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Coordinated voltage control in 3 phase unbalanced distribution system with multiple regulators using Genetic Algorithm

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Abstract

The continued interest in the distributed generation in recent years is leading to a number of generators connected to distribution network. The introduction of DG in the distribution system changes the operating features and has significant technical impact. One of the main obstacle for high DG penetration in the distribution feeder is the voltage rise effect. Present network design practice is to limit the generator capacity to a level at which the upper voltage limit is not exceeding; this reduces the efficiency of DG system. This paper presents an efficient algorithm for voltage control in 3 phase unbalanced system with multiple voltage regulators. The genetic algorithm is successfully applied on 13 bus unbalanced radial system for different load conditions to control the voltage level. The voltage profiles are improved & are within the specified limits with optimal setting of voltage regulators like Load ratio transformer (LRT), Static Var Compensator (SVC), Shunt Capacitor (SC) and DGs reactive power for providing smooth voltage profiles at all the load conditions.

Keywords: Distribution system, Distributed Generators, Voltage Control, Genetic Algorithm, Fuzzy cluster, Voltage Regulators;

1. Introduction

The problems of global warming and exhaustion of fossil fuels have seen an increase in the usage of distributed generation, such as clean natural energy generation, cogeneration system of high thermal efficiency, and many others in recent years. Many of the distributed generations are set up in the vicinity of the customer, and there is an advantage that this decreases transmission loss, has a short period of

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construction and low investment risk [1,4]. DG is expected to play an increasing role in emerging power systems. Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG, such as wind turbines, photovoltaic, fuel-cells, biomass, micro turbines, small hydroelectric plants, etc. Its impact on distribution systems may be either positive or negative depending on the system's operating condition DGs characteristics and location. The potential positive impacts are improving system reliability, loss reduction, and deferment of new generation and improving power quality. To achieve these benefits, DG must be reliable, dispatchable, of appropriate size, and at suitable locations. More important, DGs should be properly coordinated with protection systems [2,5]. The penetration of DG in the distribution system changes the power flow configuration in the traditional network of electric power distribution system from unidirectional to multidirectional system. The introduction of DG in the distribution system changes the operating features and has significant technical impacts. One of the main obstacles for high DG penetration in the distribution feeder is the voltage rise effect which can be rectified by the selection of appropriate size and number of DGs [3,6].

Voltage control is one of the important control scheme at a distribution substation, which conventionally involves regulation of voltage and reactive power at substation bus. The voltage control can be achieved by Load Ratio Transformer, Static Var Compensator and Shunt Capacitors. In this paper, we will analysis the impacts of distributed generators on the voltage profiles of distribution systems. To regulate voltages, suggested to use SVCs and Shunt Capacitors in distributed systems for controlling the voltage. Both SVCs and SCs are fast devices for providing reactive power. They are able to regulate the fast voltage changes due to interconnection of DGs to the system. SVCs can control line flows efficiently and regulate voltages continuously. The LRT and reactive power of distributed generators are also used for the voltage control with SVC & SC. In this effort Genetic algorithm is used for optimal setting of voltage regulators and it is simulated to verify on IEEE 3 phase 13 bus unbalanced radial distribution feeders.

2.0 Genetic Algorithm

Genetic Algorithms (GAs) are adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems. It is better than conventional AI in that it is more robust. The GA initiates the optimization search by exploiting the information contained in the initial random population and exploring information contained in the offspring of the next generation, that are generated through genetic operations[9]. By means of this selection process, it is highly probable that it eventually settles near to an optimal solution. GAs may be an alternative way of solving the problem. GAs do not require linearity, continuity, differentiability of the objective function, nor do they need continuous variables. These two features make Gas particularly effective in dealing with discrete control devices such as tap changing transformers and with objectives such as minimal number of control actions

In this paper, GA is applied to calculate the optimal setting value of voltage regulator required to voltage control on an unbalanced radial distribution system under various load conditions and keeping the voltages at all the nodes within the limits. The Algorithm for GA based voltage control is given below:

Step 1. Generate the initial population
Step 2. Run the load flow.
Step 3. Check the constraint value, if it is within the limits, stop the process.
Step 4. If the limits are violated, modify the population &
Step 5. Run the load flow and repeat the steps 3 & 4

3.0 Fuzzy Clustering

Fuzzy Clustering is an iterative clustering technique that produces an optimal c partition by minimizing the weighted within group sum of squared error objective function. Fuzzy clustering helps us to find the necessary number of prototypes (2 in our case) out of the set of vectors (13 load profiles) available [10]. We have specifically used Fuzzy Clustering Algorithm because,

1. The method allows us to identify the centroids or prototypes of the clusters defined.
2. The method associates to each load profile a membership value to each cluster, represented to each centroid. This makes fuzzy clustering more natural than hard clustering.

The Load-profiles along 13 buses can be treated as a 13 dimensional vector. Our objective is to find 2 cluster centres from 13 data-points.

1. Algorithm starts with a initial guess for the cluster centre.
2. Each data-point is allotted a membership function.
3. By iteratively updating the cluster centres and the membership grades for each data point, cluster centre is moved to the right location within a data set.
4. The iteration is based on minimizing an objective function that represents the distance from any given data point to a cluster centre weighted by that data point's membership grade.

4.0 Results and Discussions

The 5000 kVA, 4.6 kV, 3 phase,13 bus unbalanced radial system is shown in Fig 1 is used for the simulation. The line and load data for the system are taken from [11] and given in the Appendix. The voltage regulator LRT is connected near substation and SVC, SC with the rating 0.1 & 0.05 p.u. respectively are connected. The two DGs are connected at bus no 8 and 13 with active power of 0.12 p.u. and reactive power of 0.06 p.u. The GA control parameters, Generation and population are 20 & 100 respectively. The different load patterns are taken for the study. 1(a) considering peak load & 80% load. 1(b) considering fuzzy cluster load pattern, load 1 & load 2.

The objective function of GA used for the study is $\sum_{m=1}^{n} | V_{mref} - V_m |$, where V_{mref} is mth node voltage standard value, V_m is mth node voltage.

Constraint conditions: Node voltage: $V_{\min} < V_i < V_{\max}$; Reactive power of DG: $Q_{\min} < Q_i < Q_{\max}$; Tap position: $T_{\min} < T_i < T_{\max}$

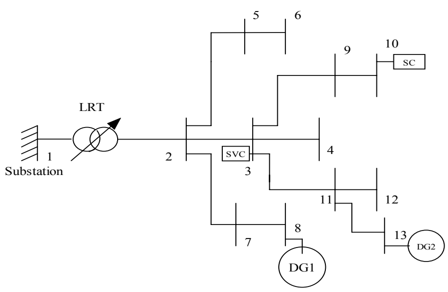

Fig 1. Three phase 13 bus radial distribution system

Case study 1(a): Voltage profiles for 100% & 80% load**:**

Voltage profiles for the system with 100% load without and with voltage control as shown in the Figs 2 & 3. Fig 2 shows the voltage profile of the system when DGs are connected to the system, there is a raise in voltage, the voltage profile of the phase b is crossing the upper limit 1.05 p.u. & other two phase voltages are within the limits. Fig 3 shows the voltage profile for the system with voltage control using voltage control devices, it can be seen that all the phase voltages are within the limits (0.95p.u-1.05 p.u).

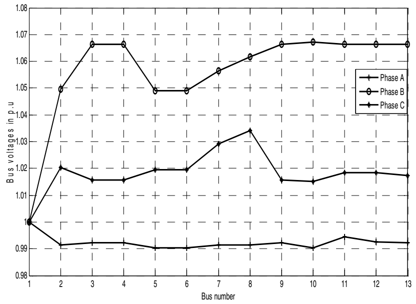

Fig.2 without voltage control for 100% load

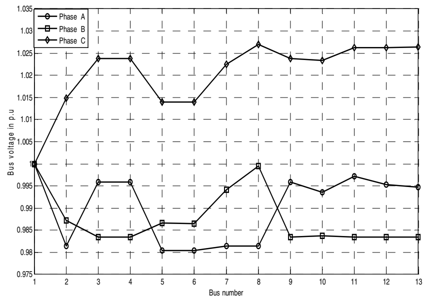

Fig 3 with voltage control for 100% load

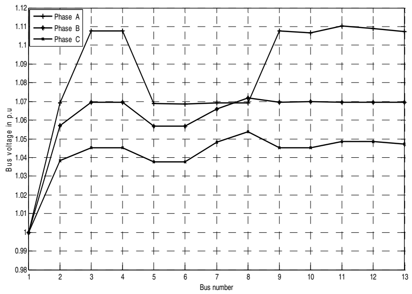

Fig 4 without voltage control for 80% load

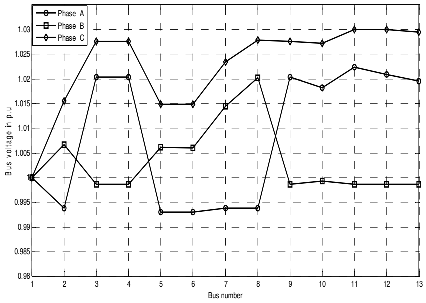

Fig 5 with voltage control for 80% load

Fig 4 shows the voltage profile of the system with DGs connected and 80% load without control. It can be seen that all the phase voltages have crossed the upper limit. The voltage profile for the system with voltage control and 80% load can been seen in the Fig 5. All the phase voltages are within the limits. The optimal setting values of the voltage regulating devices for both 100% & 80% loads are given in the Table 1.

Table 1.optimal setting values of the voltage regulating devices

Different load conditions	Voltage control devices setting values								
	LRT Phase A	LRT Phase B	LRT Phase C	SVC Phase A	SVC Phase B	SVC Phase C	DG_1 Reactive power		
							Phase A	Phase B	Phase C
100%	0.96	0.96	0.98	-0.07	0.04	0.05	0.049	0.06	0.04
80%	0.95	0.97	0.98	-0.04	-0.00	-0.00	0.050	0.06	0.06

Different load conditions	Voltage control devices setting values					
	SC Phase A	SC Phase B	SC Phase C	DG_2 Reactive power Phase A	Phase B	Phase C
100%	OFF	OFF	ON	0.017	0.035	0.033
80%	OFF	OFF	OFF	0.017	0.023	0.03

Case study 1(b): Considering fuzzy cluster load patterns.
Two sets of load pattern is generated using fuzzy cluster by considering the load data used for 100% load in the previous simulation. These two sets of load pattern are used for the simulation.

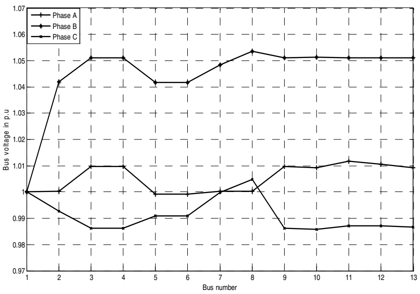

Fig 6 without voltage control for fuzzy load pattern 1

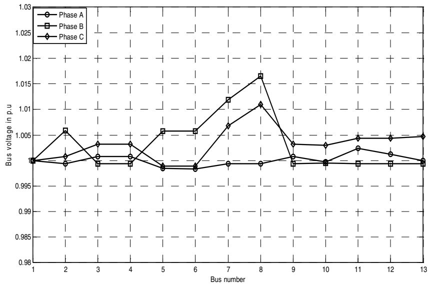

Fig 7 with voltage control for fuzzy load pattern 1

Fig 6 & 7 shows the voltage profiles of the system for the fuzzy cluster load pattern 1with & without voltage control. The voltage profile for the system, when DGs are connected to the system can be seen in the Fig 6, the voltage of phase a is above the upper voltage limit. It can be seen in the Fig 7, all the node voltages has been controlled in all the phases.

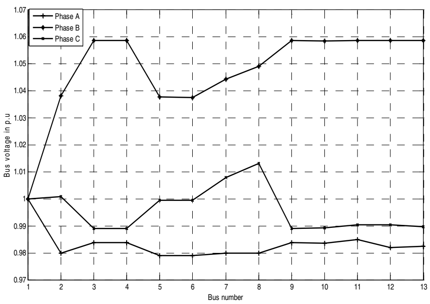

Fig 8: Without voltage control for fuzzy load pattern 2

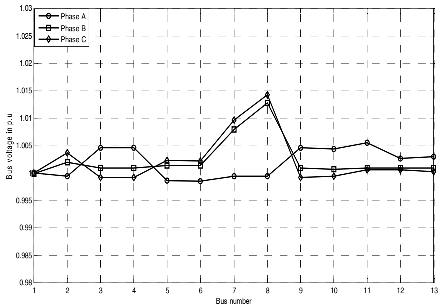

Fig 9: With voltage control for fuzzy load pattern 2

Similarly, Fig 8 & 9 shows the voltage profile for the system with fuzzy load pattern 2, with DGs connected & without voltage control & with voltage control respectively, It can be seen from the Fig 8,the phase b voltage is violating the upper limit after DGs connected & it is mitigated effectively as seen in the Fig 9 . The setting value of the voltage control devices for the fuzzy load pattern 1 & 2 is given in the Table 2.

Table 2.Optimal setting values of the voltage control devices for the fuzzy load pattern.

Different load conditions	Voltage control devices setting values						
	LRT	LRT	LRT	SVC	SVC	SVC	DG_1 Reactive power

	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Fuzzy load pattern 1	1.0	0.99	1.0	0.03	-0.003	0.04	0.059	0.025	0.017
Fuzzy load pattern 2	1.01	1.0	1.0	0.08	-0.015	-0.009	0.059	0.06	0.043

Different load conditions	Voltage control devices setting values in p.u					
	SC Ph A	SC Ph B	SC Ph C	DG_2 Reactive power		
				Ph A	Ph B	Ph C
Fuzzy load pattern 1	OFF	ON	OFF	0.037	0.052	0.056
Fuzzy load pattern 2	OFF	ON	ON	0.058	0.031	0.06

Conclusions:

The optimal voltage control with different load for three phase 13 bus unbalanced system using GA control has been done. In this paper two case studies have considered to apply GA controller for voltage control, 1(a) Steady state load at peak load & 80% load , 1(b) Fuzzy cluster load pattern 1oad 1& load 2. .At all the loads, voltage has been controlled successfully using voltage control devices like LRT, SVC, SC & DGs reactive power with the optimal setting values. It can be concluded that the system performance can be improved under the proper voltage control.

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Appendix A. Load & Line Data of 3phase 13 bus ieee radial system

A1.3 phase 13 bus unbalanced load data

Bus no.	Pa	Qa	Pb	Qb	Pc	Qc
1	0	0	0	0	0	0
2	0.0017	0.001	0.0066	0.0038	0.0117	0.0068
3	0.077	0.044	0.077	0.044	0.077	0.044
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0.032	0.022	0.024	0.018	0.024	0.018
7	0	0	0.034	0.025	0	0
8	0	0	0.046	0.0264	0	0
9	0	0	0	0	0.034	0.0302
10	0.097	0.038	0.0136	0.012	0.058	0.0424
11	0	0	0	0	0	0
12	0.0256	0.0172	0	0	0	0
13	0	0	0	0	0.034	0.016

A2.Line Data

Branch no	Zaa	Zbb	Zcc
1-2	0.0379+0.1114i	0.0369+0.447i	0.0374+0.1133i
2-3	0.0379+0.1114i	0.0369+0.447i	0.0374+0.1133i
3-4	0.0724+0.0743i	0	0.0727+0.0737i
4-5	0.0206+0.0323i	0.0205+0.0328i	0.0203+0.033i
5-6	0.011+0.0020i	0.0011+0.0221i	0.0011+0.0020i
6-7	0	0.0364+0.0369i	0.0362+0.0371i
7-8	0	0.0218+0.0221i	0.0217+0.0223i
8-9	0	0	0
9-10	0.0218+0.0122i	0.0216+0.0111i	0.0218+0.0122i
10-11	0.0218+0.0223i	0	0.0218+0.0122i
11-12	0.0588+0.0224i	0	0
12-13	0	0	0

Branch no	Zab	Zbc	Zca
1-2	0.0171+0.0549i	0.0168+0.0421i	0.0173+0.0406i
2-3	0.0171+0.0549i	0.0168+0.0464i	0.0173+0.0406i
3-4	0	0	0.0113+0.0251i
4-5	0.0043+0.0116i	0.0042+0.0105i	0.0043+0.0137i
5-6	0	0	0
6-7	0	0.0057+0.0126i	0
7-8	0	0.0034+0.0075i	0

8-9	0	0	0
9-10	0.0087+0.0009i	0.0087+0.0009i	0.0078-0.0004i
10-11	0	0	0.0034+0.0075i
11-12	0	0	0
12-13	0	0	0.0218+0.0221i

A3.3 phase 13 bus unbalanced fuzzy cluster load pattern 1

Bus no.	Pa	Qa	Pb	Qb	Pc	Qc
1	0	0	0	0	0	0
2	0.0164	0.039	0.0255	0.0367	0.0455	0.0100
3	0.0063	0.033	0.0164	0.0140	0.0286	0.0259
4	0.0228	0.0148	0.0191	0.0381	0.0259	0.0183
5	0.00855	0.0189	0.0240	0.0362	0.0103	0.0231
6	0.0354	0.0226	0.0074	0.0321	0.0178	0.0335
7	0.0306	0.0442	0.0308	0.0249	0.0286	0.0251
8	0.0347	0.0132	0.0082	0.0302	0.0308	0.0100
9	0.0088	0.0364	0.0438	0.007	0.0188	0.0240
10	0.0334	0.0248	0.0360	0.0133	0.0272	0.0137
11	0.0262	0.0190	0.0257	0.0302	0.0407	0.0321
12	0.0432	0.0117	0.0255	0.0097	0.0121	0.0381
13	0.0327	0.02218	0.0093	0.0077	0.033	0.032

A 4. 3 phase unbalanced fuzzy cluster load pattern 2

Bus no.	Pa	Qa	Pb	Qb	Pc	Qc
1	0	0	0	0	0	0
2	0.0278	0.0108	0.02521	0.01018	0.02551	0.04275
3	0.00851	0.0405	0.0167	0.0405	0.01245	0.01191
4	0.0109	0.0329	0.0301	0.0329	0.0313	0.0384
5	0.0172	0.0236	0.0387	0.0236	0.0385	0.0263
6	0.0382	0.0186	0.01542	0.0186	0.0160	0.0452
7	0.01617	0.0219	0.0284	0.0219	0.0283	0.008
8	0.0369	0.0108	0.018	0.0108	0.0178	0.0223
9	0.0136	0.020	0.0257	0.020	0.0317	0.0068
10	0.0454	0.008	0.0365	0.008	0.033	0.043
11	0.019	0.008	0.0319	0.0089	0.024	0.0039
12	0.0134	0.0158	0.0248	0.0158	0.0329	0.0368
13	0.016	0.024	0.035	0.024	0.037	0.036