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Determining the Optimum Values of Capacitor Bank and Distributed Generation and Simultaneous Placement of them in the Distributed Network to Reduce Losses and Improve Voltage Stability

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Abstract: Capacitor placement in the distribution network has been the subject of many researches and of interest for Distribution Companies because of its significant impact on supplying reactive power and reducing losses. In recent years, by developing electricity market, passing laws protecting by electricity management and increasing tendency of private sector for investment on the distributed generations, the optimum placement problem of these equipment has been considered by electricity companies and researchers to reduce losses, increase reliability of distribution network or improve power quality and many studys have been presented in this context. In this study, we discuss determining the optimum values of capacitor bank and distributed generation and simultaneous placement of them in the distribution network to specify active and reactive power values of the network in order to reduce losses and improve voltage profile. Genetic Algorithm (GA) has been used to solve the optimization problem and the proposed method has been implemented on the standard IEEE 30-bus network and the results will show that the optimum placement of distributed generation and capacitor in the network reduce losses and improve voltage profile.

Key words: Capacitor, distributed generation, improving voltage profile, simultaneous placement, Genetic Algorithm (GA)

INTRODUCTION

In today's distribution networks, the number of Distributed Generation (DG) units is on the rise. Incorporating DG units in distribution networks needs to plan and leads to operational challenges (Lee and Grainger, 1981; Grainger and Civanler, 1985).

The nature of today's distribution networks is also changing passive to active networks. The prevalence level of Distributed Generation (DG) units is on the rise and is expected to continue increasing over the coming years. At the moment, not only the number of DG units is increasing but in the certain areas, it is possible to reach the capacity of existing thermal plants and this will help to generate a significant portion of electricity (Tolabi *et al.*, 2014; Bhattacharya and Daalder, 2005).

Motivation of DG unit's development will be increased because of concerning about the extreme increase of the greenhouse gases emission, need to eliminate unnecessary transmission and distribution and also reducing related costs. Therefore, in the future, distributed generations that are the small generators located near the load centers that will be distributed in the distribution network are expected to have a significant share in the distribution networks of electrical power system (Cai *et al.*, 2004; Haghifam *et al.*, 2008).

Capacitor placement in the distribution networks has been the subject of many research and attractive for electricity companies because of its significant impact on supplying reactive power and reducing losses and due to the growth of distributed generations in the distribution networks, simultaneous placement of them is necessary to determine the optimum active and reactive power in the network in order to reduce losses and improve the voltage profile (Abu-Mouti and El-Hawary, 2011; Kavousi and Niknam, 2014).

To solve the optimization problem, Genetic Algorithm has been used and the proposed method has been applied to the standard IEEE 30-bus network. The results will show that the optimum placement of distributed generation and capacitor in the network reduce losses and improve voltage profile.

Placement of DG and capacitor in distribution networks: The capacitor can be modeled as a PQ bus and a net generator of reactive power in the network. Distributed

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generation can generate both active and reactive power, but considering that the reactive power generation by capacitor has a fewer cost in the optimum condition, the power factor of generated energy by DG can be considered equal to 1 and DG can be modeled as a PQ bus and a net generator of active power.

Formulation (mathematical method): The objective function of the problem is given based on economic issues and minimizing total cost of losses, purchase, installation, utilization and maintenance of DG and purchase, installation and maintenance of capacitor:

$$\begin{aligned}\min(J) = \sum_{i=1}^{N_{dg}} Cdg_i + \sum_{j=1}^{N_{cap}} C_{cap_J} + K_E \sum_{n=1}^{EL} E_{loss}^{avg} (1+R_{inf})^{n-1} \\ - K_E \sum_{n=1}^{EL} \sum_{i=1}^{Ndg} E_{gen,\,i}^{avg} (1+R_{inf})^{n-1}\end{aligned} \tag{1}$$

Where:

N_{dg} = Number of installed DG
C_{dgi} = Cost of ith installed DG
N_{cap} = Number of installed capacitor
C_{capj} = Cost of ith installed capacitor
K_E = Price of energy (\$ kWh^{-1})
E_{loss}^{avg} = Energy losses in year (kWh year^{-1})
$E_{gen,i}^{avg}$ = Generated energy by ith installed DG in year (kWh year^{-1})
EL = Useful life of equipment
R_{inf} = Inflation rate

As is clear the objective function includes total cost of distributed generation, total cost of capacitor, cost of losses and proceeds from the sale of distributed generation energy to the grid. Total cost of distributed generation comprising the cost of installation, purchase, utilization and maintenance of DG are as:

$$\begin{aligned}C_{dg,i} = C_{ins,i}^{dg} + K_{PRI,i}^{dg} S_{dg,i} + K_F \sum_{n=1}^{EL} H_{dg,i} S_{out,i}^{dg} \\ (1+R_{inf})^{n-1} + K_{MTN,i}^{dg} \sum_{n=1}^{EL} S_i^{dg} (1+R_{inf})^{n-1}\end{aligned} \tag{2}$$

Where:

$C_{ins,i}^{dg}$ = Installation cost of ith DG (\$)
$K_{PRI,i}^{dg}$ = Purchase cost of ith DG (\$ kVA^{-1})
$S_{dg,i}$ = Capacity of ith DG (kVA)
K_F = Fuel cost of ith DG (\$ kWh^{-1})
$H_{dg,i}$ = Average function of ith DG in year (hour year^{-1})
$S_{out,i}^{dg}$ = Average generated power of ith DG (kW)
$K_{MTN,i}^{dg}$ = Maintenance cost of ith DG (\$ kVA^{-1})

Total cost of ith capacitor including the cost of installation, purchase and maintenance of capacitor is obtained by:

$$\begin{aligned}C_{cap,j} = C_{ins,j}^{cap} + K_{PRI,j}^{cap} S_{cap,j} + \\ K_{MTN,j}^{cap} \sum_{n-1}^{EL} S_{cap,j} (1+R_{inf})^{n-1}\end{aligned} \tag{3}$$

Where:

$C_{ins,j}^{cap}$ = Installation cost of ith capacitor (\$)
$K_{PRI,j}^{cap}$ = Purchase cost of ith capacitor (\$ kVA^{-1})
$S_{cap,j}$ = Capacity of ith capacitor (kVA)
$K_{MTN,j}^{cap}$ = Maintenance cost of ith capacitor (\$ kVA^{-1})

It should be noted that the annual losses of energy in the network can be calculated using the following equation:

$$\begin{aligned}E_{loss}^{avg} = P_{loss}^{peak} \times T \times LSF \\ LSF = 0.3 \times LF + 0.7 \times LF^2\end{aligned} \tag{4}$$

Where:

P_{loss}^{peak} = Network losses in the peak load (kW)
T = Number of hours in year (h)
LSF = Losses Factor
LF = Load Factor

It should be noted if the accurate data of the load curve is available, LSF is replaced with the accurate value calculated from the load curve.

The problem constraints: The problem constraints include the circuit constraints of the network to do the load flow calculations. In addition to, the voltage of each bus should be within the allowable range and lines loading do not exceed the permitted limits:

$$P_i = V_i \sum_{i=1}^{N} V_j Y_{ij} \cos(\delta_i - \delta_j - \gamma_{ij})$$

$$Q_i = V_i \sum_{i=1}^{N} V_j Y_i \sin(\delta_i - \delta_j - \gamma_{ij})$$

$$V_{min} \le V_j \le V_{max} \quad j = 1: N_{node}$$

$$I_i \le I_{max} \quad i = 1: N_{BR}$$

Also, according to the IEEE standards and the existence rules in this field, to observe the dynamic conditions of network and avoid increasing the voltage in the off-peak and so on allowable installation capacity of DG and capacitor is limited by the penetration factors of DG and capacitor as:

$$\sum_{i=1}^{Ndg} \le K_P^{dg} \le P_{load}$$

$$\sum_{i=1}^{Ncap} \le K_P^{cap} \le Q_{load} \qquad (5)$$

Where:

$\sum_{i=1}^{Ndg} P_{max}^{dg}$ = Total active power generated by all suggested DG
P_{load} = Total active power of the studied feeder loads
$\sum_{i=1}^{Ncap} Q_{max}^{cap}$ = Total reactive power generated by all suggested capacitor
Q_{load} = Total reactive power of the studied feeder loads
K_P^{dg} = Penetration factor of DG in the network
K_P^{cap} = Penetration factor of capacitor in the network

This is a nonlinear and non-differential problem that can be presented various innovative methods and artificial intelligence-based algorithms to solve it (Kollu *et al.*, 2014; Huang, 2000; Chin, 1995; Flores *et al.*, 2014).

In this study, a Genetic Algorithm-based method has been proposed where first some candidates for installation of distributed generation and some candidates for installation of capacitor are suggested separately.

RESULTS AND DISCUSSION

In this study, the proposed algorithm is implemented on the standard IEEE 30-bus network shown on the Fig. 1, for placement of the capacitor and DG. The network data has been given in Table 1 and 2. It is assumed that the number of installable capacitor is 5 and the number of DG is 1. Before the placement of capacitor and DG, the results of load flow have been as.

Power losses:

- Active power = 0.704 MW
- Reactive power = 0.646 MVar

The cost of energy losses:

- 5.8597×10^5 (currency unit)

Figure 2 active and reactive power losses of the network before the placement of DG and capacitor.

Optimum placement of the capacitor: Figure 3 show the installation location of the capacitor and capacity of each capacitor bank. The capacitors have been installed in the buses 14, 15, 17, 20 and 25 with the capacity of 2.2226, 1.0066, 1.1836, 1.2615 and 2.8358 MVar and totally 8 Mvar. The results of distributed generation placement is as follow:

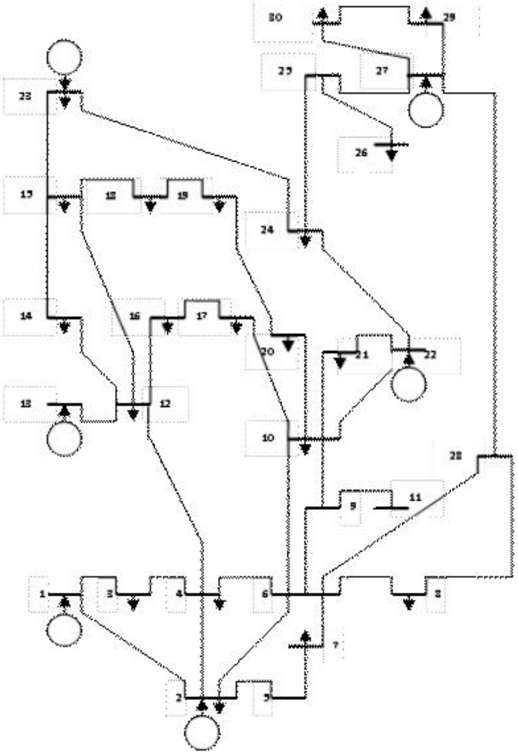

Fig. 1: The standard IEEE 30-bus network

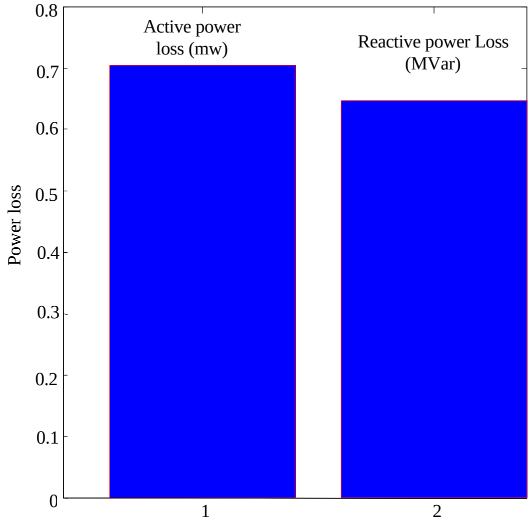

Fig. 2: The active and reactive power losses of the network before the placement of DG and capacitor

Optimum placement of DG:

- Installation location: bus 6
- capacity: 2.6 MW

Table 1: The data of 30-bus network

Line	From bus	To bus	R (pu)	X (pu)	Tap ratio	Rating (pu)
1	1	2	0192	0575		300
2	1	3	0452	1852	9610	300
3	2	4	0570	1737	9560	300
4	3	4	0132	0379		300
5	2	5	0472	1983		300
6	2	6	0581	1763		300
7	4	6	0119	0414		300
8	5	7	0460	1160		300
9	6	7	0267	0820		300
10	6	8	0120	0420		300
11	6	9	0000	2080		300
12	6	10	0000	5560		300
13	9	11	0000	2080		300
14	9	10	0000	1100	9700	300
15	4	12	0000	2560	9650	650
16	12	13	0000	1400	9635	650
17	12	14	1231	2559		320
18	12	15	0662	1304		320
19	12	16	0945	1987		320
20	14	15	2210	1997		160
21	16	17	0824	1932		160
22	15	18	1070	2185		160
23	18	19	0639	1292	9590	160
24	19	20	0340	0680		320
25	10	20	0936	2090		320
26	10	17	0324	0845	9850	320
27	10	21	0348	0749		300
28	10	22	0727	1499		300
29	21	22	0116	0236		300
30	15	23	1000	2020		160
31	22	24	1150	1790		300
32	22	24	1320	2700	9655	160
33	24	25	1885	3292		300
34	25	26	2544	3800		300
35	25	27	1093	2087		300
36	28	27	0000	3960		300
37	27	29	2198	4153	9810	300
38	27	30	3202	6027		300
39	29	30	2399	4533		300
40	8	28	0636	2000	9530	300
41	6	28	0169	0599		300

Table 2: The data of 30-bus network load

Bus	Load (MW)	Bus	Load (MW)
1	0.0	16	3.5
2	21.7	17	9.0
3	2.4	18	3.2
4	67.6	19	9.5
5	34.2	20	2.2
6	0.0	21	17.5
7	22.8	22	0.0
8	30.0	23	3.2
9	0.0	24	8.7
10	5.8	25	0.0
11	0.0	26	3.5
12	11.2	27	0.0
13	0.0	28	0.0
14	6.2	28	2.4
15	8.2	30	10.6

Active and reactive power losses of the network after the placement and installation of the capacitor and DG have been shown in Fig. 4. Their values are 0.121 MW and 0.112 MVar, respectively

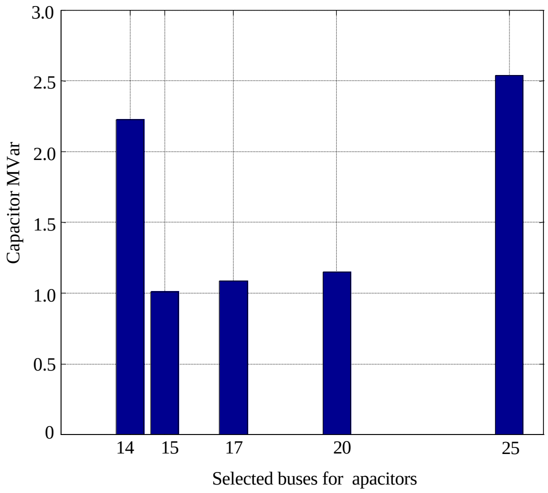

Fig. 3: Installation location of the capacitors and the capacity of each capacitor bank

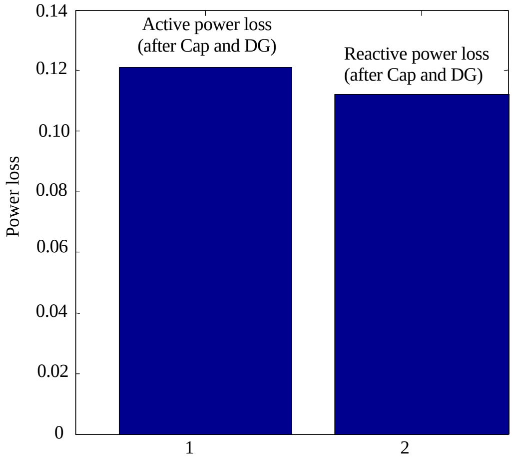

Fig. 4: The active and reactive power losses of the network after the placement and installation of the capacitor and DG

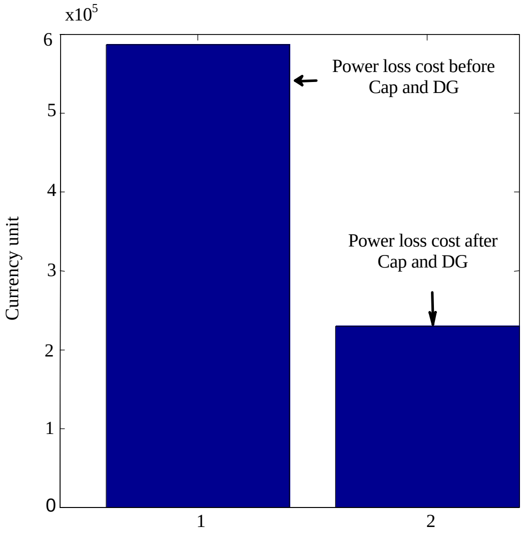

Fig. 5: Reduction of energy losses cost before and after the placement and installation of the capacitor and DG

and compared with the pre-installation capacitor and DG, they has been improved 82.81 and 82.66%, respectively.

Improvement of the energy losses cost before and after the placement and installation of the capacitor and DG is shown in the Fig. 5. The cost is decreased from 5.8597×10^5 to 2.2873×10^5 currency unit.

Figure 6 show the bus voltage in per-unit before and after the placement of the capacitor and DG. It is observed that the bus voltages are improved sensibly and is closed to 1 pu.

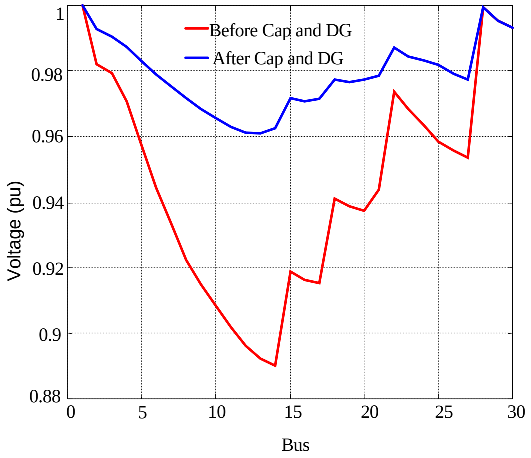

Fig. 6: The bus voltages (pu) before and after the installation of the capacitor and DG

CONCLUSION

Capacitor placement in the distribution network has been the subject of many research and of interest for Distribution Companies because of its noticeable impact on supplying reactive power and reducing losses. In recent years, by developing electricity market, passing laws protecting by electricity management and increasing tendency of private sector for investment on the distributed generations, the optimum placement problem of these equipment has been considered by electricity companies and researchers to reduce losses, increase reliability of distribution network or improve power quality and many studys have been presented in this field. In this study, the idea of simultaneous placement of the capacitors and distributed generations in order to determine the optimum location and capacity of the active and reactive power resources of the network to reduce losses and meet the voltage and current constraints was implemented using Genetic Algorithm and the results of applying this method to the standard IEEE 30-bus network was presented.

The studies shown that the simultaneous and optimum placement of the capacitor and DG reduce the losses and also improve the network voltage profile.

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