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Capacitance based Reliability Indices of a Real Time Radial Distribution Feeder

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Abstract: *Assessment of customer power supply reliability is an important part of distribution system operation and planning. Distribution system reliability assessment is a measure of continuity and quality of power supply to the consumers, which mainly depends on interruption profile, based on system topology and component reliability data. The paper mainly describes about the radial Distribution system reliability is evaluated in two methods. 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. 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. In this paper we have considered the load diversity factor for analysis of load data for real time system. Two matrices the bus-injection to branch-current matrix (BIBC), the branch-current to bus voltage matrix (BCBV) 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. The performance of the method was investigated on an 11kV real time Upadyayanagar radial distribution feeder as system of case study. A matlab program was developed and results are presented.*
Keywords: *BIBC, BCBV, Diversity Factor, BVSI, 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 reduce 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. 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 (<50kV) 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 1 ph. supply) or at 415V (as 3ph. 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 feeder’s 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[6]. 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 [1-3]. 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. Usually 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. 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 are Single-Line Equivalent Method, Very Fast Decoupled Method, Ladder Technique, Power Summation Method, Backward and Forward Sweeping Method. The proposed algorithm is tested on a Real Time system.

Formulation of Load Flow Model

(a) Algorithm Development:

The technique is based on two 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 to develop BCBV and BIBC for radial distribution feeder. For bus, the complex load S is expressed by

$S_i=P_i+jQ_i$ ----------- (1)

Where i = 1, 2, ... N

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

$I_i^k=(P_i+jQ_i/V_i^k)^*$ --------- (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 figure 1 is used to find 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, B_3 and B_5 can be expressed as

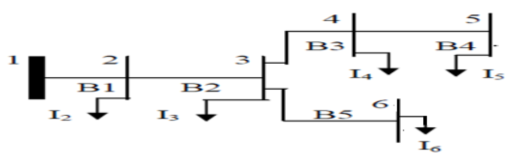

Figure 1. Simple distribution system

$$\left.\begin{aligned} B_1 &= I_2+I_3+I_4+I_5+I_6 \\ B_3 &= I_4+I_5 \\ B_5 &= I_6 \end{aligned}\right\} \text{----------- (3)}$$

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

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_5 \end{bmatrix} -----(4a)$$

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

[B]= [BIBC] [I] --------------------- (4b)

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

$V_2=V_1-B_1Z_{12}$ ------------ (5a)

$V_3=V_2-B_2Z_{23}$ ------------ (5b)

$V_4=V_3-B_3Z_{34}$ ------------- (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

$V_4=V_1-B_1Z_{12}-B_2Z_{23}-B_3Z_{34}$ ----------- (6)

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{56} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_5 \\ B_6 \end{bmatrix} --(7a)$$

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

[ΔV]= [BCBV] [B] ------------- (7b)

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

(C) Building Formulation Development:

Observing (4), a building algorithm for BIBC 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).

Step 2: 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 equation (7a and 7b), 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 multi phase line section or bus.

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

[ΔV]=[BCBV][BIBC][I]=[DLF][I] ------(8)

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

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

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

And the solution for distribution power flow can be obtained by solving iteratively. 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.

E. Losses Calculation:

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

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

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

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

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:

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

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

IV Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a Meta heuristic parallel search technique used for optimization of continues nonlinear problems. PSO has roots in two main component methodologies perhaps more obvious are ties to artificial life. 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. 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 $\{X_1(t), X_2(t)\ldots X_n(t)\}$.

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 $V_i(t)= \{v_i,1(t), v_i,2(t)\ldots\ldots v_i,k(t)\}$.

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 pre specified maximum
value.

V. Algorithm for Pso

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][17]{Qc1,Qc2,……..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.

VI 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.

$$SAIDI = \frac{Sumofcustomer\ \text{int}\ erruptionduration}{Tota\ \ln\ umberofcustomers}\ \frac{\sum U_i * N}{\sum N_i} \quad (14)$$

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,

$$\text{CAIDI}=\frac{\text{Sum of customer interruptions durations}}{\text{Total number of customers interrupptions}} = \frac{\sum U_i * N_i}{\sum \lambda_i * N_I} \ ..\ (15)$$

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). 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.

$$\text{SAIFI}=\frac{\text{Total number of customer interuptions}}{\text{Total number of customers served}} = \frac{\sum \lambda_i * N_i}{\sum N_I} \quad (16)$$

$$SAIFI = \frac{SAIDI}{CAIDI} \quad \ldots\ldots\ldots\ (17)$$

Where N_i=Total Number of customers interrupted.
λ_i=Failure Rate.

Average Service Availability Index (ASAI)

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,

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

$$ASUI = 1 - ASAI \quad \ldots\ldots\ldots\ (19)$$

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)**

$$AENS = \frac{Total energy not \sup plied}{Tota \ln umber of customers served} = \frac{\sum L_{a(i)} * U(i)}{\sum N_i} \quad . (20)$$

VII. Investigated REAL TIME SYSTEM &RESULTS

In this paper real time radial feeder is considered, UPADHYA NAGAR urban feeder located at 33Kv MANGALAM substation in Tirupati, Chittoor (Dt.), Andhra Pradesh, India. It is an fast growing residential area shown in figure 2.

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.

A software program was developed in MATLAB for Load flow solution and PSO is used for placement of capacitor to analyze the results for Radial Distribution feeder. To understand the effectives of the method, a 42-node 11kV Upadhayan urban feeder is selected. Line data for this feeder is shown in Table I. Throughout day Load is not constant; it varies from time to time. By considering the terms Diversity factor and Power Factor, five deferent conditions are considered. 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 6. Average DF Poor PF 7. Unity DF Low PF .Generally a feeder that occurs with Average DF Good PF where Average DF is 0.40 and Good PF is 0.93. 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 purpose only. The load flow solution obtained is used to know bus voltages profiles for 7 conditions which are shown in below figure 3 and losses in Table II. This Upadhayanagar 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 for above five conditions.

11KV UPADHYAYA NAGAR FEEDER

Sl. No	Name	Cap	Code
1	Sub station		
2	Lepracy colony	100	305524230080
3	New node		
4	Garudadri Nagar SS - 1	100	305524230069
5	Garudadri Nagar SS - 2	100	305524230070
6	Garudadri Nagar SS - 3	100	305524230071
7	Garudadri Nagar SS - 4	100	305524230072
8	Garudadri Nagar SS - 5	100	305524230073
9	Garudadri Nagar SS - 6	63	305524230105
10	Gosaala	100	305524230062
11	Amrulla willow unit	63	305524230078
12	Radha Govinda Nagar	100	305524230092
13	New node		
14	New node		
15	New node		
16	New node		
17	SriChakra Eden Greens SS -1	160	305524230100
18	SriChakra Eden Greens SS -2	160	305524230101
19	SriChakra Eden Greens SS -3	160	305524230102
20	New node		
21	Upadhyaya Nagar	100	305524230063
22	New node		
23	Sai Hill View Residency	160	305524230098
24	Kundhan kuteer	63	305524230095
25	Prem Nilayam	63	305524230096
26	Elyte club	100	305524230031
27	Upadhyaya Nagar SS-2	100	305524230088
28	Sri Ganesh Towers(Babji)	100	305524230083
29	Grandvilla constructions	300	
30	Grand Manor SS-2	160	305524230104
31	Grand Manor SS-1	160	305524230103
32	Sri Nagar Colony SS-2	100	305524230094
33	Sri nagar Colony	100	305524230048
34	New node		
35	Sri Nagar Colony SS-2	100	305524230048
36	Ragavendra Nagar SS-2	100	305524230039
37	New node		
38	Nirmala Mineral	100	305524230053
39	Rajiv Gandhi Colony SS-1	100	305524230001
40	Rajiv Gandhi Colony SS-2	100	305524230038
41	New Balaji Colony SS	40	305524230057
42	New node		
43	Beedi Colony	100	305524230107

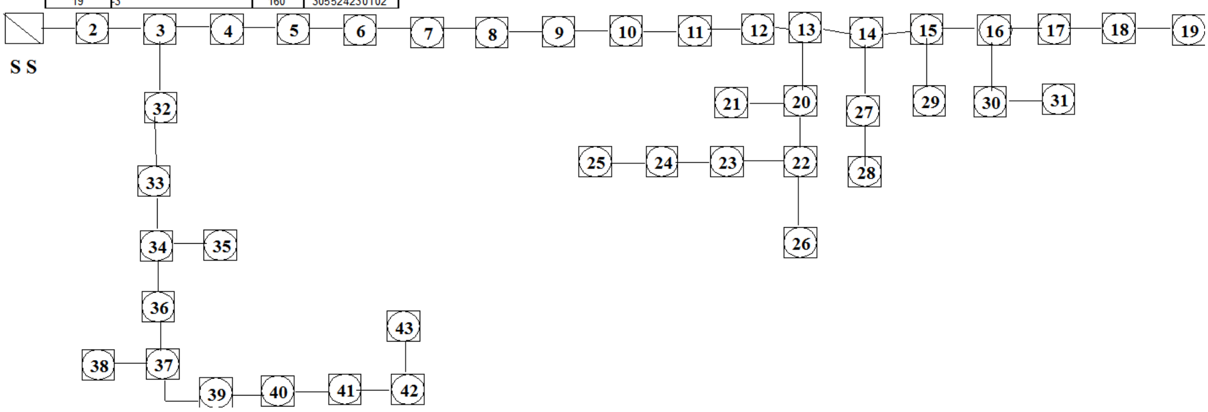

Figure 2: Upadhayanagar Radial feeder, Tirupati as per standard system

Table I Line data of Upadhayanagar Feeder, Tirupati

Bus No	From Node	To Node	Distance (KM)	R Ω	X Ω
1	1	2	0.1	0.055	0.0351
2	2	3	0.3	0.165	0.1053
3	2	4	0.2	0.11	0.0702
4	4	5	0.2	0.11	0.0702
5	5	6	0.2	0.11	0.0702
6	6	7	0.2	0.11	0.0702
7	7	8	0.2	0.11	0.0702
8	8	9	0.4	0.22	0.1404
9	9	10	0.4	0.22	0.1404
10	10	11	0.1	0.055	0.0351
11	11	12	0.3	0.165	0.1053
12	12	13	0.3	0.165	0.1053
13	13	20	0.2	0.11	0.0702
14	20	21	0.1	0.055	0.0351
15	20	22	0.1	0.055	0.0351
16	22	23	0.1	0.055	0.0351
17	23	24	0.2	0.11	0.0702
18	24	25	0.3	0.165	0.1053
19	22	26	0.2	0.11	0.0702
20	13	14	0.3	0.165	0.1053
21	14	27	0.2	0.11	0.0702
22	27	28	0.2	0.11	0.0702
23	14	15	0.1	0.055	0.0351
24	15	29	0.2	0.11	0.0702
25	15	16	0.3	0.165	0.1053
26	16	30	0.1	0.055	0.0351
27	30	31	0.1	0.055	0.0351
28	16	17	0.1	0.055	0.0351
29	17	18	0.3	0.165	0.1053
30	18	19	0.1	0.055	0.0351
31	3	32	0.1	0.055	0.0351
32	32	33	0.4	0.22	0.1404
33	33	34	0.2	0.11	0.0702
34	34	35	0.1	0.055	0.0351
35	34	36	0.1	0.055	0.0351
36	36	37	0.4	0.22	0.1404
37	37	38	0.1	0.055	0.0351
38	37	39	0.5	0.275	0.1755
39	39	40	0.2	0.11	0.0702
40	40	41	0.2	0.11	0.0702
41	41	42	0.2	0.11	0.0702
42	42	43	0.1	0.055	0.0351

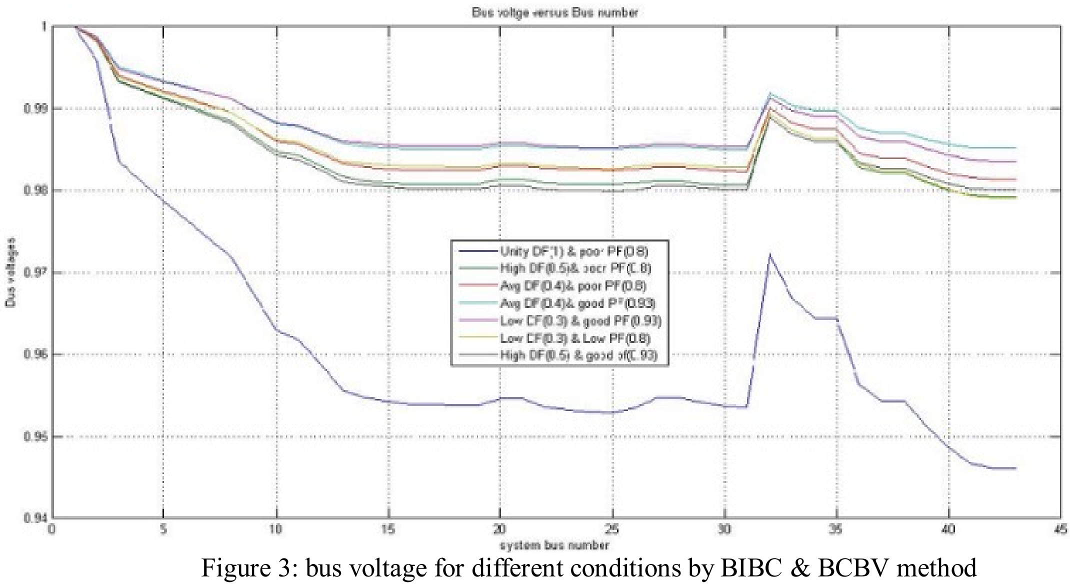

Figure 3: bus voltage for different conditions by BIBC & BCBV method

Bus Voltage Sensitivity Index (BVSI):

Load flow with capacitor capacity of 15% of the total feeder loading capacity is carried out to find BVSI at various buses using (20). Figure 4 shows the variation of VSI at various buses. As seen from this Figure5.4, bus number 17 is having the lowest BVSI value of 0.2639. Therefore, bus 17 is considered as the candidate bus for the capacitor placement.

$$BVSI_i = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)^2}{n}} \qquad (20)$$

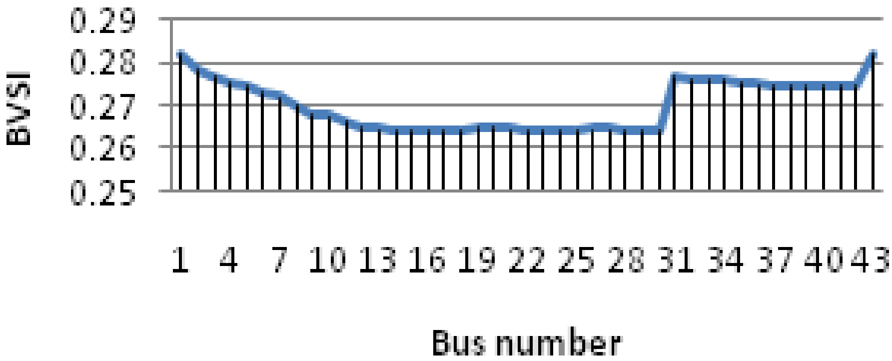

Figure 4: bus Variation of BVSI with bus number.

The results shows that following buses are sensitive bus voltages (< 0.95 pu) 36,37,38,39,40,41 and 42 and are instable bus voltages, that can be improved by placing capacitor at single node or by placing capacitor at multiple nodes. By using Particle Swarm Optimization Technique (Section V). Multiple placed capacitors have higher voltages profiles than the single placement shown figure 4. The results for power losses are shown in table III for before and after placement of capacitor. These losses are compared with losses obtained by using load flow and energy consumption method. Energy losses are computed for Updahayanagar feeder by real time energy consumed data by the feeder from substation. It is observed that the computed energy losses closely match with the calculated energy (real time data) losses

Table II: Losses at different conditions

Conditions	Real Power losses (KW)	Reactive Power losses (KW)	Total Losses (KW)
Avg DF Poor PF	37.2237	23.7555	60.9791
AVG DF Good PF	25.6313	16.3574	41.9887
High DF Good PF	45.9267	29.3096	75.2362
High DF Poor DF	48.0106	30.6395	78.6501
Low DF Good PF	28.4457	18.1536	46.5993
Low DF Poor DF	42.3634	27.0355	69.3989
Unity DF Poor PF	296.6474	189.315	485.9624

Table III: Power loss of the feeder before and after compensation

Single Placement of capacitor	Multiple Placement of Capacitor
Q _ loss = 189.315KVAR	Q _loss = 152.8818 KVAR
P _loss=296.6474KW	P _loss=239.5584 KW
MIN_V=0.9462	MIN_V=0.9462
Rank= 36, 37, 38, 39, 40 41, 42, 43	Rank= 36, 37, 38, 39, 40 41, 42, 43
After Compensation	
Q _ loss =133.4080 KVAR	Q _ loss =123.9763 KVAR
P _loss=209.0438 KW	P _loss=194.2649 KW
MIN_V=0.9634	MIN_V=0.9634
Rank=0	Rank=0

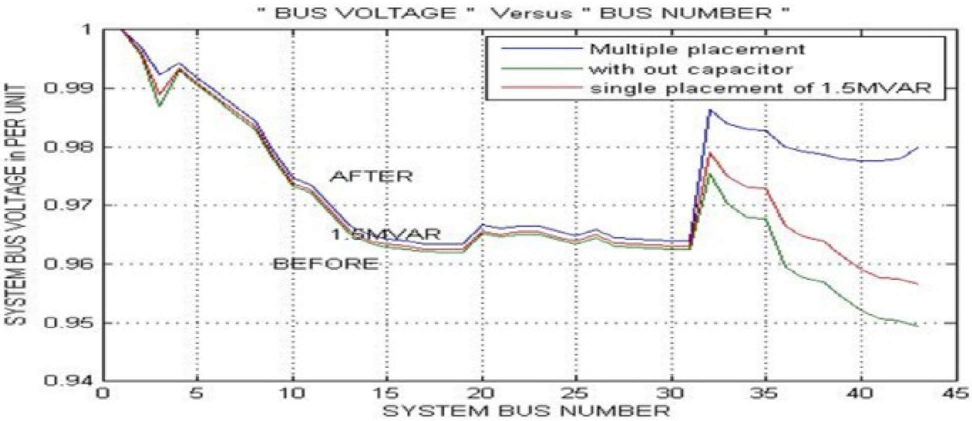

Figure 5: Voltage profiles for before, after capacitors placement using PSO.

Table IV Injected Reactive Power using PSO at different nodes

Nodes Compensated		36,38
Best Node=36	Best Particle	-1344.9 KVAR
Best Node=38	Best Particle	-880.5 KVAR
Total Injected Reactive Power		-2225.4KVAR

Table IV represents the compensated nodes after placing capacitor at single and multiple nodes. Table V represents the losses calculated as per substation and using mat lab.

Table V. Power loss calculation by using load flow method

Upadyayanagar Feeder		
BIBC and BCBV Method		
Avg. DF Gud. PF		
TLP =	25.6313	KW
TLQ =	16.3574	KVAR
TL =	41.9887	KW
Energy Loss =(TLP*24*31)	19067.7	Units
=	3.72	%
Energy Loss as per PPL Sheet= 3.72% of 512330=20083.3 Units		

The details of the distribution system are shown in Table VI. There are 5 interruption cases during the year 2012-2013. (Table VII). When the feeder was not provided with isolators, all load points got affected during the 5 interruptions. The Distribution System Reliability Indices are calculated by using section VI and the results are tabulated in IX. When the feeder is provided with isolator at 13th node, the load point 13 will only be affected and the number of load points affected is reduced from 43 to 35during 5 interruption cases. Distribution Reliability Indices are shown in Table IX. The percentage of indices is represented in pie chart as shown in Figure 7 with and without isolator. When the feeder is not provided with isolator the Average Energy Not Supplied (AENS) is 2.272 KWh/Customer. When the feeder is provided with isolator at 13th node the Average Energy Not Supplied (AENS) is reduced to 1.272 KWh/Customer

Table VI Details of Distribution System

S.NO	No. of Customers	P (KW)	Avg. Load
1	0	0.00	0.00
2	120	106.00	0.88
3	0	0.00	0.00
4	179	151.00	0.84
5	1	2.00	2.00
6	1	2.00	2.00
7	1	2.00	2.00
8	1	2.00	2.00
9	76	86.00	1.13
10	15	30.00	2.00
11	0	0.00	0.00
12	50	75.00	1.50
13	0	0.00	0.00

14	0	0.00	0.00
15	0	0.00	0.00
16	0	0.00	0.00
17	12	84.00	7.00
18	1	2.00	2.00
19	1	2.00	2.00
20	0	0.00	0.00
21	113	391.00	3.46
22	0	0.00	0.00
23	60	150.00	2.50
24	8	50.00	6.25
25	10	60.00	6.00
26	41	87.00	2.12
27	3	6.00	2.00
28	15	85.00	5.67
29	1	300.00	300.00
30	16	100.00	6.25
31	36	220.00	6.11
32	218	416.00	1.91
33	218	416.00	1.91
34	0	0.00	0.00
35	138	191.00	1.38
36	409	564.00	1.38
37	0	0.00	0.00
38	138	191.00	1.38
39	489	578.00	1.18
40	490	571.00	1.17
41	426	543.00	1.27
42	0	0.00	0.00
43	214	319.00	1.49
	3501	5782.00	

Interruption data

Table VII Interruption effect in a calendar year (without isolator)

Interruption Case	**Load Point Affected**	**Duration (hrs)**	**Cause of Interruption**
1	All load points get affected	0.52	Line clearence for Transformer maintaince
		1.35	Main supply failed due to Distribution line damage
2	All load points get affected	0.15	Fault in distribution line
		1.15	Line clearance for Transformer erraction
		0.25	main supply failed due to line Fault
3	All load points get affected	3.00	Trip due to environmental conditions
		0.20	main supply failed due to fault
		3.50	Load shut for general maintaince in the feeder
4	All load points get affected	0.30	main supply failed due to fault
5	All load points get affected	6.00	Three line clearances for erraction of new transformers
	All load points get affected	0.45	main supply failed due to fault 4 no's
	All load points get affected	2.25	Line break down due to fault 2 no's

Table VIII Interruption effect in a calendar year (with isolator)

Interruption Case	Load Point Affected	Duration (hrs)	Cause of Interruption
1	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31	0.52	Line clearance for Transformer maintaince
		1.35	Main supply failed due to Distribution line damage
2	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31	0.15	Fault in distribution line
		1.15	Line clearence for Transformer erraction
		0.25	main supply failed due to line Fault
3	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31	3.00	Trip due to environmental conditions
		0.20	main supply failed due to fault
		3.50	Load shut for general maintaince in the feeder
4	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31	0.30	main supply failed due to fault
5	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,32	6.00	Three line clearances for erraction of new transformers
	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,33	0.45	main supply failed due to fault 4 no's
	14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,34	2.25	Line break down due to fault 2 no's

Table IX Distribution system Reliability Indices with without Isolator

ndices	Without isolator	With isolator
AIFI	5.000 interruptions/customer	1.075 interruptions/customer
AIDI	21 hrs/customer	4.517 hrs/customer
AIDI	4.2 hrs/customer interruption	4.2 hrs/customer interruption
SAI	0.9976	0.99948
SUI	0.002397	0.000516
ENS	2.272 KWh/customer	1.272 KWh/customer

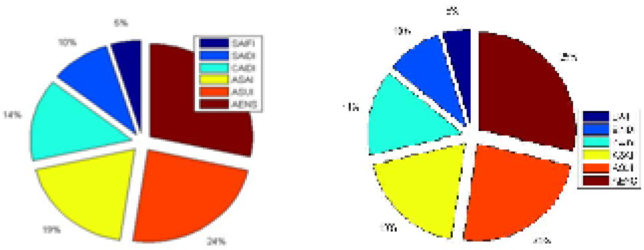

Figure 6.Indices representation in pie chart with and without isolator

VIII Conclusion

The radial distribution 11Kv Upadyanagar feeder is applied with load flow and the feeble voltage profiles are identified and those nodes are proposed for capacitor placement using particle swarm optimization technique. The voltages profiles and losses before and after compensation using PSO for single and multiple placement of capacitor, the voltage profiles get improved and losses get reduced. Distribution system Reliability indices are evaluated for the feeder and results are presented. It is concluded that by providing more isolators in the radial feeder we can reduce the Average Energy Not Supplied (AENS) to the customers their by improves the continuity of power supply

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