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Optimal Size and Location of Capacitor Bank for Reactive Power Compensation Using Genetic Algorithm

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Abstract

Power system operators are always faced with the dilemma of how to reduce the transmission loss. There are many ways to attain this target. In this thesis, new method for optimal capacitor placement for transmission loss minimization is planned. Proposed methods are based on the optimal capacitor placement formulations, which allow the cost benefit analysis and multi-objective optimization consideration of reactive power support investment. For better design of proposed methods, they are applied to a real and test transmission networks. A distribution system is an interface between bulk power system and consumer. Among these radial distribution is popular because of low power and simple design. In distribution system voltage reduce when moved away from the substation also loses are high. The main reason of high amount of losses and reduce voltage is insufficient amount of reactive power which can be minimized by the capacitor, but the accurate size and proper allocation of capacitor is always a challenge thus the optimal capacitor placement problem is to determine the location and size of capacitors to be placed in distribution networks in an well-organized way to decrease the power losses and get better the voltage outline of the system. Genetic algorithm technique is used to determine the correct condenser place and size to reduce losses and general condenser costs.

Keywords: *Power system, power losses, genetic algorithm, distribution networks, capacitor, ORPC, shunt capacitor banks, MATLAB, KVAR, Dimension Reducing Load Flow, Reactive power support*

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INTRODUCTION

In the production, transmission and distribution of energy involve important costs mainly fixed costs and operating costs. Based on these two types of costs, utility companies have established rate structures that attempt to be as fair as possible for their customer. The charges are based upon the amount of energy consumed (kWh) and the power factor of the load. In electrical power consuming, the value will record energy consumed for billing purpose. If the consumer uses electrical power wastefully; for example used load such as, air conditioner, motor and others load which is drawn more current, the power utilities have to supply additional current to create up for the loss caused by poor power factor.

To improve the voltage quality two basic methods are reactive power compensation and voltage regulation. Many mechanisms have been done aiming at the optimal compensation on distribution and transmission network. On the base of mathematical programming or physical characteristic analysis, Intelligent Search and Heuristic Algorithm Optimal reactive power compensation (ORPC) models and algorithm research in distribution networks have made abundant progress.

In this paper described how to design the capacitor bank in intermediate voltage system. There have quite a lot of processes in order to design the capacitor bank, this method involve of formative capacitor size, location and connection type of Wye or Delta. To get the exact result in capacitor bank design, the optimization capacitor placement should be considered.

CAPACITOR BANK DESIGN AND THEIR PROTECTION

Most of the shunt capacitor banks (SCB) are mounted to provide capacitive reactive compensation for correction of the power factor. The use of SCBs has risen as they are comparatively cheap, simple and fast to install and can be deployed nearly anywhere in the network. Its installation has other positive impacts on the scheme such as: load voltage enhancement, better voltage regulation (if properly designed), loss reduction and decrease or postponement of transmission investments [1–5].

BANK CONFIGURATIONS

Fuses play a significant part in designing the SCBs when protecting the condenser bank and its place (inside the condenser unit on each component or outside the unit). They play an important part in the capacitor unit's failure mode and impact the bank security design. Different type of capacitor configuration is suitable for different application which is defined as following:

Externally Fused

A separate fuse which is externally mounted between the capacitor unit and the capacitor bank fuse bus, protects each capacitor unit with any kind of interruption. The externally fused capacitor device can be intended for a comparatively high voltage due to the ability of the internal fuse to interrupt a high voltage fault. In a capacitive bank with the smallest number of series groups, the use of capacitors with the highest possible voltage rating will result, as shown in Figure 1.

Internally Fused

Inside the condenser unit, each condenser component is combined. The fuse is nothing but a simple piece of wire that is sufficient to limit the current and is encapsulated in a cover that can withstand the arc's heat. The fuse only removes the impacted component by leading a failure of the condenser component. The other components, which are attached in the same group in parallel, stay in service but have a slightly greater voltage over them, as shown in Figure 2.

A typical capacitor bank that uses merged condenser units. In particular, banks that use internally fused condenser units are fitted with fewer condenser units in parallel and more series unit groups than those used in banks that use externally fused condenser units. The capacitor units are usually big because it is not anticipated that an entire unit will fail.

Fuseless Shunt Capacitor Banks

The fuseless design is often implemented more than about 34.5 kV for system voltages. The reason behind this is that there will be more than 10 components in sequence to prevent the bank from being removed from service for the failure of one component because the voltage across the remaining components would increase by a factor of about E (E–1), where E is described as the amount of components in the string, as shown in Figure 3.

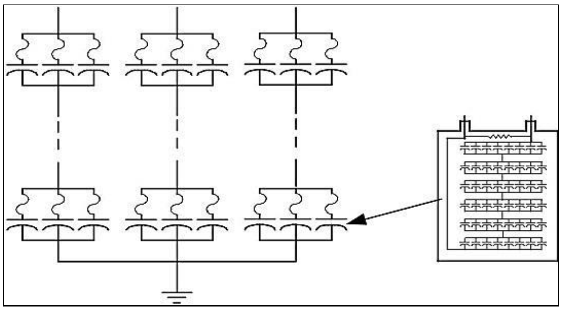

Fig. 1: *Externally Fuse.*

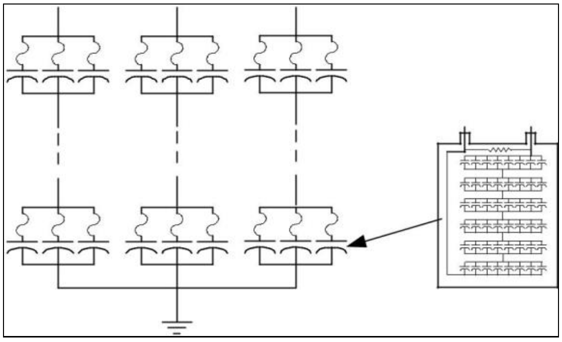

Fig. 2: *Internally Fused.*

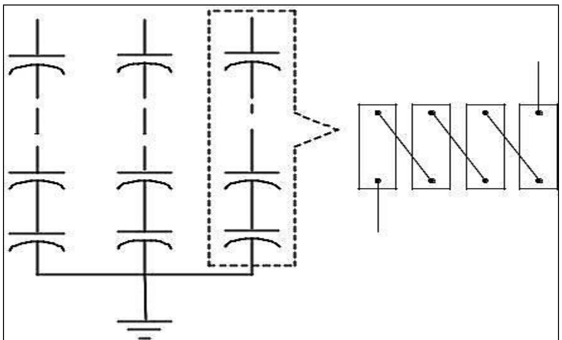

Fig. 3: *Fuseless Shunt Capacitor Bank.*

No capacitor units are directly linked in parallel so that discharge energy is reduced. Another advantage of fuseless banks is that no delay to coordinate with the fuses for the unbalance protection [6–8].

Unfused Shunt Capacitor Banks

Turnaround to the fuseless configuration, where the units are connected in series, a series / parallel connection of the capacitor units is used by the unfused shunt condenser bank. The unfused design would usually be used on banks below 34.5 kV, where condenser unit series strings are not realistic, or with small parallel energy on greater voltage banks. In the design of the unfused shunt condenser bank, not as many condenser units as an externally fused bank require.

SIMULATION AND RESULT

Optimal Capacitor Placement (OCP) Using Ga

Earlier capacitor installation, a load flow program based on Dimension Reducing Load Flow method is run to obtain the present system conditions. The proposed solution methodologies have been implemented in MATLAB 7.10.0. The solution algorithm based on Genetic algorithm and tested on 69 Bus System has been designed only to find the optimal solution for this problem. All loads are presumed to be linear in the genetic algorithm scheme. To locate the optimal solution, computer programs for these algorithms were written based on the corresponding processes mentioned previously [9–15]. The parameters are defined as shown below:

Population size =100
Mutation rate= 0.01
Crossover rate = 0.8
NO. Of generation before algorithm is terminated = 300

The optimal placement and KVAR rating of shunt capacitor banks had been best determined for the studied distribution network using Genetic algorithm, as shown in Figures 4–6 and Tables 1–8.

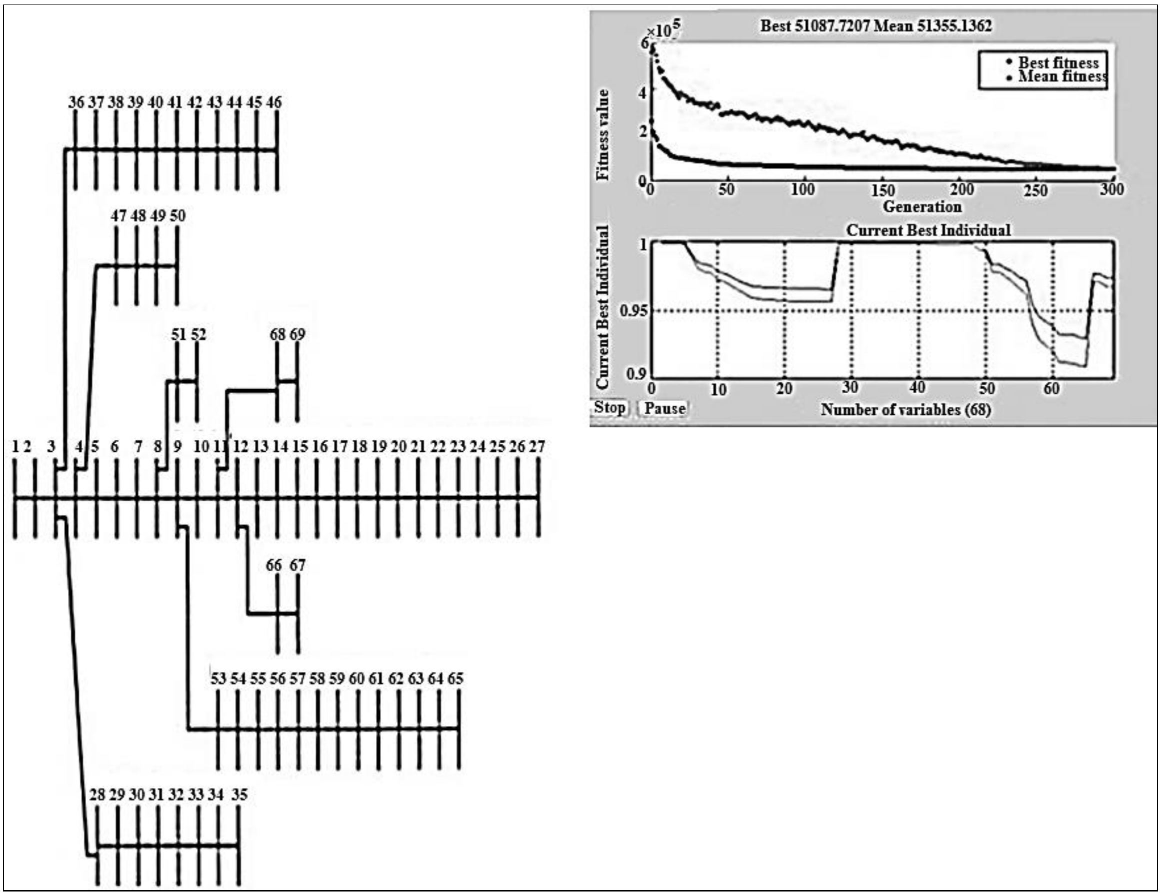

Fig. 4: *69 Radial bus system [4].*

Output Waveform

Table 1: *Load Level and Load Duration Time.*

Load level	**0.5 (Light)**	**1.0 (Medium)**	**1.6 (Peak)**
Time Duration (h)	2000	5260	1500

Table 2: *Base Case Load of 69–bus System.*

Bus Number	**Voltage Magnitude in (pu.)**	**Angle in Degree**	**Bus Number**	**Voltage Magnitude**	**Angle in Degree**
1	1.0000	0.0000	36	0.9990	-0.0029
2	0.9999	-0.0012	37	0.9989	-0.0093
3	0.9999	-0.0025	38	0.9995	-0.0118
4	0.9998	-0.0059	39	0.9990	-0.0125
5	0.9990	-0.0185	40	0.9985	-0.0125
6	0.9900	-0.0491	41	0.9985	-0.0235
7	0.9807	-0.1206	42	0.9985	-0.0282
8	0.9785	-0.1377	43	0.9984	-0.0.282
9	0.9774	-0.1465	44	0.9984	-0.0288
10	0.9724	-0.2311	45	0.9997	-0.0307
11	0.9713	0.2499	46	0.9941	-0.0307
12	0.9681	0.3025	47	0.9785	-0.0077
13	0.9652	0.3487	48	0.9785	-0.0525
14	0.9625	0.3955	49	0.9746	-0.1916
15	0.9623	0.4415	50	0.9714	0.2114
16	0.9595	0.4501	51	0.9669	0.1380
17	0.9589	0.4643	52	0.9629	0.1382
18	0.9577	0.4644	53	0.9625	0.1684
19	0.9581	0.4730	54	0.9400	0.1939
20	0.9576	0.4785	55	0.9290	0.2294
21	0.9573	0.4874	56	0.9247	0.2644
22	0.9568	0.4875	57	0.9400	0.6609
23	0.9568	0.4889	58	0.9290	0.8635
24	0.9567	0.4818	59	0.9247	0.9444
25	0.9566	0.4949	60	0.9197	1.10489
26	0.9564	0.4960	61	0.9123	1.1180
27	0.9563	0.4966	62	0.9127	1.1207
28	0.9563	-0.0027	63	0.9116	1.1243
29	0.9999	-0.0053	64	0.9097	1.1422
30	0.9998	-0.0032	65	0.9091	1.1476
31	0.9997	-0.0028	66	0.9712	0.2510
32	0.9997	-0.0009	67	0.9712	0.2510
33	0.9996	-0.0035	68	0.9678	0.3086
34	0.9993	-0.0093	69	0.9678	0.3086
35	0.9992	0.0104			

Table 3: *Cost of Energy Loss and Minimum System Voltage.*

	Load Level		
	0.5 (Light)	*1.0 (Medium)*	*1.6 (Peak)*
Energy loss cost	$6,192	$70,997	$58,716
Minimum system voltage(v)	0.95668	0.90919	0.84449

Table 4: *Optimal Capacitor Placement Location and Size.*

Optimal Location	**Control Setting (MVAR)**			**Optimal size**
	1.6	*1.0*	*0.5*	
20	300	300	-	300
59	-	300		300
60	300	-	300	300
61	600	300	-	600
62	600	600	-	600
64	300	-	-	300

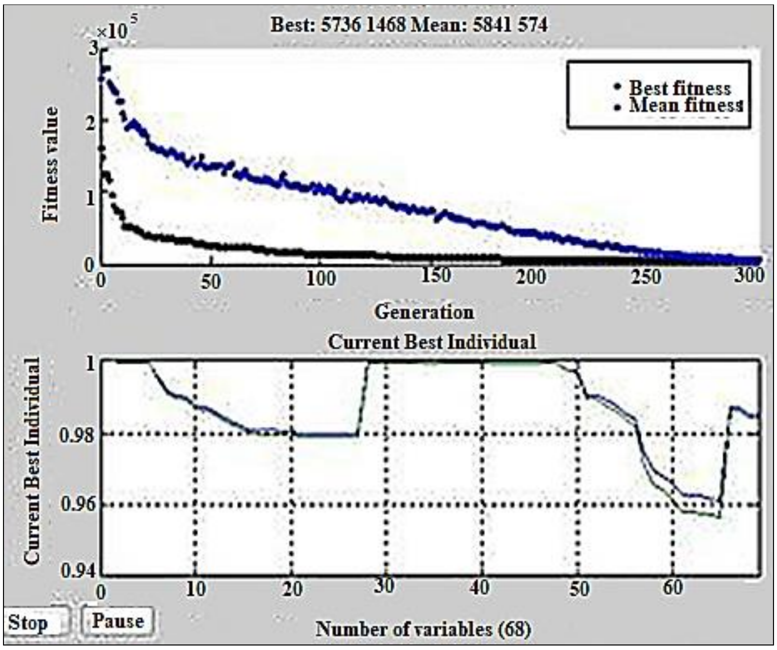

Fig. 5: *Output Waveform.*

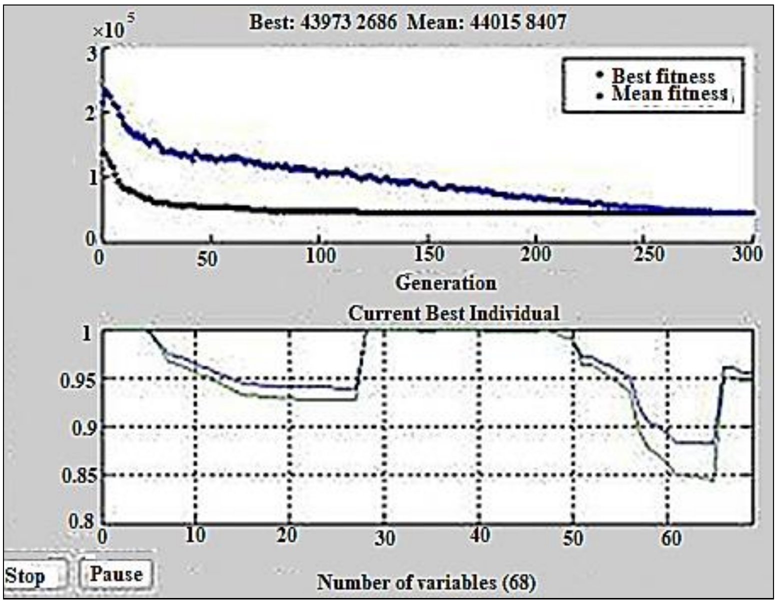

Fig. 6: *Output Waveform.*

Table 5: *System Condition Without and with Capacitor.*

Load levels	**Min Bus Voltage/Real Power Losses**	**Without Capacitor**	**With Capacitor GA Method**	**With Capacitor**
Load level 0.5 (Light)	Minimum bus voltage	0.95668	0.9613	0 .9622
	Real Power Loss (KW)	51.50	40.30	40.48
Load Level 1.0 (Medium)	Minimum Bus Voltage	0.90921	0.9298	0.93693
	Real Power Loss (KW)	224.96	147.61	156.62
Load Level 1.6 (Peak)	Minimum Bus Voltage	0.84449	0.8819	0.90014
	Real power Loss (KW)	652.40	418.59	460.45

Table 6: *Comparison of the Result without and with Capacitor Placement for 69 Bus System.*

	Without Capacitor	**With Capacitor GA Method**	**With Capacitor**
Total Losses Cost ($/ year)	1,35,905	89.095	95,727
Total capacitor Reaquired	0	2400	3100
Total capacitor Cost ($/kvar)	0	7200	9,300
Total Cost ($/year)	1,35,905	96,295	105,027
Total annual Saving ($/year)	-	39,610	30,878

Table 7: *Simulated Result of 69- bus System.*

S. No.	**Bus No.**	**Before Capacitor Placement**		**AFTER Capacitor Placement**	
		Voltage (p.u)	Angle (degree)	Voltage (p.u)	Angle (degree)
1	18	0.9577	0.4633	0.967594	-0.8221
2	62	0.9127	1.1170	0.933244	-1.54433

Table 8: *Comparison 69-bus.*

ITEM	**Uncompensated**	**Compensated**
Total losses (kW)	224.0783	146.7111
Minimum Voltage (p.u)	0.9096	0.9302
Total KVAR Placed	-	1571.174

CONCLUSION

Genetic algorithm for capacitor allocation is an easy technique for finding out suitable location of capacitors for loss minimization. As regards to traditional methods like nonlinear programming or sensitivity analysis where the problem formulation is complex and requires consideration of number of parameters. Genetic algorithm gives optimum results with simpler formulation willing to help all the necessary constraints.

The method improves the voltage profile and reduces losses in the power distribution system simultaneously. The study has been carried out 69 radial bus systems.

Optimal capacitors allocation can provide the efficacy industry with a very efficient cost reduction method. With plant costs and fuel costs continually increasing, electric utilities benefit whenever new plant investment can be deferred or eliminated and energy requirement abridged. Thus capacitors allocation aids in minimizing operating expenses and allow the utilities to serve new loads and customers with minimum system investment.

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