Volt/Var Control in a Microgrid with Consideration of Uncertainty of Generation in Both Grid-Connected and Islanded Modes of Operation

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ABSTRACT

In this paper, a strategy based on Genetic algorithm for optimal allocation of reactive power resources in distribution system with microgrid is presented. In the proposed approach uncertainty in power generation of renewable based DG is considered. The main objective is to allocate fixed and switched capacitors as reactive power resources for voltage control within the desired limits on a distribution system with microgrid in both grid connected and islanded modes of operation in single stage.
Case study was carried out in a local distribution system with DGs to demonstrate the effectiveness of the proposed methodology.

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.
Due to various environmental problems and increasing in fossil fuel cost as well, the significant amount of DG units in distribution systems are renewable energy based. Considering the fact that these resources are uncertain in nature and vary with time, generation of them must be modeled in terms of time and uncertainty [4]. On the other hand 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]. Renewable based DG units typically are not equipped to supply reactive power to the network. So, in some cases it is better to supply the reactive power using fixed or switchable capacitors.
Hence Volt/Var control is 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 meet demand and regulate bus voltages within specified limits. If the reactive power is not properly compensated, serious problem like microgrid overall losses, abnormal voltages and system instability can occur. According to the Mentioned above, 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 with renewable type DG units in order to have normal bus voltages in both grid-connected and islanded modes in presence of time varying loads.

MICROGRID CONFIGURATION

In this paper 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.

CONSIDERATION OF UNCERTAINTY IN DG POWER PRODUCTION

In recent years, due to environmental concerns and increment of fossil fuel rate utilization of renewable energy resources are increased. Since all types of renewable energy resources have stochastic nature, its produced power is also stochastic. In this paper, generation of renewable type DG units is represented with a probabilistic approach, in which a probability distribution function is utilized. For simplicity, it is assumed that there is a high probability for nominal power production and there is a low probability for higher or lower than nominal production. This representation of DG generation could help to decreasing the amount of calculation in comparison with DG hourly power generation modeling.
In this paper in the grid-connected mode, the other 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. Except the renewable type DG the other generation units are operated in PV bus type mode.

CONSIDERATION OF TIME VARYING LOAD

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.

PROBLEM FORMULATION

Objective function

An optimization function which is used in this study consists of the following terms:

Term1: Cost of energy loss: total cost of energy loss in the planning period obtained by summing up the energy losses at each load level considering varying load condition.

$$CE_{Loss} = C_e \left(\sum_{j=1}^{M} \sum_{i=0}^{N-1} P_{Loss(i,i+1)}^{\Delta T_j} .\Delta T_j \right) \quad (1)$$

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.

Term2: Cost of peak power loss: one of the important benefits of capacitor placement is reduction of peak load loss and demand. Cost of active power loss during the peak load can be computed as:

$$CP_{Loss}^{Peak} = C_p .P_{Loss}^{Peak} \quad (2)$$

P_{Loss}^{Peak} is the peak power loss (kW), C_P is the annual cost of peak power loss (\$/kW-year)

Term3: Capacitor cost: The second term includes the total cost of purchase and installation of fixed and switchable capacitors.

$$C_{capacitor} = (M_f .C_{If} + \sum_{i=1}^{N} C_{vf} .Q_{fi}) + (M_s .C_{Is} + \sum_{i=1}^{N} C_{vs} .Q_{si}) \quad (3)$$

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 per kVar cost of fixed and switched capacitors (\$/kVar-year), Q_{fi} and Q_{si} are the rating of fixed and switched capacitors on bus–i (kVar).

Term4: value of loss load: If a bus voltage in a microgrid bellows the allowed level subsequent to an islanding event, it is possible to losing the load in that busbar, the total value of loss load in the islanding-mode operation can be computed as:

$$C_{Lossload} = \sum_{J=1}^{M} \sum_{k=1}^{nbuv} \left(P_{I_J} * P^J{}_{Luv_K} * \Delta T_I * VOLL_J \right) \quad (4)$$

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)

The aggregation of the mentioned above terms are as follows:

$$F = CE_{Loss} + CP_{Loss}^{Peak} + C_{capacitor} + C_{Lossload} \quad (5)$$

The main objective function with consideration of the probability for renewable typed DG power production levels can be described as below:

$$\min f = \sum_{I=1}^{GL} \alpha_I .F_{I|P_I} \quad (6)$$

Where α_I Probability for Ith level of power production of renewable typed DG, Is the value of cost function (from (5)) corresponding to the Ith level of power production for renewable typed DG (P_I)

Constraints

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (7)$$

Where $V_i^{\min}, V_i^{\max}$ are the upper and lower limits of each bus voltage.

$$S_{(i,i+1)} \le S_{(i,i+1)}^{\max} \quad (8)$$

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

$$\sum_{i=1}^{N} \left(Q_{fi} + Q_{si} \right) \le \sum_{i=1}^{N} Q_{Loadi} \quad (9)$$

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

OPTIMIZATION METHOD

Finding optimal point in capacitor allocation in a distribution system with 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. The optimal allocated capacitors in both grid-connected and islanding modes of microgrid can be determined using this proposed algorithm in a 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 this coding for different capacitor options, the proposed structure of problem coding is shown in Fig. 2. This structure is called as surface chromosome.

In the proposed method each chromosome has n columns and m rows for optimization in multi level loads. So, n is the 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

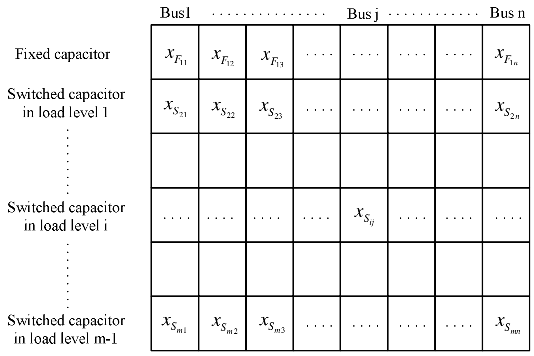

Fig. 2. Structure of the chromosome (surface chromosome)

In the proposed chromosome:

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

According to the problem coding, the proposed optimization algorithm consists of the following steps.

Step 1: Initial population: For initial population a random number between *0* and *M* (maximum capacitor option in coding table in Fig.1 is generated for each gene. Repeating this procedure generates an initial population.

Step 2: Crossover. The crossover operator is used for the generation reproduction. 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.

Step 3: Mutation: After crossover is performed mutation takes place. The mutation diversifies the search and prevents all the solution of the populations from falling into a local optimum point. Two different types of mutation are used.

1) Mutation type-1: In this stage a row of chromosome is selected randomly and its gens can be 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.

Step 4: Objective function evaluation: For each generation level of renewable typed DG unit(P_l), the load flow of distribution system with updated reactive power at buses in both grid-connected and islanding modes of operation would be done 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 is added to the cost function, otherwise, cost function (6) is calculated without this term.

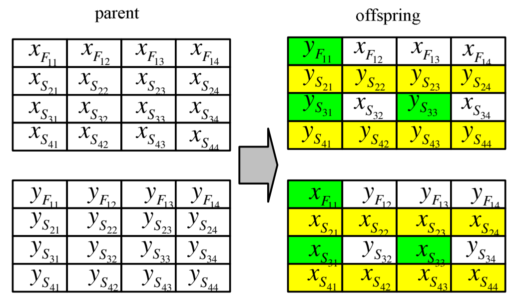

Fig. 3. Crossover;Type-2 for a distribution system with four buses and three load levels

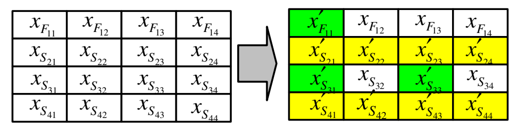

Fig. 4. Mutation, Type-2 for a distribution system with four buses and three load levels

Step 5: Selection: The selection of new population will be done between two old and new generations, according to their fitness value, chromosomes are sorted and a defined number of them are selected as elite population. The fitness function in this work is the reverse of objective function

Step 6: Termination: If convergence is performed, the procedure will be finished; otherwise algorithm comes back to the step2 and the whole trend is continued until convergence is performed.

IMPLEMENTATION

In order to show the capability of the proposed methodology for optimal capacitor allocation in a distribution system with microgrid in both grid–connected and islanding modes of operation, a 18 bus, 20-kV local distribution network is considered as a test system for study case. Single-line diagram of this network is illustrated in Fig. 5. The peak load and line data of the system are given in [5]. In this system, the microgrid system is assumed to be a portion of distribution feeder and is supplied by three distributed generation (DG) units that connected at buses 3, 5 and 7 respectively. DG1 and DG2 are 2.1MW conventional synchronous generator and reactive power capacity of +1.5MVar/-0.7 MVar. DG3 is a wind turbine, a probabilistic distribution function utilized for this DG output modeling.

In this case, the power production of DG3 is assumed in three levels with corresponding probability (Fig. 6). This DG unit considered as negative load and modeled as PQ bus in the load flow program.

Three load level and load duration time data for system are given in Table 1. The cost data and some planning parameters are presented in Tables 2. 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.

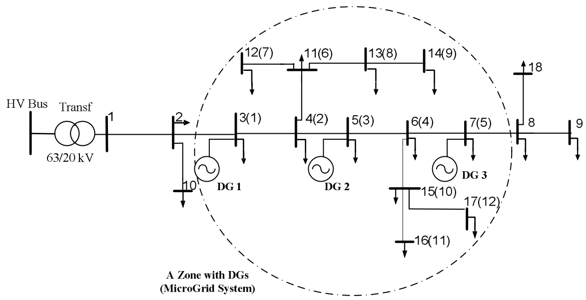

Fig. 5. Single-line diagram of the study system

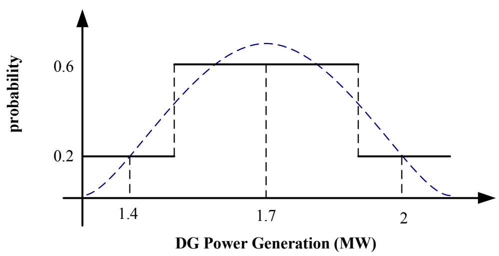

Fig. 6. DG3 Probability distribution function

TABLE 1 LOAD LEVEL AND LOAD DURATION TIME

Load Level	$S_1 = 0.35$	$S_2 = 0.7$	$S_3 = 1$
Time duration (h)	1000	6760	1000

Results of capacitor placement and switching table in different load level are shown in Table 3. From the results it can be found that the total kVar of fixed and switchable capacitors installed in the microgrid is 4050 kVar while remaining kVar allocated in the rest of the distribution network. As a result, it is clear that allocating a large capacitor in the microgrid is due to compensating the reactive power needs from wind turbine (DG3).

TABLE 2 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	hour	3
$VOLL_J$	$/kWh	(10,20,30)

The comparison result with and without considering capacitor placement in grid-connected and islanding modes of operation can be found in Table 4.

TABLE 3 Location and sizing of fixed and switching capacitors

Bus No	Fixed (kVar)	Switched Capacitor (kVar)		
		$S_1 = 0.35$	$S_2 = 0.7$	$S_3 = 1$
6	600	0	0	0
7	450	0	0	300
8	450	0	150	150
9	0	0	0	150
11	0	0	150	450
13	0	0	150	300
14	300	0	0	0
15	300	0	150	0
16	0	0	0	600
17	150	0	0	150

TABLE 4 Comparison result with and without capacitor placement

	Without capacitor	With capacitor
Power loss cost	$ 150,324	$108,694
Value of loss load	$55,672	0
Capacitor cost	0	$31,500

Before capacitor placement in islanding-mode 5 buses have the voltage magnitude lower than 0.95 p.u, and bus 9 has the greatest voltage magnitude violation with 0.9315 at peak load level but after capacitor placement, all bus voltages satisfy 0.95 p.u voltage constraint and the voltage of bus18has improved to 0.9541 pu.

CONCLUSION

The ability to operate microgrids in an islanded mode can bring significant advantages. On the other hand all types of renewable energy resources have stochastic nature, its produced power is also stochastic and are not equipped to supply reactive power. So in this paper a novel algorithm with new objective function and GA-based optimization method using new coding and operators has presented to find the most appropriate location of the fixed and switchable capacitors as reactive power resources to supply microgrid with consideration uncertainty for renewable typed DG units while maintaining bus voltages of the microgrid within the desired limits in both normal and islanded mode operation in single stage.

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