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Impact of Distributed Generation on Volt/Var Control in Distribution Networks

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***Abstract*— As power system in many countries is going to be restructured and deregulated. After deregulation, because of numerous advantageous of Distributed Generation (DG), the number of this kind of generators are going to be increased. DGs can affect entire system and especially distribution networks. One of the important control schemes at distribution system that DGs can change it, is Volt/Var control. This paper presents an efficient approach for Volt/Var control in radial distribution networks takes DGs performance into consideration. In general Distributed Generations can be considered as PV or PQ nodes. In this paper DGs are modeled as PV nodes. The goal of this approach is to minimize power losses at distribution system through controlling the tap of Load Tap Changer (LTC), size of substation capacitor, local controller settings and voltage amplitude of DGs. DGs, Voltage Regulators, Local Controllers, and Load Tap Changer (LTC) are modeled completely and the optimization problem has been solved by using Genetic Algorithm. Finally the method is tested on IEEE 34 bus radial distribution feeders.**

***Keyword:* Distributed Generation, PV node, Volt/Var Control, Genetic Algorithm.**

I. INTRODUCTION

DISTRIBUTED Generation (DG) is defined as the generation which is dispersed throughout a utility's service territory and either connected to the utility's distribution system or small and Grid Isolated. DG technologies include Photovoltaic, Wind Turbines, Fuel Cells, Micro Turbines and so on.

During, the last decade many electrical power systems around the world have been deregulated and DG is predicted to play an increasing role in the electric power system of the near future. A study by the Electric Power Research Institute (EPRI) indicates that by 2010, 25% of the new generation will be distributed, and also, a study by Natural Gas Foundation concluded that this figure could be as high as 30%[1].

Apart from advantages of DGs, they can affect some parameters of power systems such as stability, voltage control, power quality and so on where in this paper the impact of these kind of generators on Volt/Var control is going to be studied.

Volt/Var control is one of the important control schemes at a distribution substation, which conventionally involves regulation of voltage, and reactive power at substation bus. The control is achieved by Load Tap Changer (LTC), Voltage Regulators (VR) and Capacitors. Some Volt/Var control algorithms have already been developed by researchers [2-6].

Since DGs can change Volt/Var control scheme at distribution network, this paper presents a new approach for Volt/Var control in radial distribution system takes DGs performance into consideration. In general Distributed generations can be considered as PV or PQ nodes. In this paper DGs are modeled as PV nodes where these performance are combined with controlling of Load Tap Changer (LTC), substation capacitor, local controller settings to minimize power losses at distribution system. In this effort Genetic algorithm is used to minimize objective function and then it is implemented to verify and testify on IEEE 34 bus radial distribution feeders.

II. OBJECTIVE FUNCTION

From a mathematical standpoint the Volt/Var control optimization problem is a minimization problem with inequality constraints. The objective function is summation of losses in distribution system for load variation. The value of the objective function is determined through power flow solution.

The objective function is given by equation (1).

$$F(x) = \min Ploss^{dt} \tag{1}$$

Subject to:

1. $V_{i\min} \le V_i \le V_{i\max}$ $\quad i=1,2,..,N$
2. $Pf_{\min} \le Pf \le Pf_{\max}$
3. $Q_{gi\min} \le Q_{gi} \le Q_{gi\max}$ $\quad i=1,2,...N_g$
4. $T_{i\min} \le T_i \le T_{i\max}$ $\quad i=1,2,...N_t$

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5. $Q_{ci\min} \le Q_{ci} \le Q_{ci\max}$ $\quad i = 1,2,...N_c$

6. Load Flow Equations $g(P,Q,V,\delta) = 0$.

Where:

V_i = bus voltage,

V_{imin}, V_{imax}= minimum and maximum voltage for each bus ,

Pf = Power factor in substation,

Pf_{min}, Pf_{max}= minimum & maximum power factor in substation,

Ploss = sum of losses in line and transformers,

Q_{gi} = reactive power for each generator,

Q_{gimin}, Q_{gimax} = minimum and maximum reactive power for each generator,

T_i = tap for LTC and VR,

T_{imin}, T_{imax} = minimum and maximum tap for each transformer,

Q_{ci}= reactive power for each capacitor,

Q_{cimin}, Q_{Cimax} = minimum and maximum reactive power for each capacitor,

dt = duration of time for load ,

N_t= number of transformers,

N_c = number of capacitors,

N_g = number of generators.

III. UNBALANCED THREE PHASE LOAD FLOW

In three phase unbalanced power flow, the following components are modeled by their equivalent circuits in term of inductance, capacitance, resistance and injected current.

a) Distributed Generators: DGs are modeled as PV node.

b) Transformers: transformers are modeled as equivalent circuit with virtual current injections.

c) Capacitors: Capacitors are represented by their equivalent injected currents.

d) Demands or Loads: system loads are basically considered asymmetric loads; because of single load and unequal three phase loads.

In this paper a network-topology-based on three-phase distribution power flow algorithm has been used. Two matrices are used to obtain the power flow solution. They are the Bus Injection to Branch Current (BIBC) and the Branch Current to Bus Voltage (BCBV) matrices [7].

IV. DISTRIBUTED GENERATION MODEL

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

1. In "parallel operation" with the feeder, i.e., the generator is located near and designed to supply a large load with fixed real and reactive power output. The net effect is the reduced load at a particular location.
2. To output power at a specific power factor.
3. To output power at a specific terminal voltage.

The generation nodes in the first two cases can be well represented as PQ nodes. The generation nodes in the third case must be modeled as a PV node. In this paper, generators are modeled as PV nodes.

PV nodes are modeled in similar manner as presented in [7].

In general voltage of DGs can be controlled in two ways:

A) Balanced three-phase voltage control of DG which use Synchronous Generators and Balanced three phase inverters such as Gas Turbines, small hydro and geothermal plants. In this case the incremental relation between the magnitude of voltage and magnitude of reactive current injection is expressed as:

$$\begin{aligned}
&[Z][I_{Injec}] = [\Delta V] \\
&[I_{Injec}] = [I_{Injec1}, I_{Injec2},..., I_{InjecN}]^T = [Z]^{-1}[\Delta V] \\
&|[I_{Injec}]| = |[Z]^{-1}[\Delta V]| \\
&[\Delta V] = [\Delta V_1, \Delta V_2,..., \Delta V_N]^T = |V_{Set}| - |V_{Calc}|
\end{aligned} \tag{2}$$

Where:

$[Z]_{N*N}$: Sensitivity Matrix, which is calculated, based on positive sequence impedance of lines.

[ΔV]: positive sequence voltage magnitude mismatch vector for PV nodes.

$[I_{Injec}]$: injection of reactive current vector in PV nodes.

$|V_{set}|$: Scheduled voltage magnitude vector for PV nodes.

$|V_{Calc}|$: Calculated positive sequence voltage magnitude vector for PV nodes.

N: Number of DGs

B) Unbalanced three phased voltage control of DGs which connected to network through an inverter that its phase voltage could be controlled separately such as Fuel cell, Micro turbine and so on. In this case the incremental relation between the magnitude of voltage and magnitude of reactive current injection is expressed as:

$$\begin{aligned}
&[Z][I_{Injec}] = [\Delta V] \\
&[I_{Injec}] = [I_{Injeca1}, I_{Injecb1}, I_{Injecc1},..., I_{InjecaN}, I_{InjecbN}, I_{InjeccN}]^T \\
&= [Z]^{-1}[\Delta V] \\
&|[I_{Injec}]| = |[Z]^{-1}[\Delta V]| \\
&[\Delta V] = [\Delta V_{a1}, \Delta V_{b1}, \Delta V_{c1},..., \Delta V_{aN}, \Delta V_{bN}, \Delta V_{cN}]^T \\
&= |V_{Set}| - |V_{Calc}|
\end{aligned} \tag{3}$$

Where:

$[Z]_{3N*3N}$: Sensitivity Matrix which is calculated based on three phase impedance matrix of lines.

[ΔV]: voltage magnitude mismatch vector for PV nodes.

$[I_{Injec}]$: injected reactive current vector in PV nodes.

$|V_{set}|$: Scheduled voltage magnitude vector for PV nodes.

$|V_{Calc}|$: Calculated voltage magnitude vector for PV nodes.

Since in power system there is nonlinear relation between voltage and current, we have used an iterative method for voltage mismatch correction as follows:

Step1: solve the power flow equation with initial condition (Qgi=0).

Setp2: calculate mismatched voltage for each PV nodes. If these values are less than thresholds go to next step, otherwise stop.

Step3: calculate injection reactive current amplitudes.

In case A): Balanced three phase voltage control

$$
\begin{aligned}
I^{\gamma}_{Injeca} &= \left|I_{Injec}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{via})} \\
I^{\gamma}_{Injecb} &= \left|I_{Injec}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{vib})} \qquad (4) \\
I^{\gamma}_{Injecc} &= \left|I_{Injec}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{vic})}
\end{aligned}
$$

In case B): Unbalanced three phase voltage control

$$
\begin{aligned}
I^{\gamma}_{Injeca} &= \left|I_{Injeca}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{via})} \\
I^{\gamma}_{Injecb} &= \left|I_{Injecb}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{vib})} \qquad (5) \\
I^{\gamma}_{Injecc} &= \left|I_{Injecc}\right|^{\gamma}_{i} e^{j(\pm 90+\delta^{\gamma}_{vic})}
\end{aligned}
$$

In above equations positive/negative signs are used when voltage mismatch is positive/negative.

Step4: calculate reactive power for each DGs based on obtained voltage and current values.

Step5: check calculated reactive power with DGs reactive power limits. If any calculated reactive power is outside the bound discard the extra value, and consider this PV node as PQ node, and then update sensitivity matrix.

Step6: calculate injected reactive current based on calculated reactive power in previous step.

Step7: Power flow calculation, go to step2.

V. VOLTAGE REGULATOR AND LTC MODEL

Voltage regulators and LTCs often control voltage along primary feeders. Voltage Regulators are autotransformers with individual taps on their windings. LTC and Voltage Regulators are modeled as follows:

Assume the transformer has connected between buses M and N, and has initial tap ratio (t) and physical admittance (Y) [Fig.1 (a)]. This transformer is described by the π model, with indirect representation of the transformer tap ratio [Fig. 1(b)] by its series and shunt admittances.

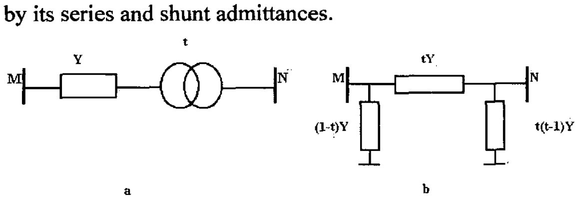

Fig. 1. Transformer and Voltage Regulator model

When the transformer tap ratio is changed from t to t+Δt the transformer model should be changed as it is shown in Fig. 2(a). In this case correspondent matrix should be refactorized. Another way to simulate the tap positions change is to modify model Fig.l(b) by adding virtual injected currents as it is shown in Fig. 2(b).

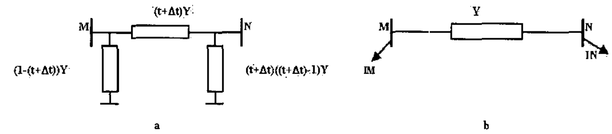

Fig. 2. (a) Transformer model with a new ratio. (b) Equivalent with virtual current injections.

In order to make voltages and currents in the systems 2a and 2b to be the same, fictitious injection currents are calculated as follows:

$$
\begin{aligned}
I_M &= (1-(t+\Delta t))*Y*V_N \\
I_N &= (1-(t+\Delta t))*Y*V_M + ((t+\Delta t)^2-1)*Y*V_N
\end{aligned}
\qquad (6)
$$

VI. GENETIC ALGORITHM

Genetic Algorithm is searching and optimization method based on a model of evolution adaptation in nature. It is very powerful search algorithm and is different from convention search algorithms. GA does not need derivatives or other auxiliary knowledge.

GA works with a population of individuals and each individual stands for a solution. The quality of a solution is evaluated by its fitness, which is calculated by fitness function [8].

In this paper, an Integer string instead of binary coding are used to represent value of variables, and includes these process:

1. Representation and initialization
2. Fitness function
3. Reproduction Operation
4. Crossover Operation
5. Mutation Operation

VII. FLOW CHART OF ALGORITHM

Since Volt/Var control is an optimization problem, Genetic Algorithm has been used to solve it. Fig .3. shows flow chart of algorithm.

At first in this approach, initial population is produced based on control variables including voltage amplitude of DGs, reactive power of substation capacitor, tap of LTC and local controller setting (for this paper there are 7 control variables). Initial population has to meet constraints. The value of taps and capacitor reactive power is considered discrete. Then for each member of initial population, with considering of local controllers and PV nodes, unbalanced three-phase power flow is solved. After that, electric power losses for each member are calculated and sorted, then a number of good members (N_{good}) that have minimum losses, are selected. New offspring, based on selected population, are produced by Roulette wheel reproduction rule. Any new offspring outside the bound is discarded in favor of the other two. Mutation operator is applied to each gene according to mutation probability independently. After mutation, losses are calculated and sorted for each member of new population. Then a number of good members that have minimum losses are selected. This process is repeated, until convergence is met.

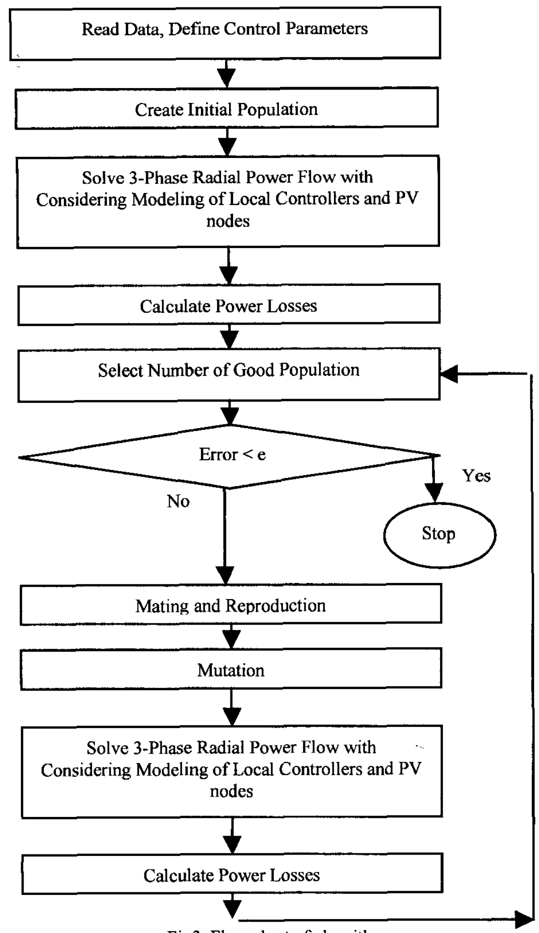

Fig3. Flow chart of algorithm

In this approach, local controllers are coordinated based on theirs response times. In the other word, at first local controllers in which have the shortest response time, will response to power flow alterations. Slower controller response will be based on output of faster local controllers. It is assumed response time of Voltage Regulators is less than capacitors.

VIII. SIMULATION

In this section, Volt/Var control algorithm is tested on the 34 Bus IEEE test feeder, whose one line diagram is given in Fig.4. The feeder line and load data is taken from [9].

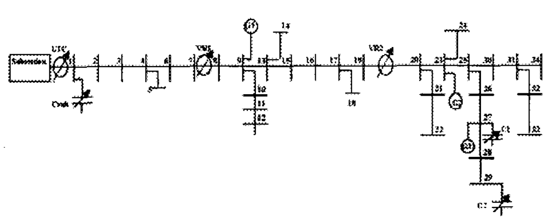

Fig.4. 34 Bus IEEE test feeder with DGs

It is assumed, there are 3 generators, that they have been located on 9, 23 ad 27 buses. The characteristic of generators is given in Table.1.

TABLE I
CHARACTERISTIC OF GENERATORS

	G1	G2	G3
Active Power (kW)	90	120	150
Max Reactive Power(kVar)	72	96	120
Min Reactive Power (kVar)	-54	-72	-90
Maximum Voltage	1.015	1	1
Minimum Voltage	0.98	0.98	0.98
Kind of voltage control	Case A	Case A	Case B

Figure 5 shows the load curve profile in all load point in the network.

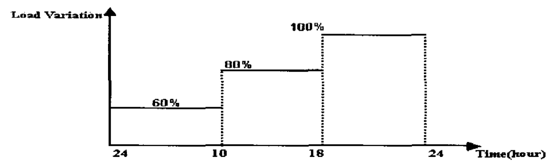

Fig.5. Variation of load.

Now for using the GA to determine the state variable of the system i.e. tap of LTC, size of capacitors, tap of Voltage regulators and voltage amplitude of generators, the following assumption is made:

Initial population: 2000
Number of good population: 300
Number of load level: 3
Limit of voltage magnitude: 0.95-1.05
$RT_{VR1} < RT_{VR2} < RT_{Cap1} < RT_{Cap2}$
Limit of power factor in substation: 0.95-1
Limit of tap position: .97-1.05
Size of tap: 0.0001
Limit of substation capacitor: 0-1000 kVar
Limit of local capacitors:
C1:0-450 kVar
C2:0-300 kVar
Mutation: $\mu = 0.04\, e^{-Counter}$
ε=0.000001

$$Error = \sum_{n=1}^{Ngood} \left| Cost_n - Cost_{Ngood+1} \right|$$

Where:

Counter and $Cost_i$ are number of iteration and value of objective function for the ith population respectively. RT_i is response time for each local controller.

In the following section the application of the method for various load conditions are presented.

A) PEAK LOAD

In this case it is assumed that in all load nodes, the load is in its maximum level. Table II represents result of simulation for this case.

TABLE II
OUTPUT RESULTS OF SIMULATION FOR PEAK LOAD

	With DG	Without DG
Tap of LTC	1.03	1.03
Size of substation capacitor (kVar)	522	858
PF in substation	0.9995	0.9978
Power losses (kW)	36.61735	87.416
Tap of Voltage Regulator (1)	1.0068	1.03
Tap of Voltage Regulator (2)	1.0135	1.0173
Size of Capacitor1 (kVar)	0	0
Size of Capacitor2 (kVar)	0	0
QG1 (kVar)	72	-
QG2 (kVar)	96	-
QG3A (kVar)	40	-
QG3B (kVar)	12.408	-
QG3C (kVar)	40	-
Voltage amplitude of DG1	1.00909	-
Voltage amplitude of DG2	0.9941	-
Voltage amplitude of DG3	0.9993	-

The voltage profile also has been presented in Table III.

TABLE III
VOLTAGE PROFILE FOR PEAK LOAD

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0299	1.0299	1.0299
3	1.0296	1.0296	1.0297
4	1.0241	1.0247	1.0251
5		1.0246	
6	1.0177	1.0192	1.0197
7	1.0126	1.0148	1.0155
8	1.0067	1.0105	1.0116
9	1.0066	1.0105	1.0116
10	1.0065		
11	1.0027		
12	1.0019		
13	1.0052	1.0087	1.0099
14		1.0087	
15	1.0051	1.0086	1.0097
16	1.0023	1.0053	1.0063
17	1.0023	1.0053	1.0062
18		1.0052	
19	0.9973	0.9995	1.0002
20	1.0004	1.0011	1.0011
21	0.9864	0.9870	0.9871
22	0.9861	0.9868	0.9868
23	0.9999	1.0005	1.0004
24	0.9999		
25	0.9991	0.9995	0.9994
26	0.9991	0.9995	0.9994
27	0.9990	0.9993	0.9993
28	0.9989	0.9992	0.9992
29	0.9989	0.9992	0.9992
30	0.9990	0.9994	0.9993
31	0.9989	0.9994	0.9992
32	0.9989	0.9994	0.9992
33	0.9989		
34	0.9989	0.9994	0.9992

With DG

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0298	1.0299	1.0298
3	1.0293	1.0294	1.0294
4	1.0200	1.0216	1.0211
5		1.0215	
6	1.0094	1.0127	1.0116
7	1.0009	1.0056	1.0040
8	1.0091	1.0174	1.0145
9	1.0090	1.0173	1.0144
10	1.0089		
11	1.0052		
12	1.0043		
13	1.0068	1.0149	1.0119
14		1.0149	
15	1.0066	1.0148	1.0117
16	1.0022	1.0103	1.0067
17	1.0021	1.0102	1.0066
18		1.0102	
19	0.9942	1.0023	0.9976
20	0.9950	1.0033	0.9963
21	0.9809	0.9893	0.9821
22	0.9806	0.9890	0.9819
23	0.9941	1.0024	0.9952
24	0.9941		
25	0.9930	1.0013	0.9940
26	0.9930	1.0012	0.9939
27	0.9928	1.0010	0.9937
28	0.9928	1.0009	0.9937
29	0.9927	1.0009	0.9937
30	0.9929	1.0012	0.9938
31	0.9928	1.0011	0.9938
32	0.9928	1.0011	0.9938
33	0.9928		
34	0.9928	1.0011	0.9938

Without DG

Bus is single phase

B) 80% PEAK LOAD

In the second case it is assumed that the load in various nodes are 0.8 of its peak value. Table IV represents result of simulation for this case.

TABLE IV
RESULT OF SIMULATION FOR 80% PEAK LOAD

	With DG	Without DG
Tap of LTC	1.03	1.03
Size of substation capacitor (kVar)	318	654
PF in substation	0.9936	0.9987
Power losses (kW)	16.9689	54.47581
Tap of Voltage Regulator (1)	0.9997	1.0209
Tap of Voltage Regulator (2)	1.0022	1.0106
Size of Capacitor1 (kVar)	0	0
Size of Capacitor2 (kVar)	0	0
QG1 (kVar)	72	-
QG2 (kVar)	96	-
QG3A (kVar)	40	-
QG3B (kVar)	26	-
QG3 C(kVar)	40	-
Voltage amplitude of DG1	1.00913	-
Voltage amplitude of DG2	0.99324	-
Voltage amplitude of DG3	0.999969	-

The voltage profile has been presented in Table V.

TABLE V
VOLTAGE PROFILE FOR 80% PEAK LOAD

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0299	1.0299	1.0299
3	1.0297	1.0298	1.0298
4	1.0260	1.0267	1.0269
5		1.0267	
6	1.0218	1.0234	1.0235
7	1.0184	1.0208	1.0208
8	1.0096	1.0137	1.0136
9	1.0095	1.0136	1.0136
10	1.0094		
11	1.0065		
12	1.0058		
13	1.0086	1.0125	1.0124
14		1.0124	
15	1.0085	1.0124	1.0123
16	1.0066	1.0102	1.0099
17	1.0066	1.0102	1.0099
18		1.0102	
19	1.0033	1.0064	1.0056
20	0.9985	1.0009	0.9992
21	0.9873	0.9897	0.9880
22	0.9871	0.9895	0.9878
23	0.9982	1.0005	0.9987
24	0.9982		
25	0.9976	0.9998	0.9980
26	0.9975	0.9998	0.9980
27	0.9975	0.9996	0.9979
28	0.9974	0.9996	0.9978
29	0.9974	0.9995	0.9978
30	0.9975	0.9997	0.9979
31	0.9974	0.9997	0.9978
32	0.9974	0.9997	0.9978
33	0.9974		
34	0.9974	0.9997	0.9978

With DG

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0298	1.0299	1.0299
3	1.0294	1.0295	1.0295
4	1.0222	1.0234	1.0231
5		1.0234	
6	1.0138	1.0164	1.0156
7	1.0072	1.0109	1.0097
8	1.0113	1.0177	1.0155
9	1.0112	1.0176	1.0155
10	1.0111		
11	1.0082		
12	1.0075		
13	1.0095	1.0157	1.0135
14		1.0157	
15	1.0093	1.0156	1.0133
16	1.0058	1.0121	1.0094
17	1.0058	1.0120	1.0093
18		1.0120	
19	0.9995	1.0058	1.0022
20	0.9972	1.0035	0.9982
21	0.9860	0.9923	0.9869
22	0.9858	0.9921	0.9867
23	0.9965	1.0027	0.9973
24	0.9965		
25	0.9956	1.0019	0.9963
26	0.9956	1.0018	0.9963
27	0.9955	1.0017	0.9962
28	0.9954	1.0016	0.9961
29	0.9954	1.0016	0.9961
30	0.9955	1.0018	0.9962
31	0.9955	1.0018	0.9962
32	0.9955	1.0018	0.9962
33	0.9954		
34	0.9955	1.0018	0.9962

Without DG

Bus is single phase

C)60% PEAK LOAD

The final case is that one which assumed the loads in various nodes as 0.6 of its peak value. Table VI represents result of simulation for 60%peak load.

TABLE VI
RESULT OF SIMULATION FOR 60% PEAK LOAD

	With DG	Without DG
Tap of LTC	1.02	1.03
Size of substation capacitor (kVar)	246	390
PF in substation	0.9697	0.9993
Power losses (kW)	5.59806	29.92189
Tap of Voltage Regulator (1)	0.9942	1.0107
Tap of Voltage Regulator (2)	0.9923	1.0033
Size of Capacitor1 (kVar)	0	0
Size of Capacitor2 (kVar)	0	0
QG1 (kVar)	52.4436	-
QG2 (kVar)	96	-
QG3A (kVar)	37.9446	-
QG3B (kVar)	20.9672	-
QG3 C(kVar)	36.8281	-
Voltage amplitude of DG1	1.01049	-
Voltage amplitude of DG2	0.99243	-
Voltage amplitude of DG3	0.99704	-

The voltage profile for this case has been presented in Table VII.

TABLE VII
VOLTAGE PROFILE FOR 60% PEAK LOAD

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0300	1.0300	1.0300
3	1.0299	1.0299	1.0299
4	1.0278	1.0281	1.0284
5		1.0281	
6	1.0254	1.0262	1.0265
7	1.0235	1.0247	1.0251
8	1.0127	1.0149	1.0155
9	1.0127	1.0149	1.0155
10	1.0126		
11	1.0104		
12	1.0099		
13	1.0122	1.0141	1.0148
14		1.0141	
15	1.0121	1.0141	1.0148
16	1.0111	1.0127	1.0133
17	1.0111	1.0127	1.0133
18		1.0127	
19	1.0093	1.0104	1.0108
20	0.9977	0.9979	0.9979
21	0.9893	0.9895	0.9895
22	0.9891	0.9893	0.9893
23	0.9975	0.9976	0.9976
24	0.9975		
25	0.99709	0.99712	0.99709
26	0.99708	0.99711	0.99708
27	0.99703	0.99703	0.99703
28	0.99699	0.99696	0.99698
29	0.99699	0.99695	0.99697
30	0.99702	0.99708	0.99700
31	0.99697	0.99705	0.99697
32	0.99697	0.99705	0.99697
33	0.99694		
34	0.99697	0.99704	0.99697

With DG

No	Va	Vb	Vc
1	1.0300	1.0300	1.0300
2	1.0298	1.0299	1.0298
3	1.0295	1.0296	1.0296
4	1.0242	1.0251	1.0249
5		1.0251	
6	1.0181	1.0200	1.0194
7	1.0132	1.0159	1.0151
8	1.0117	1.0163	1.0148
9	1.0116	1.0162	1.0148
10	1.0116		
11	1.0093		
12	1.0088		
13	1.0103	1.0149	1.0133
14		1.0148	
15	1.0102	1.0147	1.0132
16	1.0076	1.0121	1.0102
17	1.0076	1.0121	1.0102
18		1.0121	
19	1.0029	1.0074	1.0049
20	0.9967	1.0012	0.9974
21	0.9883	0.9928	0.9890
22	0.9882	0.9927	0.9888
23	0.9962	1.0006	0.9968
24	0.9962		
25	0.9955	1.0000	0.9960
26	0.9955	0.9999	0.9960
27	0.9954	0.9998	0.9959
28	0.9954	0.9998	0.9958
29	0.9954	0.9998	0.9958
30	0.9955	0.9999	0.9959
31	0.9954	0.9999	0.9959
32	0.9954	0.9999	0.9959
33	0.9954		
34	0.9954	0.9999	0.9959

Without DG

Bus is single phase

Comparison between results achieved by using GA in the above mentioned problem and those found by other investigations [3] shows the high accuracy and applicability of GA optimization algorithm in Volt/Var control in distribution network incorporating DGs and control devices.

In tables II, IV and VI, comparison of system losses between pre and post installation of DGs is shown. After, installation of DGs, since they reduce the line current flow, the system losses in each load level is reduced. For example, for 60% peak load, DGs are caused power losses in distribution system decrease from 29.92189kW to 5.59806 kW. As can be seen Distributed generation placement affects on active and reactive power flows, so if they are placed at suitable locations, power losses can be decreased enormously.

Also, the results of these tables show that in peak and %80 peak load cases, only phase B of third DG could be considered as PV node in Volt/Var control process. On the other hand, it is necessary that these DGs be operated in theirs maximum reactive powers to obtain minimum losses in these cases.

Comparison of voltage profile between pre and post installation of DGs for load variation has been shown in tables III, V and VII. The results show that imbalance has been reduced when we have used DGs.

IX. CONCLUSION

Since number of DGs is increasing and also DGs affect voltage and reactive power control, it is necessary, that impact of DGs on Volt/Var control be studied. This paper presented an efficient algorithm for Vol/Var control in distribution with DGs. In the three phase unbalanced power flow calculation while modeling the local controllers of devices, the distribution system components are modeled by their equivalent circuits in terms of inductance, capacitance, resistance and injected current. DGs can be modeled as PV or PQ nodes. In this paper whilst DGs were modeled as PV nodes, an approach was presented to model of them. Genetic algorithm is used to obtain the solution of the optimization problem. By using this algorithm the performance of IEEE 34 bus radial test feeders when DGs existed or not existed was analyzed and it has been shown that while the system losses decreased enormously in the case of existence of DGs, imbalance of voltages have improved. So it is revealed that by proper placement of DGs and using appropriate controller for them, it is possible to have much better control for Volt/Var in network along with decreasing the system losses in network.

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XI. BIOGRAPHIES

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