AN APPROACH BASED ON DIFFERENTIAL EVOLUTION FOR VOLT/VAR CONTROL AT DISTRIBUTION NETWORK CONSIDERING DISTRIBUTED GENERATORS

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ABSTRACT

This paper presents an approach for Volt/Var control at distribution networks considering Distributed Generators (DGs). Due to private ownership of DGs, a cost based compensation method is used to encourage DGs in active and reactive power generation. The objective function is summation of electrical energy generated by DGs and substation bus (main bus) in the next day. A Differential Evolution(DE) algorithm is used to solve the Volt/Var control problem. The approach is tested on an IEEE34 buses distribution feeder.

INTRODUCTION

These days, a lot of factors such as competition in the power systems, economical consideration, and environmental impacts and so on, have been caused the number of small scale generators or Distributed Generations, connected to the distribution networks, to be increased. The studies carried out by the research institutes indicate that the electricity generated by DGs will be about 25% of the new generations in the future [1]. Therefore, it is necessary to study their impacts on the power systems. The distribution systems are the first part of power systems, which can be affected by the DGs. The Volt/Var control is one of the most important control schemes in the distribution networks that the impact of DGs on this problem should be studied.

Generally, the Volt/Var control is defined as regulation of voltage over the feeders and reactive power (or power factor) at the substation bus. The control is achieved by LTCs or Voltage Regulators (VRs) and capacitor banks so that the objective function is minimized, and the constraints are met.

Many researchers have investigated reactive power and voltage control in distribution networks but in most of them, the impact of DGs on distribution system performance has not been studied in detail yet [2-16]. In this paper, the Volt/Var control at distribution network considering DGs are presented.

Since the Volt/Var control is a nonlinear optimization problem, one of the optimization algorithms should be used. Evolutionary methods can be used to solve these sorts of problems owing to independence on the type of objective function and constraints. In this paper, a differential evolution is used to solve the Volt/Var control in the distribution networks.

In the following, the formulation of the proposed Volt/Var control, evaluation cost of DGs, differential evolution algorithm and simulation results are presented.

VOLT/VAR CONTROL AT DISTRIBUTION NETWORKS CONSIDERING DISTRIBUTED GENERATORS

From a mathematical standpoint the Volt/Var control at distribution network with regard to distributed generation is an optimization problem with equality and inequality constraints. The objective function is the summation of electrical energy generated by DGs and substation bus as follows:

$$f(X) = \sum_{t=1}^{Nd} (Price^t * P_{Sub}^t * \Delta t_t + \sum_{i=1}^{N_g} C_{Pgi}(P_{gi}^t) * \Delta t_t) \quad (1)$$

$$\overline{X} = [\overline{Tap}, \overline{Q_G}, \overline{U_C}, \overline{P_G}]$$

s.t:

1. $(P_{gi}^{\ t})^2 + (Q_{gi}^{\ t})^2 \le S^2_{gi,\max} \qquad i = 1,2,3,\ldots. N_g$
   $P_{gi}^{\ \min} \le P_{gi}^{\ t} \le P_{gi}^{\ \max}$
   $Q_{gi}^{\ \min} \le Q_{gi}^{\ t} \le Q_{gi}^{\ \max}$
2. $\left|P_{ij}^{Line}\right|^t < P_{ij,\max}^{Line}$
3. $\text{Tap}_i^{\min} < \text{Tap}_i^{\ t} < \text{Tap}_i^{\max} \qquad i = 1,2,3,\ldots. N_t$
4. $\text{DOT}_i^{\text{Trans}} \le \text{MADOT}_i^{\text{Trans}} \qquad i = 1,2,3,\ldots.N_t$
5. $\sum_{t=1}^{Nd} \text{U}_{ci}^t \le \text{MADOT}_i^{\text{Cap}} \qquad i = 1,2,3,\ldots, N_c$
6. $\text{Pf}_{\min} \le \text{Pf}^t \le \text{Pf}_{\max}$
7. Unbalanced - three - phase - power - flow equations
8. $\text{V}_i^{\min} \le V_i^t \le \text{V}_i^{\max}$

where N_c, N_g , N_d *and* N_t are the number of capacitors, DGs, load variation steps and transformers, respectively. t is an index which represents the time step of load level. $\overline{X}$ is the vector of state variables. $\overline{Tap}$ is the tap vector which represents the tap positions of transformers for the next day. $\overline{Q_G}$ is the DGs reactive power vector including the reactive powers of all DGs for the next day. $\overline{U_C}$ is the capacitors switching vector including the states of all capacitors for the next day. $\overline{P_G}$ is the DGs active power vector including the active powers of all DGs for the next day. Δt_t is the time interval. $\Pr ice^t$ is the electrical energy price for the t[th] load level step. $C_{Pgi}\left(P^t{}_{gi}\right)$ is the cost of electrical energy generated by the i[th] DG during time "t". V_i^t is the current voltage magnitude at the i[th] bus during time "t". $V^{min}{}_i$ and $V^{max}{}_i$ are the minimum and maximum values of voltage at the i[th] bus, respectively. $MADOT_i^{Trans}$ and $MADOT_i^{Cap}$ are the maximum allowable daily operating times of the i[th] transformer and capacitor, respectively. $\left|P_{ij}^{Line}\right|^t$ and $P_{ij,\max}^{Line}$ are the absolute power flow over distribution lines and maximum transmission power between the nodes *i* and *j*, respectively. $Tap_i^{\min}$, $Tap_i^{\max}$ and Tap_i^t are the minimum, maximum and current tap positions of the i^{th} transformer, respectively. $Pf_{\min}$, $Pf_{\max}$ and Pf^t are the minimum, maximum and current power factor at the substation bus during the time step t. Q_{gi}^t, P_{gi}^t *and* $S_{gi,\max}$ are the reactive and active powers for the t[th] load level step and the apparent power of the i[th] DGs, respectively. U_{ci}^t is the state of the i[th] capacitor in the light of turning on and off during time "t" ,which equals 0 or 1.

In this problem, it is assumed that tap position of transformers changes stepwise.

EVALUATION COST OF DISTRIBUTED GENERATION

Generally, costs of distributed generation to customers include the installed cost of the equipment, fuel costs, non-fuel operation and maintenance (O&M) expenses, and certain costs that the customers' utility imposes.

Generally, the cost of DGs (per kWh/$) can be defined as follows:

$$C(P) = a + b * P \tag{2}$$

In mentioned equation a & b coefficients can be evaluated as follows:

$$a = \frac{CapitalCost(\$/kW) * Capacity(kW) * Gr}{LifeTime(Year) * 365 * 24 * LF} \tag{3}$$

$$b = FuelCost(\$/kWh) + O\&MCost(\$/kWh)$$

where Gr and LF are yearly rate of benefit and DG loading factor.

DIFFERENTIAL EVOLUTION ALGORITHM

Evolutionary algorithm is a kind of global optimization techniques that use selection and recombination as their primary operators to tackle optimization problems. Differential evolution (DE) is a branch of evolutionary algorithms developed by Rainer Storn and Kenneth Price for optimization problems over continuous domains [17-18].

Differential evolution is similar to Genetic Algorithm(GA) but differs from GA with respect to the mechanism of mutation, crossover and selections. In overall view, the DE, based on the mutation rules, is classified into five different strategies as follows [17-18]:

1. Best / Rand

$$Xp_{i,j+1} = X_{best} + \alpha * (X_{r1,j} - X_{r2,j}) \tag{4}$$

2. Rand / Rand

$$Xp_{i,j+1} = X_{r1,j} + \alpha * (X_{r2,j} - X_{r3,j}) \tag{5}$$

3. Old / Best / Rand

$$Xp_{i,j+1} = X_{i,j} + \alpha * (X_{best} - X_{i,j} + X_{r1,j} - X_{r2,j}) \tag{6}$$

4. Best / Rand – Rand

$$Xp_{i,j+1} = X_{best} + \alpha * (X_{r1,j} - X_{r2,j} + X_{r3,j} - X_{r4,j}) \tag{7}$$

5. Rand / Rand - Rand

$$Xp_{i,j+1} = X_{r1,j} + \alpha * (X_{r2,j} - X_{r3,j} + X_{r4,j} - X_{r5,j}) \tag{8}$$

where

X is set of population;

$Xp_{i,j+1}$ is a partner for mating for the next generation;

$X_{i,j}$ is ith member of the current population;

X_{best} is the best member in population;

α is constant factor between [0,2];

j is the current generation;

$j+1$ is next generation;

$X_{r1,j}$, $X_{r2,j}$, $X_{r3,j}$, $X_{r4,j}$ *and* $X_{r5,j}$ are the randomly selected population in the current generation.

After creation of partner for mating, crossover is applied on the member as follows:

$$X_{i,j+1} = X_{i,j} * (1 - P_c) + Xp_{i,j+1} * P_c \tag{9}$$

where P_c is crossover probability.

New generation is compared with its limits.

To apply DE to solve the Volt/Var control at distribution network, at first in this method, initial population is produced based on control variables including active and reactive power of DGs, reactive power of capacitors and tap of LTC and voltage regulators. The value of taps and capacitor reactive power is considered as discrete. Then for each member of initial population, an unbalanced three-phase power flow is solved. After that, the objective function for each member is calculated. The next generations are produced by selection one of strategies mentioned before. After the next generation, the objective function is calculated for each member of new population. This process is repeated, until convergence is met.

SIMULATION

In this section the proposed method is applied to Volt/Var control on an IEEE 34 bus radial distribution test feeders (Fig(1)), where the lines and loads specification are presented in [18].

For this system it is assumed that there are three DGs connected at 9, 23 and 27 respectively, which their specifications are presented in Table I.

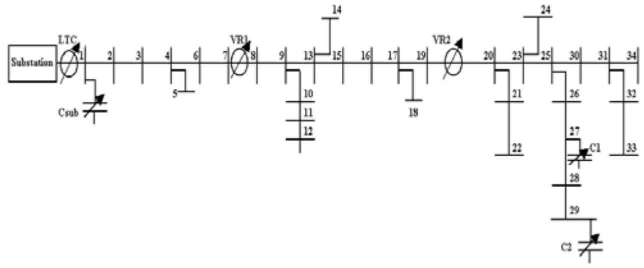

Fig.1 Single Line Diagram

TABLE I
CHARACTERISTIC OF GENERATORS

	G1	G2	G3
Maximum Active Power(kW)	100	400	600
Maximum Reactive Power (Kvar)	80	320	480
Minimum Reactive Power (Kvar)	-60	-240	-360
Location	6	16	29
Kind of DG	Micro Turbine CHP	Large Wind Turbine	Combustion Turbine CHP

In the simulation process it is assumed that daily energy price variations and daily load variations are changed as Figs 2 and 3.

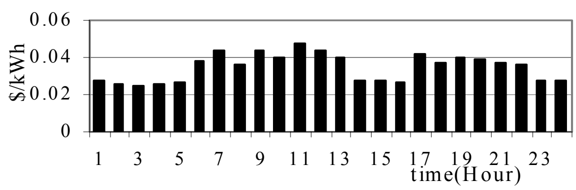

Fig.2. Daily energy price variations

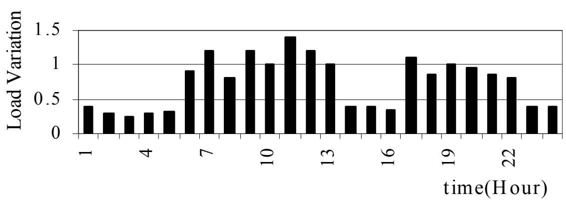

Fig.3. Daily load variations

Table II presents a comparison among the results of DE and Genetic Algorithm for 300 random tails.

Table II
Comparison of Average and Standard Deviation for 300 Trails

Method	Average	Standard Deviation	Worst solution	Best solution
DE	1141.96	102.12	1267.47	1028.92
GA	1145.76	101.32	1268.24	1026.46

The voltage changes of some buses and power factor at the substation bus are shown in Figs.4, 5 and 6.

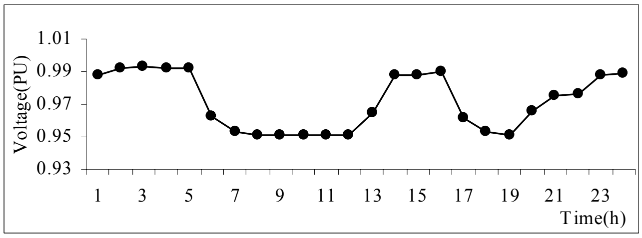

Fig.4. Voltage variations of bus21 over a day

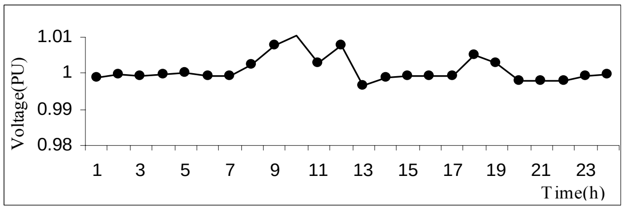

Fig.5. Voltage variations of bus34 over a day

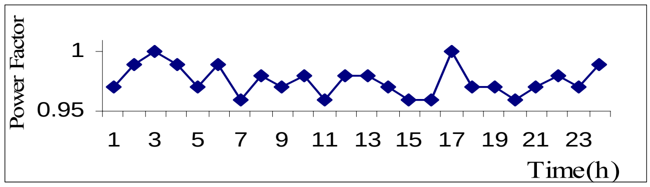

Fig6.Power factor variations at substation bus over a day

As shown in Table II, the DE can be used to apply to Volt/Var control at distribution networks. DE can be applied to a wide variety of similar optimization problems. On the other hand, the algorithm can be used to non-differential and non-continuous objective function and constraints.

Since most of DGs have private ownership, the cost of active power generation can be used as an encouraging signal. The voltage magnitude at each bus and the substation power factor are in the desire limits when DGs are controllable.

CONCLUSION

As the number of DGs will be increasing, their impacts on power system should be studied. One of the most important issues in distribution system is Volt/Var control, which can be affected by DGs. In this paper a new approach for Volt/Var control at distribution networks with regard to DGs presented. The simulation result showed that the DE could be implemented in practical distribution networks. Since the most of DGs owned by private section, active and reactive power generation costs of DGs considered as optimal parameter control of them.

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