REACTIVE POWER CONTROL IN A MICROGRID IN BOTH GRID-CONNECTED AND ISLANDING MODES OF OPERATION

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ABSTRACT

In this paper, a novel method based on Genetic algorithm for placement of reactive power sources in microgrids is presented. The main objective is to allocate fixed and switched capacitors to supply microgrid while maintaining bus voltages of the microgrid within the desired limits in both the normal operating conditions as well as when it operates in the islanded mode in single stage. . One of the significant characteristics of the proposed GA–based method is providing the switching table for allocated capacitors in various loading.

INTRODUCTION

Distributed power generation system is emerging as a complementary infrastructure to the traditional central power plants. This infrastructure is constructed on the basis of decentralized generation of electricity close to consumption sites using distributed generation sources. The increase in DG penetration depth and the presence of multiple DG units in electrical proximity to one another have brought about the concept of the microgrid [1]. A microgrid is defined as a cluster of DG units and loads, serviced by a distribution system and can operated in the grid-connected mode and islanded mode, and ride-through between the two modes. Volt/Var control and loss reduction problems are significant issues for microgrid planning and operation. Microgrid reactive power needs to be compensated and managed in a way that ensures sufficient amount are being produced in order to met demand and regulated voltage in within specified limits so the microgrid can run efficiency. If the reactive power is not properly compensated, serious problem like microgrid overall losses, abnormal voltages and system instability can occur.

Supply of active and reactive powers from generators significantly reduce feeder losses and improve voltage profile, but for power utilities, reactive power and voltage control is generally accomplished at the cost of generating capacity [2]. Furthermore some technologies are typically not equipped to supply reactive power, which in any event is better supplied by fixed or controlled capacitors distributed throughout the network; it would help the utility generators to generate at their maximum capacities, thus enhancing overall generation.

According to the above description, in this context a new method based on Genetic algorithm with new coding and operators is presented for determining the optimal allocation of fixed and variable shunt capacitors to supply a microgrid and have bus voltages of the microgrid be within the desired limits in both grid-connected an islanded modes.

MODELLING OF MICROGRID, LOAD AND DISTRIBUTED GENERATION

In this section, modeling of microgrid, load and distributed generation are explained.

Microgrid structure

Under the regulation governing distribution system operation, an islanding scenario is permitted only for loads with dedicated generation units. To consider the islanding operation of microgrids, in this paper the distribution system is divided into several zones in such a way that in each zone, there is no DG, or there is any, balance of generation and consumption in that zone is possible regardless of main grid and by using only the power generated by DGs that exist in that zone [4]. In other words, the distribution system is divided in two categories: the first category includes those zones that have no DG and their loads are fully supplied through the main grid, and the second category includes those zones that have one or more DGs and are capable of operating in the islanded mode.

Considering of time varying load

Capacitor placement is determined based on electrical energy demand curve, which means, on load versus time plot. In practice, load in distribution networks can vary with time over a wide range and depends on the point on the feeder where measurements are taken.

In order to define the operation control program of switched capacitor banks, load duration curve (LDC) is approximated with piecewise curve. By increasing the numbers of segments in LDC results are more accurate but time consuming and vice versa [3]. In this work it approximated by a three ladder function corresponding to the schedules of peak, medium and light load levels.

Distributed generation model

Depending on the contract and control status of a DG unit, it may be operated in one of the following modes:

1. Real power production with the specific power.
2. Real power production with the capability of terminal voltage control

The generation nodes in the first mode can be well represented as PQ nodes. The generation nodes in the second mode must be modeled as a PV node. In this paper in the grid-connected mode, DG units are expected to supply their local demand or operated in their optimal operating point from efficiency point of view. This can be due to the economics aspect, hence in this mode DGs operate at constant power factor (close to unity) and do not control grid voltage actively. In the islanding-mode, one DG acts as slack bus. Generation limits must of course be enforced, but the other generation units are operated in PV mode.

PROBLEM FORMULATION

Objective function

The proposed cost function consists of four main terms. The first term denotes the cost of energy loss obtained by summing up the energy losses at each load level considering varying load condition. The second term includes the total cost of purchase and installation of fixed and switchable capacitors. The third term is the cost of active power loss during the peak load condition of the network. Finally the last term is the total value of loss load in the islanding-mode operation. If a bus voltage in a microgrid bellow the allowed level subsequent to an islanding event, it is possible to losing in that busbar. The aggregation of the above mentioned costs in a single objective function can be formulated as follows:

$$\begin{aligned} Min.F = C_p.P_{Loss}^{Peak} + C_e\left(\sum_{j=1}^{M}\sum_{i=0}^{N-1} P_{Loss(i,i+1)}^{\Delta T_j}.\Delta T_j\right) \\ +\sum_{J=1}^{M}\sum_{k=1}^{nbuv}\left(P_{I_J} * P^{J}{}_{Luv_K} * \Delta T_I * VOLL_J\right) \qquad (1) \\ +(M_f.C_{If} + \sum_{i=1}^{N} C_{vf}.Q_{fi}) + (M_s.C_{Is} + \sum_{i=1}^{N} C_{vs}.Q_{si}) \end{aligned}$$

Where F is the monetary objective function ($), C_P is the annual cost of peak power loss ($/kW-year), P_{Loss}^{Peak} is the peak power loss (kW), C_e is the energy loss cost ($/kWh), M is the total number of load levels in a year, N is the total number of network buses, $P_{Loss(i,i+1)}^{\Delta T_j}$ is the active power loss of the $(i,i+1)$ branch at load level j (kW), ΔT_j is duration of jth load level, M_f and M_s are the number of fixed and switched capacitors locations, C_{If} and C_{Is} are the installation cost of fixed and switched capacitors ($), C_{vf} and C_{vs} are the annual purchase of fixed and switched capacitors cost ($/kVar-year), Q_{fi} and Q_{si} are the rating of fixed and switched capacitors on bus–i (kVar). P_{I_J} is the probability of islanding event at load level jth, $P^{J}{}_{Luv_K}$ is the active power of kth bus of microgrid with violated voltage (kW), ΔT_I is the average time that maybe stand in islanding mode, $VOLL_J$ is the value of loss load at jth load level (kWh)

Constraints

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad (2)$$

Where $V_i^{\min}, V_i^{\max}$ are the margin of allowable voltage in bus-i

$$S_{(i,i+1)} \le S_{(i,i+1)}^{\max} \qquad (3)$$

Where $S_{(i,i+1)}^{\max}$ is the rating of section $(i,i+1)$

$$\sum_{i=1}^{N}\left(Q_{fi} + Q_{si}\right) \le \sum_{i=1}^{N} Q_{Loadi} \qquad (4)$$

Where Q_{Loadi} is the Var of load in bus-i.

$$(M_f.C_{If} + \sum_{i=1}^{N} C_{vf}.Q_{fi}) + (M_s.C_{Is} + \sum_{i=1}^{N} C_{vs}.Q_{si}) \le B \qquad (5)$$

Where B is the budget available for investment in the capacitor installation.

OPTIMIZATION METHOD

Load of buses in distribution networks are changed during months, seasons and years. Hence, finding optimal point in capacitor allocation in a microgrid in both grid-connected and islanding modes must be done by consideration of various load level in buses. In this section an efficient new algorithm based on Genetic Algorithm (GA) for optimization in varying load level is proposed. With using this algorithm capacitors are allocated in both grid-connected and islanding modes in single stage.

Codification of chromosomes

Before definition of chromosome, first coding table for capacitors options is introduced. In Fig. 1, $C_1,...C_K,...,C_M$ are all available capacitors for installation on buses. Using the above mentioned coding for different capacitor options, sample of the proposed structure of the chromosome is shown in Fig. 2. This structure is called as chromosome surface.

In proposed method each chromosome has *n* columns and *m* rows for optimization in multi level loads. In this *n* is number of network buses, and the first row denotes the size of fixed capacitor should be installed in each network buses, and the other rows *(m-1)* denote the size of switched capacitor should be installed in each load level.

C_1	----------	C_k	----------	C_M
1	----------	k	----------	M

Fig. 1. Coding table for capacitor option

In the proposed chromosome:

$$x_{F_{1,j}}, x_{S_{i,j}} = \begin{cases} 0 & i = 2,3,...m \\ k & j = 1,2,...,n \end{cases} \tag{6}$$

	Bus1				Bus j			Bus n
Fixed capacitor	$x_{F_{11}}$	$x_{F_{12}}$	$x_{F_{13}}$	....	....	....	....	$x_{F_{1n}}$
Switched capacitor in load level 1	$x_{S_{21}}$	$x_{S_{22}}$	$x_{S_{23}}$	....	....	....	....	$x_{S_{2n}}$
Switched capacitor in load level i	....	....	....	....	$x_{S_{ij}}$	....	....	....
Switched capacitor in load level m-1	$x_{S_{m1}}$	$x_{S_{m2}}$	$x_{S_{m3}}$	....	....	....	....	$x_{S_{mn}}$

Fig. 2. Structure of the chromosome (surface chromosome)

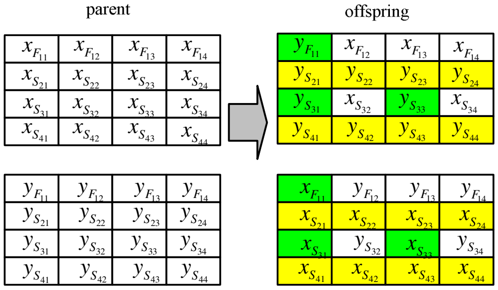
With respect to the above explanations, the proposed optimization algorithm consists of the following steps.

Step 1: Initialisation. For initial population random numbers between *0* and *M* (maximum capacitor option in coding table in Fig.1) are generated.

Step 2: Crossover. In this paper two different types of crossover are proposed.

1) Crossover type-1: In this stage two chromosomes can act as a parent. Then they are crossed over with probability P_c and two rows from chromosome are substituted.

2) Crossover type-2: This type of crossover is performed with due consideration to P_{cc} between array similar pair with a view to gen place on the chromosome pair as shown in Fig.3.



$x_{F_{11}}$	$x_{F_{12}}$	$x_{F_{13}}$	$x_{F_{14}}$
$x_{S_{21}}$	$x_{S_{22}}$	$x_{S_{23}}$	$x_{S_{24}}$
$x_{S_{31}}$	$x_{S_{32}}$	$x_{S_{33}}$	$x_{S_{34}}$
$x_{S_{41}}$	$x_{S_{42}}$	$x_{S_{43}}$	$x_{S_{44}}$

$y_{F_{11}}$	$x_{F_{12}}$	$x_{F_{13}}$	$x_{F_{14}}$
$y_{S_{21}}$	$y_{S_{22}}$	$y_{S_{23}}$	$y_{S_{24}}$
$y_{S_{31}}$	$x_{S_{32}}$	$y_{S_{33}}$	$x_{S_{34}}$
$y_{S_{41}}$	$y_{S_{42}}$	$y_{S_{43}}$	$y_{S_{44}}$

$y_{F_{11}}$	$y_{F_{12}}$	$y_{F_{13}}$	$y_{F_{14}}$
$y_{S_{21}}$	$y_{S_{22}}$	$y_{S_{23}}$	$y_{S_{24}}$
$y_{S_{31}}$	$y_{S_{32}}$	$y_{S_{33}}$	$y_{S_{34}}$
$y_{S_{41}}$	$y_{S_{42}}$	$y_{S_{43}}$	$y_{S_{44}}$

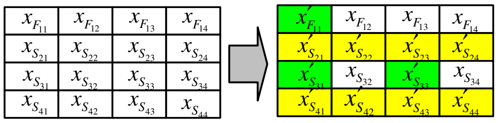
$x_{F_{11}}$	$y_{F_{12}}$	$y_{F_{13}}$	$y_{F_{14}}$
$x_{S_{21}}$	$x_{S_{22}}$	$x_{S_{23}}$	$x_{S_{24}}$
$x_{S_{31}}$	$y_{S_{32}}$	$x_{S_{33}}$	$y_{S_{34}}$
$x_{S_{41}}$	$x_{S_{42}}$	$x_{S_{43}}$	$x_{S_{44}}$

Fig. 3. Crossover;Type-2 for a distribution system with four buses and three load levels

Step 3: Mutation. The mutation diversifies the search and prevents all the solution of the populations from falling into a local optimum of the solved problem. Two different types of mutation are used.

1) Mutation type-1: In this stage a row of chromosome is selected randomly and it can be totally changed with P_m probability.

2) Mutation type-2: With a given probability P_{mm}, random alterative in several arrays in a chromosome may occur as shown in Fig. 4.



$x_{F_{11}}$	$x_{F_{12}}$	$x_{F_{13}}$	$x_{F_{14}}$
$x_{S_{21}}$	$x_{S_{22}}$	$x_{S_{23}}$	$x_{S_{24}}$
$x_{S_{31}}$	$x_{S_{32}}$	$x_{S_{33}}$	$x_{S_{34}}$
$x_{S_{41}}$	$x_{S_{42}}$	$x_{S_{43}}$	$x_{S_{44}}$

$x'_{F_{11}}$	$x_{F_{12}}$	$x_{F_{13}}$	$x_{F_{14}}$
$x'_{S_{21}}$	$x'_{S_{22}}$	$x'_{S_{23}}$	$x'_{S_{24}}$
$x'_{S_{31}}$	$x_{S_{32}}$	$x'_{S_{33}}$	$x_{S_{34}}$
$x'_{S_{41}}$	$x'_{S_{42}}$	$x'_{S_{43}}$	$x'_{S_{44}}$

Fig. 4. Mutation, Type-2 for a distribution system with four buses and three load levels

Step 4: Fitness evaluation. Population fitness is usually measured by objective function so for objective function calculation the load flow of distribution system with updated reactive power at buses in both grid-connected and islanding modes will be run for each chromosome in the population. If a bus voltage in an islanding mode below the allowed level in this situation, the total value of loss loads will be added to cost function otherwise, cost function will calculated without this term. The fitness function in this work is reverse of objective function. Then sorting chromosomes according to their fitness value and selecting a defined number as elite population.

Step 5: Convergence. If convergence is performed, the procedure is finished; otherwise algorithm comes back to the third stage and the whole trend is continued.

APPLICATION STUDY

A 18-bus, 20-kV distribution network is considered as a test system for simulation. Single-line diagram of this network is illustrated in Fig. 5. The peak load and line data of the system are given in the Table 1. The last section of the network that consists of DG units and loads is capable of operating in islanded mode from the main grid. This section constitutes the microgrid system. Microgrid system is supplied by three distributed generation (DG) units that connected at buses 5 and 7 and 9 respectively with rated capacity of 2.1 MW and maximum reactive power 1.5 MVar and minimum reactive power (- -0.7MVar). Three load level and load duration time data for system is given in Table 2 and cost data is listed in Table 3. Allowable voltage deviation is considered as $\Delta V = \pm 5\%$. Each capacitor bank capacity is 150 kVar and maximum number of capacitor banks is 4.

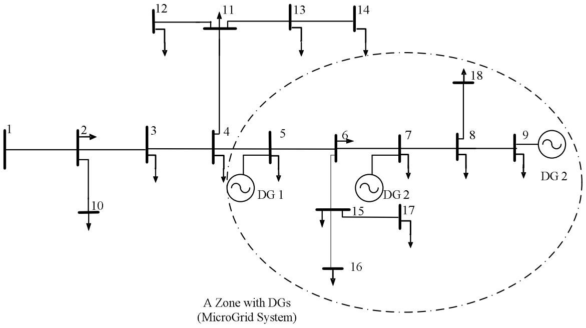


Fig. 5. Single-line diagram of the study system

TABLE 1 Line and peak load data for 18-bus test system

Br.no	Send. End IS(i)	Recv. End IS(i)	R (pu)	X (pu)	PL(MW)	QL(Mvar)
1	1	2	0.006	0.004	0.48	0.31
2	2	3	0.010	0.006	0.58	0.34
3	3	4	0.011	0.013	0.6	0.42
4	4	5	0.013	0.014	0.58	0.42
5	5	6	0.012	0.012	0.58	0.36
6	6	7	0.012	0.013	0.49	0.37
7	7	8	0.017	0.012	0.51	0.33
8	8	9	0.024	0.010	0.56	0.36
9	9	10	0.022	0.160	0.37	0.26
10	10	11	0.007	0.007	0.45	0.33
11	11	12	0.010	0.004	0.63	0.47
12	12	13	0.012	0.008	0.5	0.35
13	13	14	0.017	0.007	0.37	0.27
14	14	15	0.007	0.008	0.385	0.28
15	15	16	0.071	0.003	0.63	0.42
16	16	17	0.011	0.007	0.39	0.27
17	17	18	0.013	0.009	0.69	0.45

TABLE 2 LOAD LEVEL AND LOAD DURATION TIME

Load level	$S_1 = 0.3$	$S_2 = 0.7$	$S_3 = 1$
Time duration (h)	1000	6760	1000

TABLE 3 Cost data used in this study

Parameter	Unit	Value
C_P	$/kW-year	120
C_e	$/kWh	0.1
C_{lf}	$	20
C_{vf}	$/kVar-year	3
C_{ls}	$	30
C_{vs}	$/kVar-year	9
P_{I_J}	-	(0.2,0.3,0.5)
ΔT_I	h	3
$VOLL_J$	$/kWh	(10,20,30)

Results of capacitor placement and switching table in different load level are shown in Table 4.

TABLE 4 Location and sizing of fixed and switching capacitors for 18-bus test system

Bus No	Fixed	Switched		
	All	$S_1 = 0.3$	$S_2 = 0.7$	$S_3 = 1$
4	450	0	0	0
7	0	0	150	600
8	150	0	0	0
9	150	0	0	0
12	0	0	0	150
13	600	0	0	0
15	0	0	300	600
16	150	0	0	0
17	0	0	300	300
18	300	0	150	300

The comparison result with and without considering capacitor placement in grid-connected and islanding modes can be found in Table 5.

From the result in can be found that the total kVar of fixed and switchable capacitors installed in the microgrid is 3450 kVar while remaining kVar allocated in the rest of the distribution network. Before capacitor placement in islanding-mode 5 buses have the voltage magnitude lower than 0.95 p.u, and bus 18 has the greatest voltage magnitude violation with 0.9458 at peak load level but after capacitor placement, all bus voltages satisfy 0.95 p.u voltage constraint and bus voltage 18 has improved to 0.9570.

TABLE 5 Comparison result with and without capacitor placement in 18-bus test system (grid-connected & islanding)

Grid-connected mode		Without capacitors	With capacitors
Total losses cost		$148,728	$107,278
Total capacitor cost		0	$28710
Load level 1.0	$V_{\min}^{18}$	0.9414	0.9502
	Losses(kW)	285.3197	193.8505
Load level 0.7	$V_{\min}^{18}$	0.9606	0.9705
	Losses(kW)	123.6281	93.9547
Load level 0.3	$V_{\min}^{18}$	0.9981	0.9992
	Losses(kW)	23.8734	11.1691
Islanding- mode		**Without capacitors**	**With capacitors**
Load level 1.0	$V_{\min}^{18}$	0.9458	0.9570
	Losses(kW)	156.6923	97.5809
Load level 0.7	$V_{\min}^{18}$	0.9705	0.9889
	Losses(kW)	70.3750	36.0505
Load level 0.3	$V_{\min}^{18}$	0.9981	1.0028
	Losses(kW)	16.9615	9.1140

CONCLUSION

A GA-based optimization method with new coding and operators has presented in this paper to find the most appropriate location of the fixed and switchable capacitors to supply microgrid while maintaining bus voltages of the microgrid within the desired limits in both the normal operating conditions as well as when it operates in the islanded mode in single stage.

In future works, authors will attempt to develop approaches that could be considered unbalanced systems.

REFERENCES

[1] .Shahabi, M.R.Haghifam, M.Mohammadian, S.A.Navabi-niaki " Microgrid Dynamic performance Improvement Using a Doubly Fed Induction Wind Generato, IEEE TRANSACTION ON ENERGY CONVERSION, VOL.24. NO. 1,MARCH 2009

[2] R. Caldon *, F. Rossetto, A. Scala Scala 'Reactive power control in distribution networks with dispersed generators: a cost based method' Electric Power Systems Research 64 (2003) 209_/217

[3] Haghifam, M.-R., Malik, O.P'Genetic algorithm-based approach for fixed and switchable capacitors placement in distribution systems with uncertainty and time varying load' IET Proc., Gener. Trans. Distrib., 2007 (2), pp. 244-252

[4] S. M. Brahma and M. P. Papadopoulos. " Development of adaptive protection scheme for distribution system with high penetration of distributed generation." IEEE Trans. Power Del., vol. 19. no. 1, pp. 56-63, Jan. 2004 .