is not constant throughout the day; it varies from time to time. By considering the terms Diversity factor and Power Factor five deferent conditions are consered.

1.Average DF Good PF. 2.High DF High PF.
3.High DF Low PF. 4.Low DF High PF.
5.Low DF low PF

General condition that occurs is Average DF Good PF where Average DF is 0.60 and Good PF is 0.92. When the load is high (High DF) and the PF is also high (High PF), this condition does not occur in the day but for the analysis only it considered. When the load is high (High DF), the PF decreases (Low PF), this condition occurs during the peak demand.

When the load in Low (Low DF) then the PF is high (High PF), this condition occurs during the light load conditions. Low DF and Low PF condition does not occur in the day. This condition is assumed for analysis only. The load flow calculations are performed to get the voltages at each node & the total power losses for 5 conditions. The voltage magnitudes and the power losses are obtained by solving the simple algebraic equations which are illustrated in section-III. Table II and Table III gives the voltage magnitudes at each node and losses respectively for Eramitta feeder at different conditions. The nodes which are close to the source are having the higher voltage magnitude is the nodes that are far away from the source are of lower voltage magnitude (due to higher drop in voltage).

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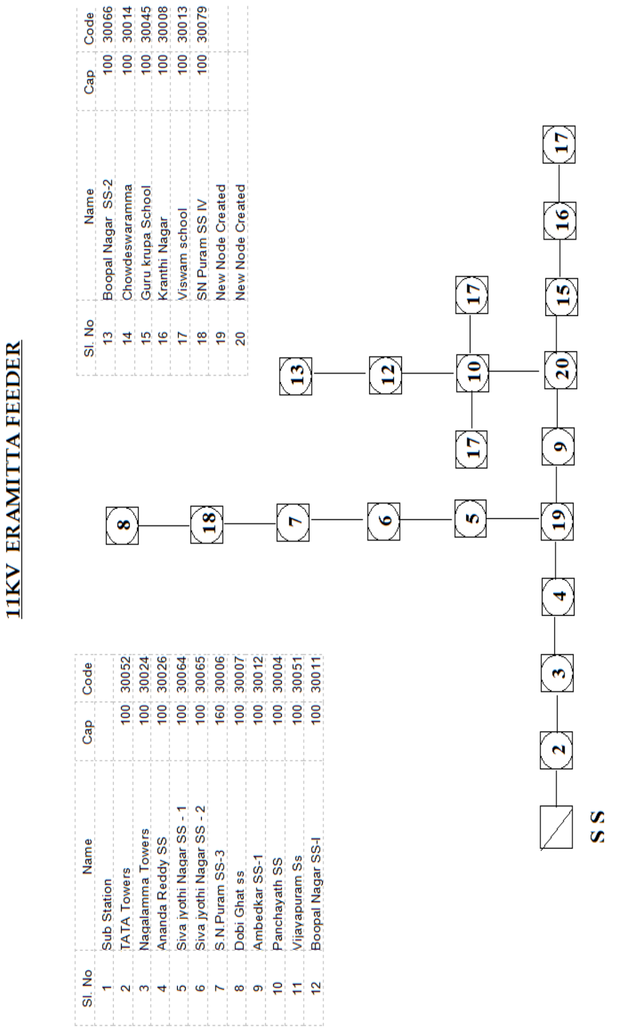

Fig 2: Eramitta Radial feeder as per standard system

TABLE I
Line data of Eramitta Feeder

Bus No	From Node	To Node	Distance (KM)	R Ω	X Ω
1	1	2	0.5	0.28	0.176
2	2	3	0.4	0.22	0.14
3	3	4	0.3	0.17	0.105
4	4	19	0.4	0.22	0.14
5	19	9	0.3	0.17	0.105
6	9	20	0.3	0.17	0.105
7	20	15	0.2	0.11	0.07
8	15	16	0.5	0.28	0.176
9	16	17	0.5	0.28	0.176
10	19	5	0.2	0.11	0.07
11	5	6	0.1	0.06	0.035
12	6	7	0.4	0.22	0.14
13	7	18	0.2	0.11	0.07
14	18	8	0.1	0.06	0.035
15	20	10	0.2	0.11	0.07
16	10	11	0.2	0.11	0.07
17	10	14	0.2	0.11	0.07
18	10	12	0.2	0.11	0.07
19	12	13	0.3	0.17	0.105

TABLE II
Voltage magnitudes at different conditions by BIBC & BCBV method

Bus No	Avg DF gud PF	High F High PF	High DF Low PF	Low DF High PF	Low DF Low PF
1	1	1	1	1	1
2	0.995	0.9918	0.9904	0.9953	0.9946
3	0.9909	0.9853	0.9827	0.9916	0.9902
4	0.988	0.9804	0.977	0.9888	0.987
5	0.9835	0.9734	0.9688	0.9848	0.9823
6	0.9833	0.973	0.9683	0.9846	0.9821
7	0.9824	0.9718	0.9669	0.9839	0.9812
8	0.982	0.9713	0.9662	0.9835	0.9807
9	0.9827	0.9719	0.9672	0.9838	0.9812
10	0.9807	0.969	0.9637	0.9821	0.9792
11	0.9806	0.9688	0.9635	0.982	0.9791
12	0.9804	0.9685	0.9632	0.9818	0.9789
13	0.9802	0.9681	0.9627	0.9815	0.9785
14	0.9807	0.969	0.9637	0.9821	0.9792
15	0.981	0.9692	0.9641	0.9822	0.9794
16	0.9804	0.9683	0.9632	0.9817	0.9789
17	0.9801	0.9675	0.9624	0.9813	0.9785
18	0.9821	0.9714	0.9664	0.9835	0.9808
19	0.9842	0.9745	0.9701	0.9854	0.983
20	0.9813	0.9698	0.9647	0.9826	0.9798

The radial diagram of 20-node Eramitta feeder shown in Figure 3 is having 2-laterals to the main feeder. The first lateral (5, 6, 7, 18, 8) and the second lateral (10, 12, 13) are close to the source, so the voltage magnitudes at each node are higher).This Eramitta feeder is not installed by any capacitor bank at LT side. Without installation also there are no nodes having voltages less than 0.95 p.u. So there is no need of capacitor placement.

The improved voltage magnitudes by Single placement of capacitor at 7th node and the voltage magnitudes by multiple placement of capacitor using PSO at node 7th and 8th are tabulated in Table VII.

TABLE III
Losses at different conditions

Avg DF Good PF		
TLP =	27.4942	KW
TLQ =	17.5463	KW
TL =	45.0405	KW
High DF High PF		
TLP =	74.5279	KW
TLQ =	47.5624	KW
TL =	122.0903	KW
High DF Low PF		
TLP =	100.5572	KW
TLQ =	64.1738	KW
TL =	164.731	KW
Low DF High PF		
TLP =	24.7279	KW
TLQ =	15.7809	KW
TL =	40.5088	KW
Low DF Low PF		
TLP =	32.7562	KW
TLQ =	20.9044	KW
TL =	53.6607	KW

In future if the demand increases (because it is an urban feeder fast growing residential area) in the feeder then this network must be installed by capacitor bank. For this condition i am assuming Unity DF with Low PF (Table IV). The load flow results for Unity DF Low PF condition are represented in Table V. From Table V, it can be found that the following nodes are sensitive as voltages are less than 0.95 p.u ,Nodes: 7,8,18,Voltages at sensitive nodes can be improved by placing capacitor at single node or by placing capacitor at multiple nodes. By using Particle Swarm Optimization Technique (Section IV) the capacitors are placed at multiple nodes and the voltage profiles are shown in Figure 4. Compensated Nodes by using PSO are tabulated in Table VI. By placing the 1.5 MVAR capacitor bank at 7th node the voltage profiles are shown in Figure 4.

TABLE IV
Load data (Unity DF and Low PF)

DTR	No of Customers	Total Connected Load	Unity DF Good PF	
			DF=1	PF=0.866
			P(KW)	Q(KVAR)
1	0	0	0	0
2	42	44.21	44.21	45.1
3	229	293.35	293.35	258.71
4	337	394.28	394.28	295.71
5	105	138.15	138.15	140.94
6	105	130.72	130.72	98.04
7	213	283.9	283.9	289.64
8	533	603.25	603.25	615.44
9	144	139.48	139.48	142.3
10	162	185.71	185.71	189.46
11	246	312.82	312.82	275.88
12	295	407.93	407.93	305.94
13	2	4	4	1.31
14	489	487.47	487.47	192.66
15	46	53	53	17.42
16	450	426.29	426.29	206.46
17	413	391.49	391.49	232.3
18	92	121.67	121.67	75.4
19	0	0	0	0
20	0	0	0	0

TABLE V
Voltage magnitudes for Unity DF Low PF condition

Bus No	BIBC & BCBV Method
1	1
2	0.9844
3	0.972
4	0.9633
5	0.9569
6	0.9553
7	0.9491
8	0.948
9	0.9606
10	0.9601
11	0.9581
12	0.9583
13	0.956
14	0.959
15	0.9597
16	0.9548
17	0.9537
18	0.9486
19	0.9622
20	0.9606

The status of networks before and after compensation for single placement of 1.5MVAR capacitor at node 7 and multiple placement of capacitor using PSO at nodes 7 and 8 are shown in Table VII. From Table VIII, it is observed that when a capacitor placed at multiple nodes using PSO the losses are much reduced when compared with single capacitor placement at single node with highest capacity. The details of the distribution system are shown in Table IX. There are 4 interruption cases during the year 2011-2012 (Table X). When the feeder was not provided with isolators, 14 load points got affected during the 4 interruptions. The Distribution System Reliability Indices are calculated by using section IV and are tabulated in Table XI and the percentage of indices is represented in pie chart as shown in Figure 5.

TABLE VI

Injected Reactive Power using PSO at different nodes

Nodes Compensated		7,8
Best Node=7	Best Particle	-1106 KVAR
Best Node=8	Best Particle	-377 KVAR
Total Injected Reactive Power		-1483 KVAR

TABLE VII
Voltages for Single and Multiple Placement (PSO) of capacitor

BEFORE		Single Placement	Multiple Placement
Bus No	Voltages	Voltages	Voltages
1	1	1	1
2	0.9844	0.9867	0.9886
3	0.972	0.9762	0.9796
4	0.9633	0.9689	0.9735
5	0.9569	0.9634	0.9689
6	0.9553	0.9618	0.9672
7	0.9491	0.9557	0.9612
8	0.948	0.9546	0.96
9	0.9606	0.9662	0.9708
10	0.9601	0.9657	0.9703
11	0.9581	0.9646	0.97
12	0.9583	0.9648	0.9703
13	0.956	0.9639	0.9705
14	0.959	0.9646	0.9702
15	0.9597	0.9653	0.9701
16	0.9548	0.9605	0.9653
17	0.9537	0.9593	0.9642
18	0.9486	0.9552	0.9606
19	0.9622	0.9677	0.9724
20	0.9606	0.9662	0.9708

TABLE VIII

Status of Networks Before and After Compensation

Single Placement of capacitor	Multiple Placement of Capacitor
Q _ LOSS = 152.8818 KVAR	Q _ LOSS = 152.8818 KVAR
P _ LOSS = 239.5584 KW	P _ LOSS = 239.5584 KW
MIN_V=0.9480	MIN_V=0.9480
Rank= 7,8,18	Rank= 7,8,18
After Compensation	
Q _ LOSS = 115.9827 KVAR	Q _ LOSS =108.8445 KVAR
P _ LOSS = 181.7393 KW	P _ LOSS 170.5541 KW
MIN_V=0.9546	MIN_V=0.9600
Rank=0	Rank=0

When the feeder is provided with isolator at 20th node, the load point 20 will only be affected and the number of load points affected are reduced from 14 to 9 during 4 interruption cases. Distribution Reliability Indices are shown in Table III. The percentage of indices is represented in pie chart as shown in Figure 6.

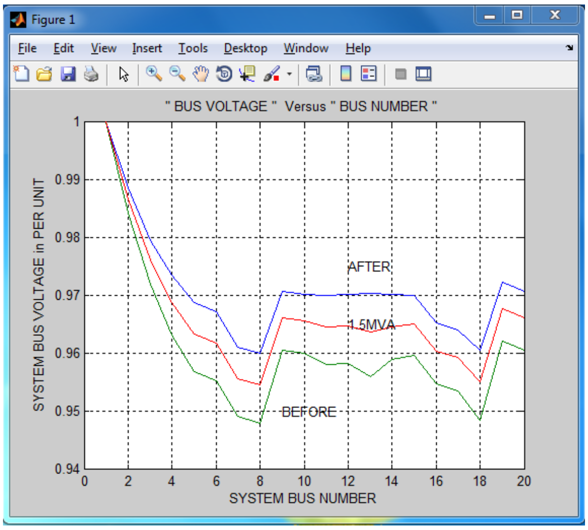

Fig 4. Voltage Graphs for Before, Single placement and multiple placement using PSO

Interruption data

Table IX
Details of Distribution System

Load Points	No of Customers	Total Connected Load(KW)	Average Connected load(KW)
1	0	0	0
2	42	44.21	1.0526
3	229	293.35	1.281
4	337	394.28	1.17
5	105	138.15	1.3157
6	105	130.72	1.2449
7	213	283.9	1.3329
8	533	603.25	1.1318
9	144	139.48	0.9686
10	162	185.71	1.1464
11	246	312.82	1.2716
12	295	407.93	1.3828
13	2	4	2
14	489	487.47	0.9969
15	46	53	1.1522
16	450	426.29	0.9473
17	413	391.49	0.9479
18	92	121.67	1.3225
19	0	0	0
20	0	0	0
Total	3903	4417.71	

TABLE X
Interruption effect in a calendar year (without isolator)

Interruption Case	Load Point Affected	Duration (hrs)	Cause of Interruption
1	11	3	DTR failure and for replacement
2	7	10	
	8	10	Newly erected DTR
	18	10	
3	13	3	DTR failure and for replacement
4	20	10	
	10,14	10	
	11,12	10	Shifting of DTR from one place to another place and shifting of customers
	13,15	10	
	16	10	
	17	10	

TABLE XI
Distribution system Reliability Indices without Isolator

SAIFI	0.817 interruptions/customer
SAIDI	7.726 hrs/customer
CAIDI	9.456 hrs/customer interruption
ASAI	0.999118
ASUI	0.000882
AENS	8.641 KWh/customer

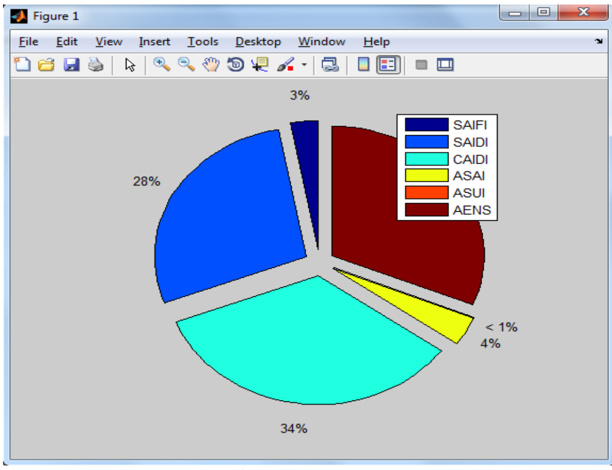

Fig 5. Percentage of Indices representation in pie chart

Table XII:
Interruption effect in a calendar year (with isolator)

Interruption Case	Load Point Affected	Duration (hrs)	Cause of Interruption
1	11	3	DTR failure and for replacement
2	7	10	
	8	10	Newly erected DTR
	18	10	
3	13	3	DTR failure and for replacement
4	20	10	
	15	10	Shifting of DTR from one place to another place and shifting of customers
	17	10	
	16	10	

Table XIII
Distribution system Reliability Indices (with isolator)

SAIFI	0.511 interruptions/customer
SAIDI	4.667 hrs/customer
CAIDI	9.130 hrs/customer interruption
ASAI	0.999467
ASUI	0.000533
AENS	5.059 KWh/customer

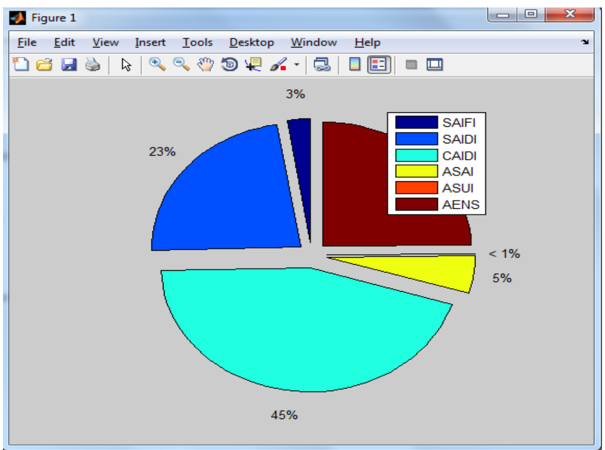

Fig 6: Percentage of Indices representation in pie chart

When the feeder is not provided with isolator the Average Energy Not Supplied (AENS) is 8.641 KWh/Customer. When the feeder is provided with isolator at 20^{th} node the

Average Energy Not Supplied (AENS) is reduced to 5.059 KWh/Customer.

VII. CONCLUSIONS

Eramitta feeder is applied with load flow and the weak voltage profiles are identified and those nodes are proposed for capacitor placement using particle swarm optimization technique. The voltages and losses before and after compensation are tabulated. By placement of capacitor at single node with highest capacity the voltage profiles get improved and losses get reduced, but by distributing the same capacity and placing the capacitors at multiple nodes using Particle Swarm Optimization technique the voltage profiles are good as comparing with single placement and the losses are much more reduced as compared with single placement of capacitor. From Table 11 XI and Table XIII, it is concluded that by providing more isolators in the feeder we can reduce the Average Energy Not Supplied (AENS).

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