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Failure Rate Modification For Evaluating Reliability Indices

A Case Study of IEEE 30 Bus System For Optimal Capacitor Placement

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Abstract— Utility aims Capacitor placement for power factor improvement, capacity release, voltage profile and reduction of power losses. Today reliability is an important parameter in Electrical industry to achieve high security and adequacy of the system. There are three important parameters required to introduce in reliability viz customer composite damage function, Average load and failure rate. Many researchers are working on optimal capacitor placement using intelligent method like genetic algorithm, artificial neural network, fuzzy logic, ant colony algorithm. Most of the methods include capacitor cost and savings due to reduction in power losses. In this paper in addition to above reliability cost is considered which is function of failure rate. Failure rate and modification due to number of capacitor placement is critical issues need to be addressed. Most of the researchers modify the failure rate using some of the assumptions.

This paper introduces the modification method for failure rate using thermal loading and life expectancy of transformer and overhead transmission line. Modified failure rate is applied to calculate reliability cost and hence accordingly objective function is calculated. PSO is used to find the optimal locations and capacitor sizing.

Keywords—OCP, Reliability, PSO, SAIFI, SAIDI, CAIDI

I. INTRODUCTION:

Optimal capacitor placement and sizing problem and reliability issues are rarely consider as a mixed objectives function and whenever mixed objective problem is used or consider then one of the part is objective function used is Reliability cost (or ECOSTi) which is a function of failure rate, CCDF and average load[2]. The unpredicted nature of load and increase in power demand in the electrical network forced the power system operation and control in complicated mode. Increase in power demand load results into (a) increase in number of feeder, (b) feeder capacity, (c) more generation and/or (d) expand the network by increasing substation capacity as well as equipment capacity. However such changes are not achievable in short time span and require putting lot of burden on economy. Therefore to increase KVA margin of substation, it will be more beneficial if system losses are minimized by means of reactive power management through capacitor placement. Such methods are already evaluated and employed [1-12].

Capacitor switching and number of capacitor used is always changing as per load and hence it is also responsible to introduce distortion in voltage and current waveforms results into increase in power quality problem. Reliability issues in conjunction with optimal placement problem are very rarely discussed. Numerous methods are discussed to evaluate similar problems are Artificial Neural Network, Fuzzy Logic [1], Search algorithm, Simulated Annealing, Genetic Algorithm[12,19], Tabu Search[10], Expert System[20] and Dynamic Programming. The fact of above methods is, they use certain control parameters that may be system dependent and difficult to determine. The major drawback of above methods is speed of response.

This paper introduces combined objective function for optimally capacitor placement and hence enhancement of distribution system reliability. IEEE standard 493 states reliability indices and their evaluation technique. At the same time, total harmonic distortion is also considered as one of the constraint in addition to voltage profile and power factor constraints. The multi-dimensional objective functions is evaluated using particle swarm optimization technique is presented. This paper introduces OCP and PSO algorithm. Comparison of KVA release, peak power losses, voltage and power factor is discussed for before and after OCP. Solution techniques treat nearest capacitor size as discrete variable rather than evaluated value of capacitor size. Actual cost of capacitor is considered. Active power losses and reactive power losses are evaluated separately. Most of the assumptions are minimized. For simplicity balanced distribution system is considered.

II. SYSTEM DESCRIPTION: AN OVERVIEW

Optimal capacitor placement and sizing problem is formulated based on the requirements of benefits due to reliability cost, cost of capacitor, purchase cost, operating cost, maintenance cost and savings due to transmission and distribution loss for IEEE 30 bus system. The one line diagram of an IEEE-30 bus system is shown in Fig. 1. The System data is taken from IEEE PES Society.

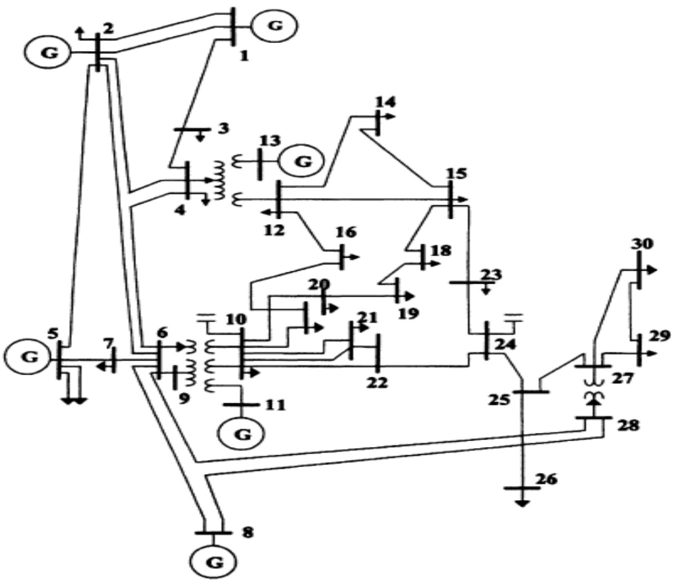
Fig. 1 IEEE 30 bus system

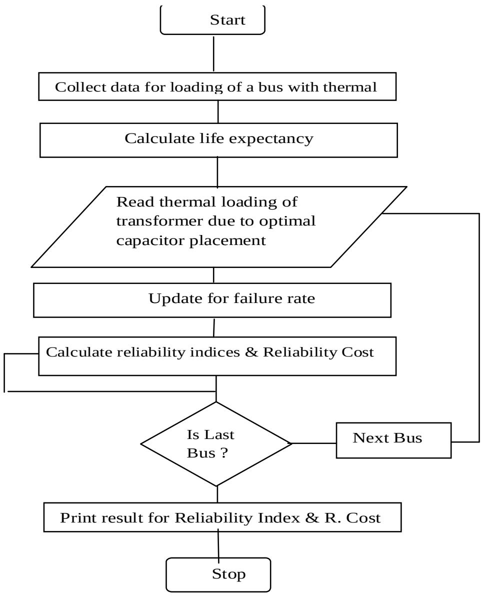

Fig. 2: Flow Chart for Failure Rate modification

TABLE 1
BUS DATA

Bus No.	Bus Voltage		Generators		Load	
	Magnitude (p.u.)	Phase Angle (degrees)	Real Power (p.u.)	Reactive Power (p.u.)	Real Power (p.u.)	Reactive Power (p.u.)
1	1.06	0.000	1.3848	-0.0279	0.000	0.000
2	1.045	0.000	0.4	0.5	0.217	0.127
3	1.000	0.000	0.000	0.000	0.024	0.012
4	1.060	0.000	0.000	0.000	0.076	0.016
5	1.010	0.000	0.000	0.37	0.942	0.19
6	1.000	0.000	0.000	0.000	0.000	0.000
7	1.000	0.000	0.000	0.000	0.228	0.109
8	1.010	0.000	0.000	0.373	0.3	0.3
9	1.000	0.000	0.000	0.000	0.000	0.000
10	1.000	0.000	0.000	0.000	0.058	0.02
11	1.082	0.000	0.000	0.162	0.000	0.000
12	1.000	0.000	0.000	0.000	0.112	0.075
13	1.071	0.000	0.000	0.106	0.000	0.000
14	1.000	0.000	0.000	0.000	0.062	0.016
15	1.000	0.000	0.000	0.000	0.082	0.025
16	1.000	0.000	0.000	0.000	0.035	0.018
17	1.000	0.000	0.000	0.000	0.09	0.058
18	1.000	0.000	0.000	0.000	0.032	0.009
19	1.000	0.000	0.000	0.000	0.095	0.034
20	1.000	0.000	0.000	0.000	0.022	0.007
21	1.000	0.000	0.000	0.000	0.175	0.112
22	1.000	0.000	0.000	0.000	0.000	0.000
23	1.000	0.000	0.000	0.000	0.032	0.016
24	1.000	0.000	0.000	0.000	0.087	0.067
25	1.000	0.000	0.000	0.000	0.000	0.000
26	1.000	0.000	0.000	0.000	0.035	0.023
27	1.000	0.000	0.000	0.000	0.000	0.000
28	1.000	0.000	0.000	0.000	0.000	0.000
29	1.000	0.000	0.000	0.000	0.024	0.009
30	1.000	0.000	0.000	0.000	0.106	0.019

In this system five generators placed at bus numbers 1, 2, 5, 8, 11and 13. Transformers are placed between the buses as 4-12; 6-9; 6-10; 9-11; 12-13 and 28-27 respectively. IEEE 30 bus system is benchmark system selected for the study case. The system is also represented in table (1) and table (2). This network consists of 30 buses, 41 branches, and 23 loads. It is observed that in this system 29 busses are rated with 33 kV, 9 buses are rated with 132 kV and 2 buses are rated with 11 KV. Considering this in mind we treat those buses which are 33 kV are part of distribution system.

TABLE 2
LINE DATA

Line No.	From Bus	To Bus	R	X	Flow limit (MW)	λ	Repair Rate
1	1	2	0.0192	0.0575	130	0.9783	0.0217
2	1	3	0.0452	0.1652	130	0.9841	0.0159
3	2	4	0.0570	0.1737	65	0.9532	0.0468
4	3	4	0.0132	0.0379	130	0.9172	0.0828
5	2	5	0.0472	0.1983	130	0.9786	0.0214
6	2	6	0.0581	0.1763	65	0.9497	0.0503
7	4	6	0.0119	0.94	90	0.9828	0.0172
8	5	7	0.0460	0.12	70	0.9760	0.0240
9	6	7	0.267	0.08	130	0.9211	0.0789
10	6	8	0.0120	0.04	32	0.9494	0.0506
11	6	9	0	0.21	65	0.9494	0.0506
12	6	10	0	0.56	32	0.9211	0.0789
13	9	11	0	0.21	65	0.9535	0.0465
14	9	10	0	0.11	65	0.9509	0.0491
15	4	12	0	0.26	65	0.9660	0.0340
16	12	13	0	0.14	65	0.9838	0.0162
17	12	14	0.1231	0.26	32	0.9754	0.0246
18	12	15	0.0662	0.13	32	0.9598	0.0402
19	12	16	0.0945	0.20	32	0.9510	0.0490
20	14	15	0.2210	0.20	16	0.9494	0.0506
21	16	17	0.0524	0.19	16	0.9494	0.0506
22	15	18	0.1073	0.22	16	0.9236	0.0764
23	18	19	0.0639	0.13	16	0.9514	0.0486
24	19	20	0.0340	0.07	32	0.9509	0.0491
25	10	20	0.0936	0.21	32	0.9666	0.0334
26	10	17	0.0324	0.08	32	0.9824	0.0176
27	10	21	0.0348	0.07	32	0.9786	0.0214
28	10	22	0.0727	0.15	32	0.9612	0.0388
29	21	22	0.0116	0.02	32	0.9462	0.0538
30	15	23	0.1000	0.20	16	0.9498	0.0502
31	22	24	0.1150	0.18	16	0.9506	0.0494
32	23	24	0.1320	0.27	16	0.9181	0.0819
33	24	25	0.1885	0.33	16	0.9483	0.0517
34	25	26	0.2544	0.38	16	0.9537	0.0463
35	25	27	0.1093	0.21	16	0.9733	0.0267
36	28	27	0	0.40	65	0.9818	0.0182
37	27	29	0.2198	0.42	16	0.9808	0.0192
38	27	30	0.3202	0.60	16	0.9564	0.0436
39	29	30	0.2399	0.45	16	0.9537	0.0463
40	8	28	0.0636	0.20	32	0.9537	0.0463
41	6	28	0.0169	0.06	32	0.9536	0.0464

PROBLEM FORMULATION

$$ECOST = \lambda_i C_{cdf} L_{avg} \tag{1}$$

ECOST– Reliability Cost
λi – failure rate
C_{cdf} – customer composite damage function
L_{avg} – average load

Equ. (1) represents reliability cost. Failure rate λ is defined as the frequency of interruption. Number of interruption or faults in given system network is due to weak systems and results into poor power system operation and control. Failure rate can be decreased with strengthening power system by means of proper reactive power management and control, maintaining power factor towards unity and voltage profile. All above can be achieved by proper capacitor placement and it's sizing. C_{cdf} represented in Equ. (1) is **c**ustomer **c**omposite **d**amage **f**unction which varies with customer type. Cost due to interruption for a customer like industrial, commercial, agricultural, municipal or domestic is different. Hence this factor is dependent and consider here as per the type of load selected for given system network for evaluation. L_{avg} is the average load converted to given bus which changes time to time at the same time as capacitor in discrete form is adding in a bus, the overall load is going to change. Considering this, the capacitor cost CC is given by,

$$CC = x_i C_{0i} + Qc_i C_{li} + B_i C_{2i} T \tag{2}$$

$$El = T_i \, P_{Li} \tag{3}$$

$$P_{Li} = \sum_{i=1}^{N_{bus}} Ploss^{(1)} + \sum_{i=1}^{N_{bus}} \sum_{h=h0}^{h_{max}} Ploss^{(h)} \tag{4}$$

First component of Equ. (4) is fundamental component where as second component of Equ. (4) is harmonic component treated separately for evaluation matrix of active and reactive power losses separately.

CC	Cost of Capacitor bank
X_i	0/1 [0 for no capacitor / 1 for capacitor]
C_{0i}	installation cost
Q_{ci}	KVAr rating of capacitor bank
C_{1i}	Rs/KVAr for bank
B_i	number of capacitor in a bank
C_{2i}	operating cost / bank /yr
T	Planning period in yr
T_i	time duration in hours
P_{Li}	total system loss at load level
El	Energy loss
N_{bus}	Bus number at evaluation is carried out

Now the problem can be stated as follows

$$\min F = ECOST + \sum_{i=1}^{N_{bus}} CC + C2 \sum_{i=1}^{N_{bus}} E_l \tag{5}$$

$$PF_{new} = \frac{PF_{old}}{1 - kva_{release}} \tag{6}$$

$$V_{new} = V_{old} + \frac{KVAr(rated)}{KVAsc} \tag{7}$$

$$V_{thd} = \frac{\sqrt{\sum_{h=2}^{50} v_h{}^2}}{v_1} \tag{8}$$

For the following constraint,

$V_{min} < V < V_{max}$
$Pf_{min} < pf$
$THD_i < THD_{max}$

Assumptions considered in the development of the objective function are (a)Balanced network considered for simplicity, (b) Capacitors are available in step size and (c) Capacitor placement affects only the flow of reactive power in the feeder.

Theta is temperature in the transformer winding or transmission line due to loading percentage. As loading increases or decreases, theta changes accordingly. Change in theta; also change the life of transformer unit or transmissition line between the buses. Failure of any equipment is changes as per life of equipment. Using average load in MW, reactive power in MVAR and MVA rating, loading per unit is calculated by Equ. (9).

$$\text{Loading}_{pu} = \frac{\sqrt{MW^2 + MVAr^2}}{MVA_{Rating}} \tag{9}$$

If $\text{Loading}_{pu} < 0$, Then $\text{Loading}_{pu} = 0.0$

If $\text{Loading}_{pu} > 1.80$ Then $\text{Loading}_{pu} = 1.8$

Life expectancy table is prepared for the range 0.01 to 1.8 per unit loading of equipment from Equ. (9) loading per unit for a given bus is calculated and respective life per unit is collected from the life expectancy table. (life expectancy table is shown in Table 3, however in practice; there are 180 per unit loadings is present in the calculation Table) As there is no modification in thermal stress, this life is treated as per unit uncompensated life and given by Lucpu. As per IEEE standard C57.100, 2011,

$$\text{Life} = e^{-\left[\frac{B}{\theta + 273} - A\right]} \tag{10}$$

Where, B = 15000

A= 27.064

Similarly in the simulation process, thermal stress of the equipment is increased or decreased as per the number of capacitor placed at bus for OCP by PSO method; which changes the resultant current and hence the loading. New life expectancy from the table is collected and is treated as per unit compensated life and given by Lcpu. Then modified Life L_m of transformer or transmission line is given by

$$L_m = \frac{L_{cpu} - L_{ucpu}}{L_{cpu}} \tag{11}$$

if actual Life of equipment is 1.0 per unit, Then Failed life or dead Life L_f of given equipment is given by,

$$L_f = 1 - L_m \tag{12}$$

Now this failed life L_f is used as multiplying factor for the update of failure rate. Now modified failure rate is given by

$$\lambda_{mod} = \lambda_{old} \ X \ L_f \tag{13}$$

Now using λ_{mod} from Equ. (13), C_{cdf} and average load $La_{(i)}$, reliability cost and reliability indices can be evaluated using Equ. (14-16).

$$SAIFI = \frac{\text{Total number of customer interruptions}}{\textit{Total number of customers served}} \tag{14}$$

$$SAIDI = \frac{\sum \textit{Customer interruption duration}}{\textit{Total number of customers served}} \tag{15}$$

$$CAIDI = \frac{\sum \textit{Customer interruption duration}}{\textit{Total number of customer interruptions}} \tag{16}$$

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TABLE 3
LIFE EXPECTANCY FOR TRANSMISSION LINE AND TRANSFORMER

$Loading_{pu}$	Theta	$L_{pu}line$	$L_{pu}Xmer$	$Loading_{pu}$	Theta	$L_{pu}line$	$L_{pu}Xmer$
0.1	40.82	114662629930.50	26550.24	1	115.9	11209369.49	3.36
0.2	45.84	54018109037.95	12802.07	1.1	130.2	2865363.72	0.89
0.3	51.48	23851212182.83	5794.78	1.2	146.2	691770.95	0.22
0.4	57.81	9845571966.22	2456.03	1.3	164.2	158757.35	5.27E-02
0.5	64.92	3792050724.17	972.72	1.4	184.4	34898.55	1.19E-02
0.6	72.90	1360973177.77	359.50	1.5	207.0	7412.24	2.63E-03
0.7	81.87	454948891.67	123.91	1.6	232.5	1535.69	5.62E-04
0.8	91.94	141716978.54	39.84	1.7	261.1	313.54	1.18E-04
0.9	103.2	41200363.39	11.96	1.8	293.2	63.75	2.47E-05

Source of Equ. (14-16) is from IEEE standard 1366, 2001. In previous research paper, modified failure rate is depending on compensated and uncompensated failure rate and in most cases it was predicted or assumed values. In this paper modified failure rate is calculated as per thermal loading of transformers and transmission line. As current loading increases, due to I^2rt thermal effect increases in the transformer or transmission line. Life expectancy is calculated and hence accordingly failure rate is modified which is then used in evaluation process of objective function which is calculated using PSO Method.

IV RESULTS

It is observed in simulation process using PSO method, that the capacitor placement reduces the power losses as active power reduction is (17719.83-17484.9)=234.93KW and reactive power reduction (41505.82-41246.02)=259.8 KVAR is achieved. Fig. (3) is graphical representation of system average interruption frequency index before OCP, where as Fig. (4) is the system average duration index SAIDI. CAIDI of IEEE 30 bus system before OCP is represented by Fig. (5). Particle swarm optimization module is run for optimally capacitor placement and sizing in the software developed by research centre, KKWAGH, Nasik. Fig. (8) is the number of capacitors placed on bus. X axis represents bus number and y axis represents number of capacitors placed. This simulation is done by using objective function.

Cost function includes reliability cost, capacitor cost and cost of power loss. In reliability cost function failure rate is modified as per flow chart given in Fig. (2). Failure rate and modified failure rate is graphically represented in Fig. (6) and Fig. (7). It is observed that failure rate is decreased as per number of capacitor placed and hence there is decrease in Reliability cost. It results into decrease in cost function. Fig. (9) and (10) represents reactive power loss changes in OCP whereas FFT analysis is represented in Fig. (11). PSO runs and observed indices are shown in Fig.(12) to Fig. (15). It can be concluded that the reliability Indices are improved, cost function shows that within 2 years cost of capacitor will be recovered and profit will be gained, system capacity is released, power factor is improved and voltage profile is maintained.

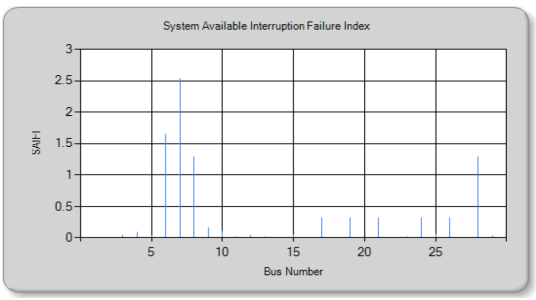

Fig. 3: SAIFI before OCP

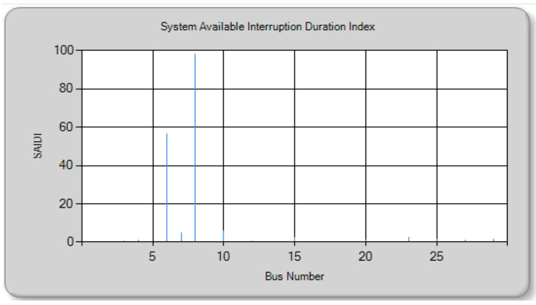

Fig. 4: SAIDI before OCP

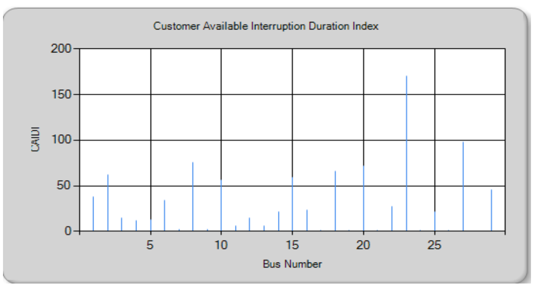

Fig.5: CAIDI before OCP

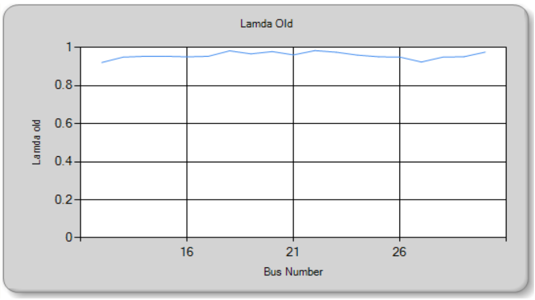

Fig. 6:Old failure rate

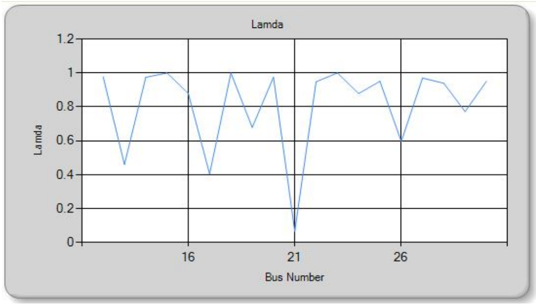

Fig. 7:Modified failure rate

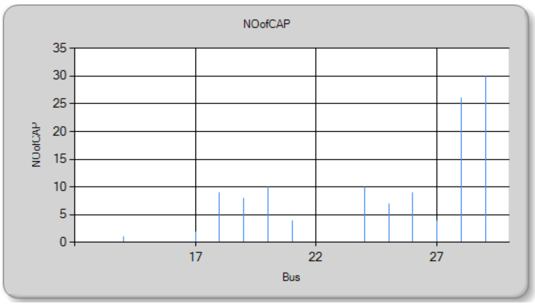

Fig. 8: Bus wise Capacitor placed after PSO

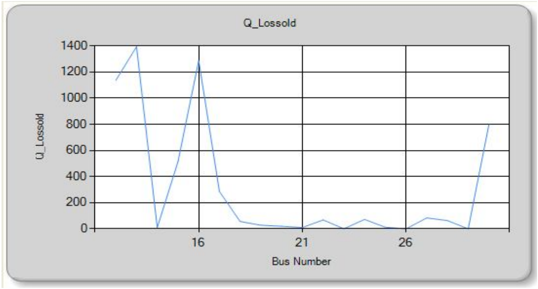

Fig. 9:Q loss old

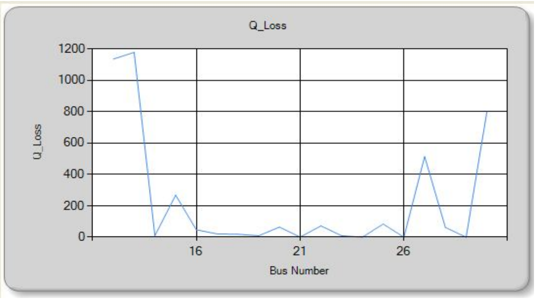

Fig. 10:modified Q loss

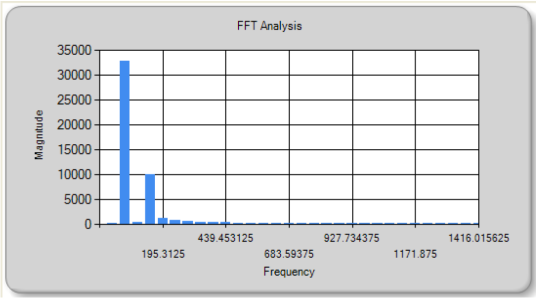

Fig. 11:FFT Analysis

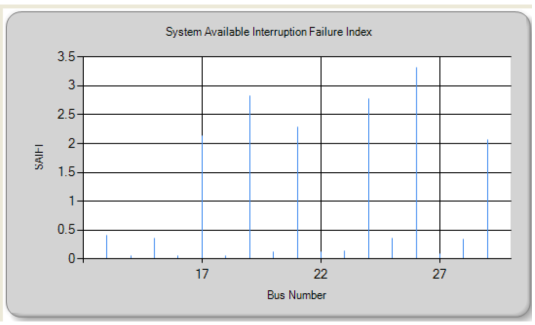

Fig. 12: SAIFI after OCP

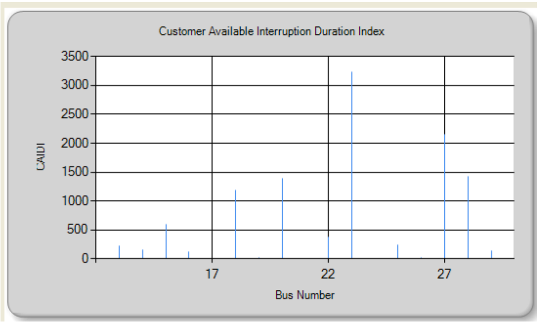

Fig. 13: CAIDI after OCP

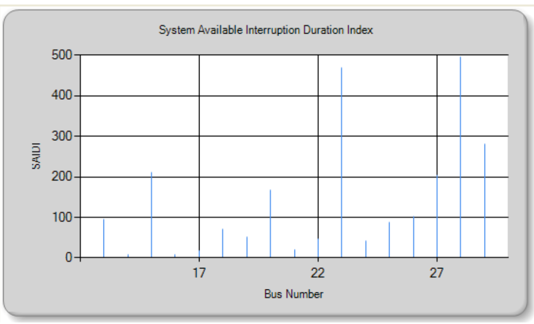

Fig. 14: SAIDI after OCP

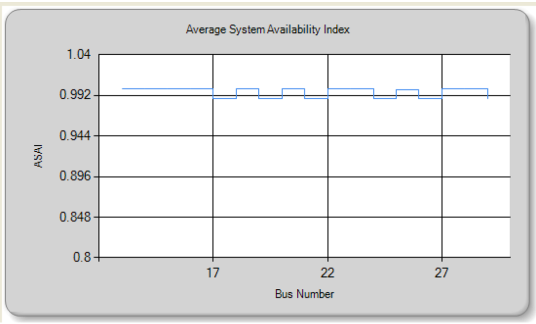

Fig. 15: ASAI after OCP

Reliability Indices before OCP are SAIFI = 9.22 ; SAIDI = 182.7; CAIDI = 948 and ASAI = 0.9964, whereas Reliability Indices WITH ALL CONSTRAINT are SAIFI = 17.54; SAIDI = 2377.52; CAIDI = 135.55; ASAI = 0.9957, Apart from this before and after capacitor placement evaluates as 13.81MVA capacity is released in this system.

V CONCLUSION

The capacitor placement can help to modify voltage parameters in the system. Profit during planning period is discussed in research work. It is observed that within two year the capacitor cost including operating cost is recovered and accumulative profit starts afterwards. In most of cases power factor is improved and voltage is within the limits as per standard. Harmonic distortion is also not violated. At the same time capacitor bank also contribute in reactive power, so wherever local reactive power is required, capacitor placed as suggested by PSO. Particle swarm optimization evaluates its fitness function in local and global platform. Evaluation of loss reduction yield to conclude that to decide cost recovery period due to cost of capacitor and installation cost. Result analysis shows that optimal capacitor configuration find proper places and size of capacitor. Failure rate is modified and evaluated as discussed. Technique used to modify failure rate is the thermal loading and life expectancy as per IEEE standard C57.100. Indices show that Reliability of the system is improved.

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