Optimal Placement of Capacitor for Voltage Support and Minimizing Overall Cost in Radial Distribution System

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ABSTRACT

Reactive power is thelatent soul of power system. Capacitor is a well-known reactive power resource and used for reactive power compensation in mainly transmission and distribution system. This paper presents the optimal placement of capacitor (OCP) as to nullify the effects of inductive loading in radial distribution system. For optimization technique Genetic Algorithm (GA) is used which is implemented in ETAP 7.0.0 Power Station software. Results such as voltage support, power lossesand annual benefits are analyzed. Computational results show compensation of reactive power which in turn results in voltage support, minimize power losses and increases annual benefits. The method is easier and time saving.

General Terms: Voltage profile improvement in radial distribution system, capacitor placement, reactive power compensation.

Keywords: ETAP7.0.0 Power station software, genetic algorithm, optimal capacitor placement, reactive power compensation.

1. INTRODUCTION

The lagging current demanded by reactive load components can be effectively cancelled by the leading current provided by a capacitor. Power factor is an important issue in this concern. Power factor is a measure of the degree to which a given load matches that of a pure resistance. The reactive power demand in a system can be supplied by placing capacitor (or capacitor bank) of adequate rating at the inductive load center. A capacitor bank is supposed to be connected at the inductive load center, far ahead from it or far beyond it, but the problem is in that case the system will not get proper advantage of capacitor bank. Here's the need of proper placement of capacitor.

No doubt placement of capacitor is a very important issue and inappropriate allocation will cause huge system losses. Many researchers have solved this issue in various ways over the last five decades. In ref[1] some heuristic algorithm is used, applied to 70 bus system and further compared to genetic algorithm process, but the method fails to find out the global optimum point and exact sizing of capacitor. In ref[2]Self-AdaptiveHybrid Differential Evolution (SAHDE) algorithm is used for sizing issue and loss sensitivity method for location issue. Two algorithms together may not give optimal solution secondly method is computationally demanding. In ref[3]Abdelsalam A. Eajalused Hybrid particle swarm optimisation technique(HPSO), a combination of discrete version of PSOand radial distribution power flow algorithm. The method is applied to unbalanced 33 bus radial distributed system, but the approach is lengthy and complex. Recently Artificial Intelligence (AI) is also used for capacitor allocation problem, but AI is based on trial and error method so total thing is time consuming. There are various ways to place capacitor bank in distribution feeder [4-15].

The solution procedures of the Optimal Capacitor Placement (OCP) start with performing a load flow analysis to analyze the steady-state performance of the power system prior to capacitor placement and after capacitor placement and to study the effects of changes in capacitor sizes and locations.Load and power flow direction are easy to establish in a radial distribution system and voltage profiles can be determined with a good degree of accuracy without resorting to exotic calculation methods, equipment capacity requirements can be ascertained exactly, capacitors can be sized, located, andset using relatively simple procedures. The study of the optimal placement and sizing of fixed capacitor banks placed on radial distribution systems using Genetic Algorithms (GA) as used in ETAP 7.0.0 is presented in this paper. Results (power losses operatingconditions and annual benefits) are obtained from solution of radial distribution systems.

1.1 Capacitor location issues:

Now a day's voltage collapse is a major problem of power system [16] and it occurs due to voltage instability, line losses `etc. Constant reactive power support is needed for the voltage stability(dynamic support). As said in section 1 capacitor placement is the novel method for compensation of reactive power in the system, sometimes it is used with reactors[17], and placed far ahead, far beyond or at the inductive load point, but the system is unable then to utilize the full advantages of capacitor bank i.e. loss minimization, reactive power compensation and voltage supportwhich would be afforded by placing the capacitor at the appropriate place. Though it is seen that maximum benefits of capacitor bank can be obtained by placing the capacitor bank near to the inductive load point[18]. Still the necessity of knowing exact KVAR demand at that point(inductive load point) is a prime factor. The capacitors are of limited sizes that also necessitate to place the capacitor banks near to load centers. Shunt capacitor bank can be installed in a distribution system as it reduces power and energy losses, increases the available capacity of the feeders and improves the feeder voltage profile system to a required level of reactive power support. Applying optimal capacitor placement on ETAP 7.0.0,the location of capacitor bank can be easily foundand loss reduction (reactive power compensation), voltage support, minimization of total cost is observed.

2. OBJECTIVE FUNCTIONS

2.1 Power Loss

The branch current(I_{mn}) connecting buses *m*and *n*is given by [1],

$I_{mn}=\frac{P_{mn}-Q_{mn}}{V_m}$ ………………. (1)

I_{mn}= Current through branch*(m and n).*
P_{mn}= Real power flow in the branch *(m, n).*
Q_{mn}= Reactive power flow in the branch (m, *n).*
V_m= Voltage at node m.

The Power Loss(PL) in the transmission

$$PL = \sum_{mn=1}^{k} |I_{mn}|^2 . R_{mn}$$

Where
k= Current through branch.
Rmn= Resistance of branch.

Branch current(I_{mn})has two components: active *(I^a)* and reactive (I^r). So, total loss associated with the active and reactive components of $I_{mn}$and can be written as

$PL_a = \sum_{mn=1}^{k} |I_{mn}|^2 . R_{mn}$
and$PL_r = \sum_{mn=1}^{k} |I_{mn}|^2 . R_{mn}$

Now active power is supplied by the source(grid/substation) at the root bus, so active component of loss(PL_a) can't be minimized for a radial bus system, but reactive power support locally can minimize the loss PL_r associated with their active parts. For a radial distribution system if the reactive current drawn is I_c for a branch set α changes only the reactive component of current. Obviously the currents of other branches is almost unaffected by the capacitor bank. Hence the new reactive current of the $(m, n)^{th}$branch can be written as

$I_{rmn} = I_{mn}^{r} + D_{mn} I_{mn}^{c}$ ………………….. (2)

Where, D_{mn}= 1,if branch (m, *n)* € α

=0, otherwise.

$I_{mn}^{r}$is the reactive current of branch obtained from the load flow solution. The loss PL_r^{com}associated with the reactive component of branch current in the compensated system (system with capacitor) is written as

$PL_r^{com} = \sum_{mn=1}^{n} (I_{mn}^{r} + D_{mn} I_c)^2 R_{mn}$…………….(3)

2.2 Capacitor size:

The total loss saving (T_{LS}) can be calculated from the above section(section 2.1) i.e. difference between eqn. (2) and eqn. (3) and can be written as :

$$T_{LS} = PL_r - PL_{rcom}$$

$$= \sum_{mn=1}^{k} (I_{mn}^{r})^2 R_{mn} - \sum_{mn=1}^{n} (I_{mn}^{r} + D_{mn} I_c)^2 R_{mn}$$

$$= \sum_{mn=1}^{k} (2 D_{mn} I_{mn}^{r} + D_{mn} I_c^2) R_{mn}$$

For maximum loss saving the magnitude capacitor current can be found out from*$dS/dI_c = 0$*

$$\sum_{mn=1}^{k} (D_{mn} I_{mn}^{r} + D_{mn} I_c^2) R_{mn} = 0;$$

Thus the capacitor current is given by

$$I_c = \frac{-\sum_{mn€\alpha} I_{mn}^{r} R_{mn}}{\sum_{mn€\alpha} R_{mn}}$$

The corresponding *capacitor size* is

$$Q_c = V_i I_c$$

Where,
Q_c= Capacitor size in KVAR
V_i= Voltage magnitude of bus 'i' in volts
I_c= Capacitor current in amps

The corresponding susceptance is

$$S = \frac{I_c}{V_m}$$

Thistechnique can also be employed to save cost of energy by identifying sequence of buses to be compensated for further loss reduction by optimal placement of capacitor, this is also a optimization based process.

3. RESULT AND ANALYSIS:

3.1 Test system:

For optimal capacitor placement, we consider an RBTS 60 Bus radial distribution system in ETAP 7.0.0. This circuit contains 1 Power Grid, 60 Buses, 22 no's of Lumped Load having total Load 12.602 MW and 6.436 MVar, 24 transformers out of which 2 transformers are used for 33 KV and 22 Transformers for 11 KV Line. The system supplies power to different types of consumers loads: Residential, Industrial, Commercial and Government and institutional (G&I). Fig.1 shows the test system. System parameters are given in Appendix A. Thetest system is simulated in ETAP 7.0.0 and for load flow technique New-Raphson load flow algorithm is used with maximum 99 iterations. Now at the base case load flow the following results(Table 1) is found.

Elements	Specification
Buses	60
Branches	60
Power Grids	1
Loads	22
Load-MW	12.602
Load-Mvar	6.436
Loss-MW	0.043
Loss-Mvar	0.588

Table 1 RBTS 60 bus system before OCP

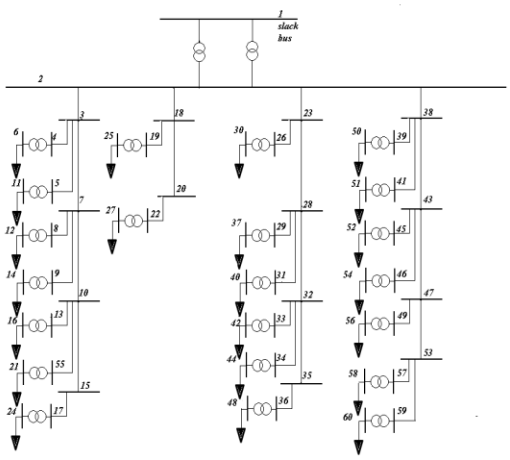

Fig.1 RBTS 60 bus radial distribution system

3.2 Analysis:

As the capacitor placement is done mainly for reactive power compensation, in this case also there is a lot improvement in reactive loss, i.e. 0.109 MVar after compensation. Obviously the prime object is to minimize the overall system cost. The cost consists of mainly four parts which are –

1. Capacitor purchase/buying cost, i.e. 105000.00$for the total system.
2. Fixed capacitor installation cost which is 11800.00$.
3. Yearly capacitor bank operating cost(maintenance and depreciation) – 4200.00$.
4. Cost of real power – 0.16$/KWh.

The constraints are - the voltage profile should be in limit, power factor should be in limit and load flow constraints. After optimal capacitor placement the sizes and location of the capacitors is fixed (Table 2).If the loss reduction saving is plotted it will be a constant curve. One can have this curve directly from ETAP.

Profit also can be shown directly from ETAP, for the given system the profit starts from second year.

Purchase cost, installation cost, operating cost if all together calculated the accumulative profit starts from 15th year of planning period. The Fig.2 shows accumulative profit of the total planning period. At the 20th year it gives a profit of 47172.04$.

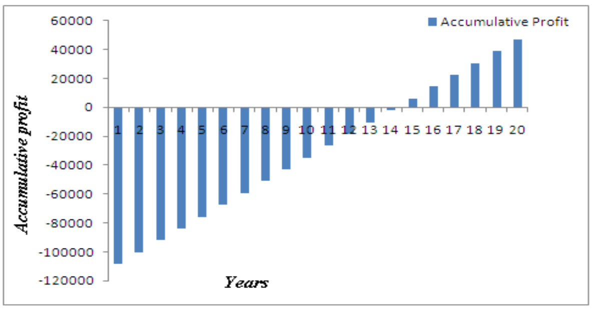

Fig.2 Accumulative profit during total planning period

Capacitor banks connected to the buses are of different sizes and different numbers(Table 2). Total 33 capacitor banks are needed to compensate the system.

Bus No	Rated KVAR/Bank	No of Banks
3	300	1
6	100	4
7	300	1
8	300	1
15	300	2
17	300	1
18	300	1
21	100	7
24	100	2
25	100	3
27	100	2
30	100	2
40	100	2
42	100	1
48	100	1
53	300	1
57	300	1

Table 2 Selected buses and capacitor sizes

As before and after placement of capacitor there is a lot of change in system values(loss and voltage). Table 3depicts the detailed change in the system.

Min voltage(PU)	Min voltage(PU) before OCP	Min voltage(PU) after OCP
	97.29	98.43
Max voltage(PU)	Max voltage(PU) before OCP	Max voltage(PU) after OCP
	98.48	99.59
Power losses in KW	Power losses in KW before OCP	Power losses in KW after OCP
	43	36
Capacitor cost($)	-----------------	105000.00
Cost of real power loss ($)	Cost of real power loss before OCP	Cost of real power loss after OCP
	1205	1009
Benefit($/year)	Benefit($/year) after OCP	Benefit($/year) after OCP
	----------------------	8198.60

Table 3 Comparison of results before and after OCP

As said in section 1.1, for voltage profile improvement the capacitor allocation is a prime issue. For this 60 bus radial distribution system the improvement of voltage profile is shown in figure 3.

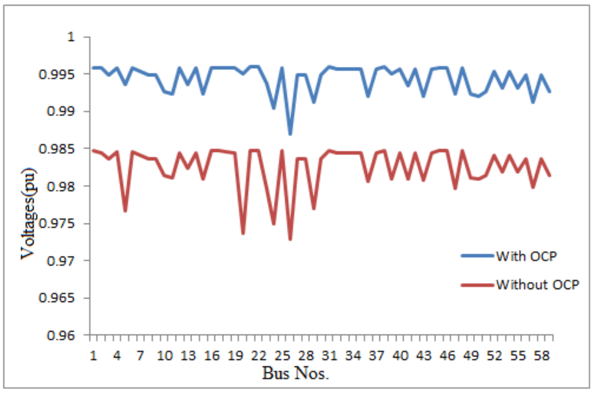

Fig.3 Improvement of voltage profile in 60 bus radial system

The above figure shows that system is much healthier with the approach used.

5. CONCLUSION:

The approach used with genetic algorithm and ETAP is obviously giving much quicker results than the other approaches as it is less computational. The method can be applied for any number of bus systems. The test system is taken as radial distribution, though as said before, themethod is applicable to ring main systems also. The method is a complete solution including power loss reduction, voltage profile improvement and overall cost minimization of capacitor allocation problem. May be due to some practical unavoidable circumstances the capacitor can't be put on the selected bus still this approach gives a nearestsolution.

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APPENDIX A:

System Parameters

From Bus	To Bus	Resistance(pu)	Reactance(pu)
3	4	0.0005	0.0012
3	5	0.0005	0.0012
7	8	0.0005	0.0036
7	9	0.0251	0.0294
10	13	0.3660	0.1864
10	55	0.3811	0.1941
15	17	0.0922	0.0470
18	19	0.0493	0.0251
20	22	0.8190	0.2707
23	26	0.1872	0.0619
28	29	0.7114	0.2351
28	31	1.0300	0.3400
32	33	1.0440	0.3450
32	34	1.0580	0.3496
35	36	0.1966	0.0650
38	39	0.3416	0.1129
38	41	0.3416	0.1129
43	45	0.3416	0.1129
43	46	0.3416	0.1129
47	49	0.3416	0.1129
53	57	0.3416	0.1129
53	59	0.3416	0.1129
2	3	0.3463	0.1145
3	7	0.7488	0.2475
7	10	0.3089	0.1021
10	15	0.1732	0.0572
2	18	0.0044	0.0108
18	20	0.0640	0.1565
2	23	0.3978	0.1315
23	28	0.0702	0.0232
28	32	0.3510	0.1160
32	35	0.8390	0.2816
2	38	1.7080	0.5646
38	43	1.4740	0.4873
43	47	0.0044	0.0108
47	53	0.0640	0.1565