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Genetic Algorithm Based Optimal Volt/Var Control of Distribution Systems with Distributed Generation

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ABSTRACT

In this paper, new voltage regulation algorithms have been proposed for Distribution System (DS) equipped with Distributed Generation (DG). Due to the ever increasing power demand, the power system sector is facing too many challenges to fulfill that demand and also to supply power with proper acceptable quality. Distributed generation is one of the most efficient solutions to meet the increasing demand. When integrated with the grid, it has its own technical as well as economical impacts. One of the critical areas of major concern resulting from the integration of DG into the DS is the voltage/reactive power (volt/var) control. Normally, loads are modeled as a constant power load model. But, in reality, loads are voltage dependant. The first part of this paper proposes new voltage regulation methods in a radial distribution system with voltage dependant loads (VDLs) along with DG. Better and accurate results can be expected by including VDLs. The second part of the paper presents Genetic algorithm (GA) based optimal volt/var control in a DS with DG. The GA based method has been used to find optimal set points of volt/var control equipments in the DS with DG. The simulation results have been found to be promising. This work can be a major step towards distribution system automation, which is one of the primary targets of power sector.

Keywords: *Algorithm, distributed generation, distribution system, genetic algorithm, line rise compensation, line drop compensation, step voltage regulator, voltage dependant loads, voltage regulation*

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INTRODUCTION

The conventional arrangement of a modern large power system has centralized generation with large generating units, high voltage (HV) transmission, and a number of distribution networks. The Distribution Networks (DNs) are designed for unidirectional flows of power and sized to accommodate customer loads only. Over the last few years, some issues such as promoting reduction in gaseous emissions, rational use of energy, deregulation policy, diversification of energy sources, national power requirement, liberalization of electricity markets, peak use capacity, alternatives to expansion, or use of the local network have prompted the use of Distributed Generation (DG). The DG comprises embedding of small generators of capacity ranging from 10 kW to 50 MW in a Distribution System (DS), scattered throughout the power system to provide electric power needed by consumers, thereby displacing the need to build additional infrastructure or upgrade local distribution lines as well as improving the system performance [1]. DG can provide benefits to the consumers as well as to the utilities in a DS.

Some of the major technical impacts of DG on the DS include change in the voltage profile, power losses, islanding, issues related with power quality, and system reliability [2, 3]. If properly interconnected, DG is a viable alternative to the electric power industry's future. The introduction of DG into the DS makes the voltage profile complicated and reversal of power flow [4]. This makes the operation of a radial DS complicated. In this paper, voltage regulation, which is the first and foremost important impact of DG on the DS, has been considered. DS voltages, if within the ANSI C84.1–1995 limits, need less attention, but when they exceed the prescribed limits proper means must be provided to control the voltage so as to bring them within the limits [2, 4, 5].

In the literature, many load flow and voltage regulation methods are addressed. Haque [6] has proposed a new load flow method applicable for both mesh-connected as well as radial-connected distribution system. Lee et al. [7] have presented a visual power distribution load flow simulator using a graphic user interface, which can work for either injection or rejection of DG to or from a DS. Rao and Deekshit [8] have proposed a load flow for a radial distribution system having common types of voltage control devices along with DG sources. Kim and Kim [9] have addressed the voltage regulation coordination method of DGs in a power distribution system by controlling the reactive power of the DGs. Gonen [10] has illustrated the line drop compensator voltage regulation method. Kim and Kim [11] have developed correlations between the load tap changing transformer (LCT), LDC, and the output of DG. Choi and Kim [12] have presented multiple LDC voltage regulation methods considering dispersed storage generation systems and unbalanced load diversity. Scott et al. [13] have proposed a load control method to tackle voltage rise issues due to embedded generation.

The constant power load model has been considered in the majority of previous works. Actually, load is voltage dependant in a real system. By including voltage-dependant loads (VDLs), better results can be expected. This paper deals with the modeling of VDLs, generators (i.e., synchronous generator and/or induction generator), volt/var control equipments like Step Voltage regulator (SVR) and SVR with Line Rise Compensation/Line Drop Compensation (LRC/LDC) function. The load flow technique considered is capable enough to cope with the situation arising due to the introduction of DG, VDL, and new voltage regulation equipments. In this study, the voltage regulation by SVR and SVR with LRC/LDC function has been addressed for a radial distribution system with DG and VDLs. For this purpose, two algorithms have been developed. With these methods, voltage profile of the DS has improved and losses have reduced.

Voltage/Reactive Power (volt/var) control task is an optimization problem. Niknam et al. [14] have proposed volt/var control in the DS with

DG using conventional Genetic Algorithm (GA). In this work, single objective function has been considered. Nerves and Savet [15] have presented volt/var control in a DS using dynamic programming approach. Batrinu et al. [16] have considered time varying loads and used nested evolutionary programming for solving the voltage control problem in a DS. However, this approach requires high computational burden even for a small test system.

In this paper, GA based approach is proposed to find the optimal set points of different volt/var control units. GA approach has been used due to its broad applicability, ease of use and high accuracy. In this approach, initially, the multi-objective optimization problem is converted into a single-objective optimization problem by using weightage factors and GA is used to solve this single-objective optimization problem. Using this approach, optimal set points like resistance setting of the LRC/LDC, reactance setting of the LRC/LDC, reactive

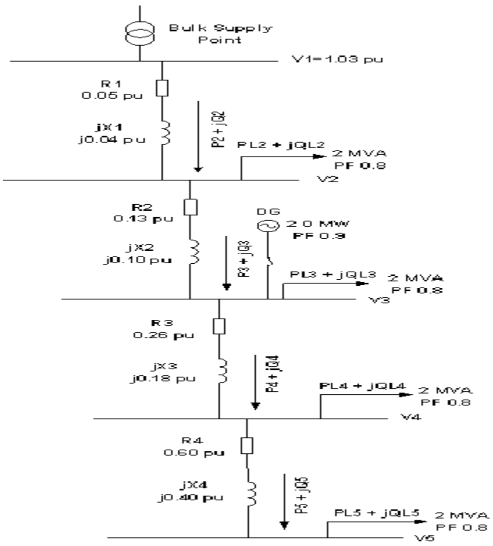

Fig. 1 Radial Distribution Network.

power output of the DG, and tap position of the SVR are found.

The key issues in volt/var control problem of a distribution system with DG includes:

(i). Improvement of voltage profile: Since introduction of DG makes the voltage profile complicated and affects the power quality, deviation of the voltage in each node from a certain reference voltage is considered as an indicator to quantify voltage profile improvement. Therefore, minimization of the voltage deviation is considered as one of the objective functions.

(ii). Network loss reduction: DG causes reverse power flow in the network and alters the power flows, thereby affecting the DS operation and economy. Hence, minimization of the losses is also considered as objective function.

Minimization of voltage deviation alone cannot minimize the losses. Therefore, in this paper, both the objective functions are considered for minimization to formulate the proposed multi-objective optimization problem.

PROBLEM FORMULATION AND METHODS ADOPTED

Method 1

Let's consider the voltage regulation of the radial distribution system shown in Figure 1 with DG and VDLs.

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The solution is obtained in two steps. In the first step, modeling of volt/var control equipments in a DS along with DG is considered and in the next step, distribution system power flow is carried out and voltage regulation is achieved using SVR. Modeling of different equipments such as DG, SVR, and different loads of the test DS is done. DG can be modeled as either PQ node or PV node depending on the mode of control. In the analysis to follow, the DG is modeled as a PQ node. SVR is modeled as an autotransformer with individual taps on its winding. Loads have been considered as voltage dependant. Constant power (CP), constant current (CC), and constant impedance (CI) load models are considered. The VDLs are modeled on the relation,

$$P = P_0 V^{\alpha} \quad (1)$$

$$Q = Q_0 V^{\beta} \quad (2)$$

Where P and Q are updated active and reactive load powers and α, β are constants. α, β are both assigned 0,1, and 2 for CP, CC, and CI loads respectively.

DS power flow is carried out to determine the steady state parameters and voltage profile of the test distribution system. Forward/backward sweep power flow method [17] is considered to accommodate DGs, voltage regulators, and different load models. The buses at which the voltages are out of statutory limits are identified. SVRs are used as voltage regulators. Voltage profile of the system is continuously monitored and voltage regulation is carried out until the voltages of all the buses are well within the statutory limits.

Method 2

In method 1, voltage regulation is carried out using SVR alone and in method 2, the voltage regulation is carried out using SVR with LRC/LDC function. The solution is obtained in two steps. The modeling of volt/var control equipments in a DS connected to a DG is considered in the first step, and in the next step, load flow is carried out and voltage regulation is achieved using SVR with LRC/LDC function. In this method also, DG is modeled as PQ node. SVR with LRC/LDC function is modeled as an autotransformer with individual taps on their winding and with variable resistance and reactance elements.

The VDLs are modeled on the relations, (1) and (2) given earlier. The steady state parameters and the voltage profile of the test DS are determined by adopting the forward/backward sweep power flow method [17]. The buses at which the voltages are out of statutory limits are identified. SVR with LRC/LDC function is used as voltage regulator. The voltage profile of the system is continuously monitored and voltage control is done until the voltages of all the buses are well within the statutory limits.

VOLT/VAR CONTROL

Principle of Voltage Regulation

SVRs are autotransformers with individual taps on their windings. This equipment modifies tap position when there is a difference between a reference voltage and calculated or measured voltage. SVRs are normally designed with 32 steps to regulate the voltage in the range ± 10%. This is equal to a voltage of 0.625% per step. It can be operated in step-up or step-down mode. The secondary voltage is given by $V_s = V_p \pm 10\%$.

A SVR installed in the feeder regulates the network voltage with the LRC/LDC function. LRC/LDC is a technique to mitigate the voltage rise/voltage drop on a bus in a DN by improving the voltage profile of DN buses with DGs connected to them or when the local load is high.

Algorithm of Voltage Regulation Using Method 1

Step-5 Check for the limits:

$$|V_s^{\min}| \le |V_s^k| \le |V_s^{\max}|$$

Step-6 f Vs is greater than the maximum limit, set Vs to the maximum limit and calculate the new tap position and fix it to the nearest lower tap position.

Step-7 If Vs is lower than the minimum limit, set Vs to the minimum limit and calculate the new tap position and fix it to nearest higher tap position.

Step-8 Check for the maximum/minimum limits of tap positions. If these exceed, fix the tap positions to the limits and recalculate Vs with the new tap position.

Step-9Update the powers using the voltages to include the effect of VDLs and continue with the load flow.

Step-10Repeat the above steps from step 3 until the voltages (at each bus) are within the limits. Display the results.

Step-11 Stop.

Note: A voltage limit of ± 5% is used in this study.

Algorithm of Voltage Regulation Using Method 2

The flow chart for the voltage regulation using SVR with LRC/LDC function is given in Figure 3 and the algorithm for the same is discussed as follows.

ALGORITHM

Step-1 Start.

Step-2 Initialize Tap position of the regulator to zero. Select proper α, β values as given in relations (1) and (2) of section 2.1 to accommodate VDLs, i.e., CP, CC, and CI. Initialize resistance setting Rset and reactance setting Xset values of LRC/LDC.

The flow chart for the voltage regulation of the DS using SVR is given in Figure 2. The algorithm is discussed as follows:

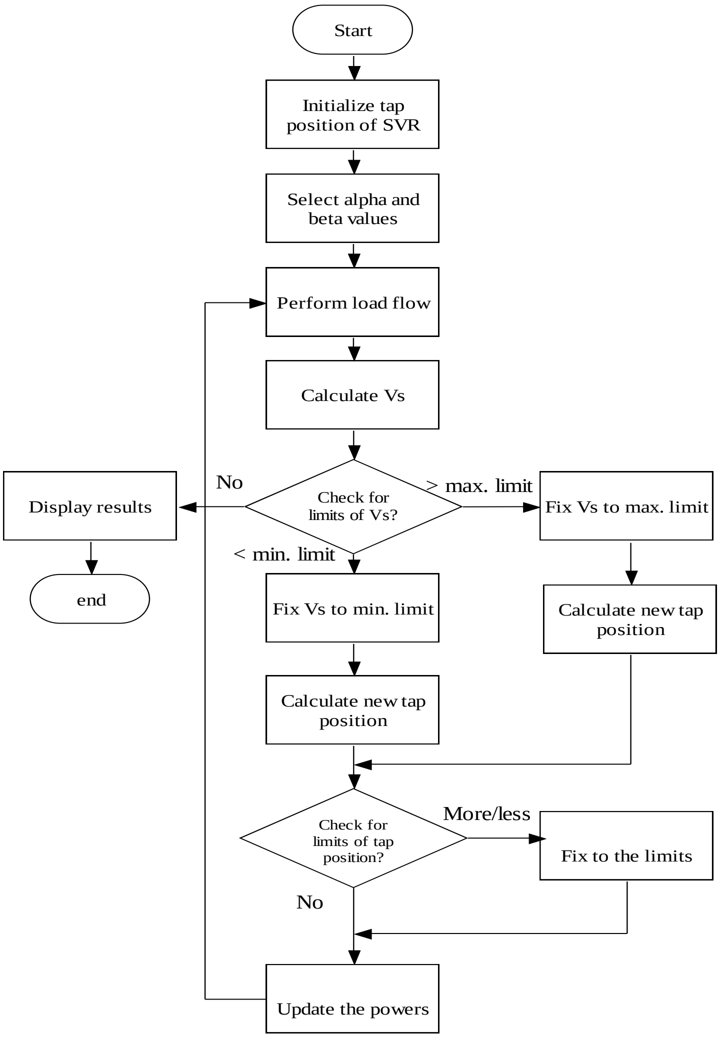


Fig. 2 Flow Chart of Voltage Regulation Algorithm–Method 1.

ALGORITHM

Step-1 Start.

Step-2 Tap position of regulator is initialized to zero. Select proper α, β values as given in relations (1) and (2) section 2.1 to accommodate VDLs, i.e., CP, CC, and CI.

Step-3 Run the forward and backward sweep load flow.

Step-4 Using the tap, R_{set}, X_{set} and line current values, calculate the secondary voltage (V_s) of the SVR.

Step-5 Check for the limits:

Step-3 Run the forward and backward sweep load flow.

Step-4 Using the tap values, calculate the secondary voltage (V_s) of the SVR.

$$|V_s^{min}| \leq |V_s^k - J_s^k (R_c + jX_c)| \leq |V_s^{max}|$$

Where, R_c and X_c are resistance and reactance values calculated using R_{set} and X_{set} values of LRC/LDC using the relation, [10]

$$R_c = R_{set} \frac{PT_n}{CT_p} \qquad (3)$$

$$X_c = X_{set}\frac{PT_n}{CT_p} \quad (4)$$

Where, PT_n and CT_p are potential transformer turns ratio and rating of current transformer primary respectively. J_s is the secondary section current of the regulator.

Step-6 If V_s is greater than the maximum limit, set V_s to the maximum limit and calculate the new tap position and fix it to nearest lower tap position.

Step-7 If V_s is lower than the minimum limit, set V_s to the minimum limit and calculate the new tap position and fix it to nearest higher tap position.

Step-8 Check for the maximum/minimum limits of the tap positions. If these exceed, fix the tap positions to the limits and recalculate V_s with the new tap position.

Step-9 Update the powers using the voltages to include the effect of VDLs and continue with the load flow.

Step-10 Repeat the above steps from step 3 until the voltages (at each bus) are within the limits and display the results.

Step-11 Stop.

Note: A Voltage limit of ± 5% is used in this study.

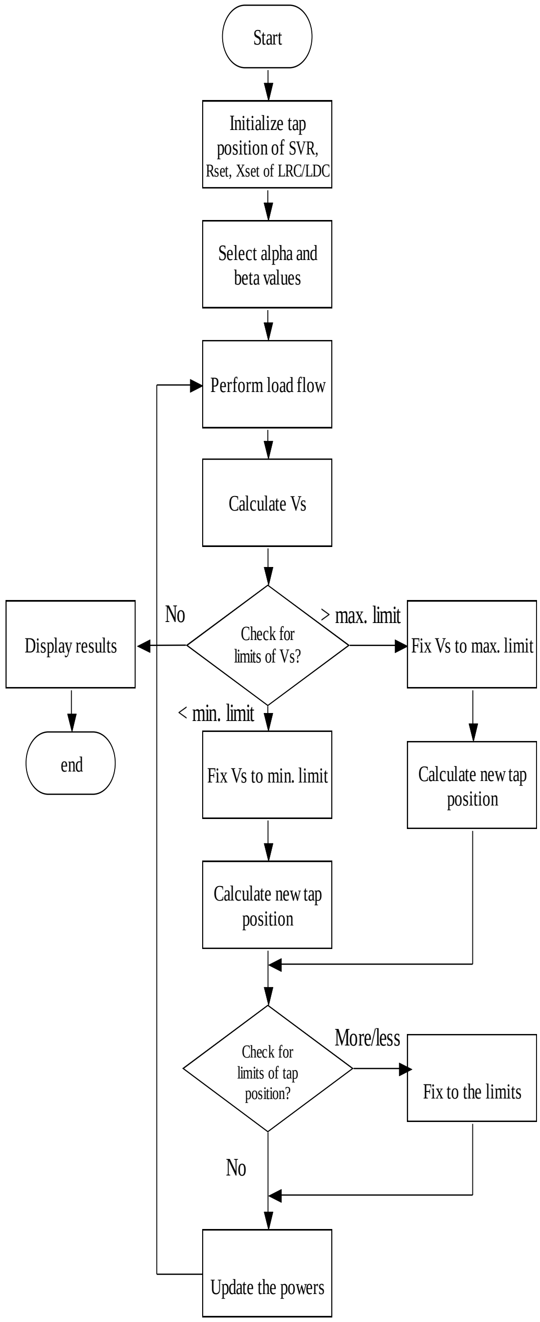


Fig. 3 Flow Chart of Voltage Regulation Algorithm–Method 2.

OPTIMAL VOLT/VAR CONTROL PROBLEM FORMULATION

Using GA, optimal volt/var control of a radial distribution network with DG is considered. SVR with LRC/LDC function is considered for the volt/var control. A multi-objective optimization problem is formulated and is converted into a single-objective function with proper weightage factors, and the optimal set points of volt/var control equipments are found.

Control Parameters

(i). Resistance of the LRC/LDC
(ii). Reactance of the LRC/LDC
(iii). Reactive power output of the DG
(iv). Tap position of the SVR

Objective Function

A multi-objective optimization problem has been formulated with the following objective functions.

(i). Minimization of the voltage deviation:

$$Min\ f_1 = \sum_{i=1}^{n} \left| V_i - V_{ref} \right|^2 \qquad (5)$$

Where n is the no. of nodes in the network considered and V_{ref} is the reference voltage.

(ii). Minimization of the losses:

$$Min\ f_2 = \sum_{j=1}^{m} loss_j \qquad (6)$$

Where m is the no. of branches (feeder segments)

CONSTRAINTS

(i). Voltage constraint: Bus voltages should be maintained within the permissible range.

$$v_{min} < v_i < v_{max} \qquad (7)$$

Where v_{min} is the minimum acceptable bus voltage, v_i is the voltage at ith bus and v_{max} is the maximum acceptable bus voltage.

(ii). Current constraint:Line currents should be maintained within the acceptable range

$$i_{min} < i_i < i_{max} \qquad (8)$$

Where i_{min} is the minimum acceptable line current, i_i is the current in the ith line and i_{max} is the maximum acceptable line current.

Overall Objective Function

Sum of the voltage deviations at each bus, sum of the losses in each branch, and total violation of voltage and current constraints are together considered to formulate the overall objective function**.** By assigning the weightage factors, the multi-objective optimization problem is converted into single-objective optimization problem.

$$Min\left(W_1 \sum_{i=1}^{n} \left| V_i - V_{ref} \right|^2 + W_2 \sum_{j=1}^{m} loss_j + W_3 g[V, I] \right)$$

where, g (V,I) total violation of voltage and current constraints. W_1, W_2, and W_3 are weightage factors.

Since the improvement of voltage profile is the primary objective of this work, the objective function of minimization of the voltage deviation is kept as the first preference and that of minimization of losses is given the second preference.

OPTIMAL VOLT/VAR CONTROL USING GA

Genetic Algorithm

GA, which is one of the evolutionary algorithms, is a search and optimization tool that works differently compared to classical search and optimization methods. GAs are a direct, parallel, and stochastic method for global search and optimization. GAs work with a set of individuals, representing possible solutions of the task.

The main ingredients of GA are chromosomes, selection, recombination, and mutation. It works with the process of generation of initial population, calculation of fitness function value, selection operation, crossover operation, mutation operation, and creation of new generation. In recent days, the GA approach has been used on various optimization problems due to its broad applicability, ease of use, global perspective, and high accuracy [18].

Scheme of Optimal Volt/Var Control Using GA

The flow chart of volt/var control algorithm using GA is given in Figure 4. The algorithm for optimal volt/var control is explained as follows:

ALGORITHM

Step-1 Start.

Step-2 Generate initial population – Select appropriate population size. The first generation is randomly selected with population size of 'N' individuals.

Step-3 Use appropriate weightage factors for the objective function considered as detailed in section 4.4.

Step-4 Perform the load flow on the test Radial DS with DG under consideration.

Step-5 Identify the buses at which the voltages are out of statutory limits.

Step-6 Perform the voltage regulation using SVRs with LRC/LDC.

Step-7 Calculate the values of the fitness function.

Step-8 Perform selection operation– individuals between population chosen to produce offspring population.
Elitism is used–best 'n' individuals directly transferred to the next generation**.** Elitism guarantees the value of the optimization function cannot get worst.

Step-9 Perform Crossover operation with proper crossover probability value-Individuals recombine with each other and new individuals created.

Step-10 Perform Mutation operation with proper mutation probability value–achieved by random change of some of the genes.

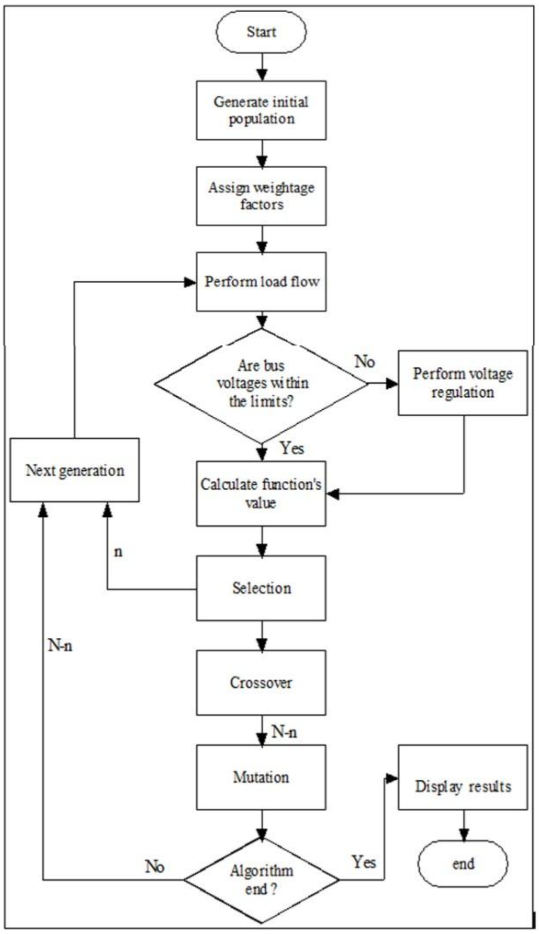


Fig. 4 Flow chart of volt/var control algorithm using GA.

Step-11 Check for the termination of the algorithm as per stopping criteria. If condition is met, display the results (i.e., optimal set points of volt/var control units considered as detailed in section 4.1) and stop or else increment generation count and go to step 4.

Step-12 Stop.

TEST SYSTEM AND SIMULATION RESULTS

The test system considered for this work has been shown in Figure 1 [19]. The parameters

TABLE I Test System Data.

Network data	
No. of buses	5
No. of branches	4
Voltage (V_1)	1.03 pu.
No. of load buses	4
No. of DGs	1
Location of DG	Bus no.3
DG details:	
P	20 MW
Pf	0.9 lagging
Q	9.686 Mvar
Base power S_{base}	100 Mva
Load size P_L Q_L	1.6 MW
	1.2 Mvar
Network voltage	11 kV

Simulation Results of Voltage Regulation

SVR and SVR with LRC/LDC voltage regulation methods are proposed to solve the volt/var control problem. The algorithms of the proposed methods are discussed in sections 3.2 and 3.3. A voltage statutory limit of ± 5% is used during simulation. Suitable resistance and reactance settings of LRC/LDC are used.

The voltage profile of the test DS without DG connected is shown in Figure 5. The voltage profile shows a continuous voltage drop towards the consumer end. When the DG is introduced into the system, the voltage profile is altered to a very large extent, which is shown in Figure 6. The voltages are clearly out of statutory limits in few buses. When the DG is connected to bus number 4, the voltages at buses 3, 4, and 5 are 1.061 pu, 1.11 pu and

1.102 pu respectively. When the DG is connected to bus number 3, the voltages at buses 3 and 4, are 1.065 pu and 1.052 pu respectively. In order to bring these voltages within the limits, the power of the DG has to be reduced to less than 50% which is not advisable.

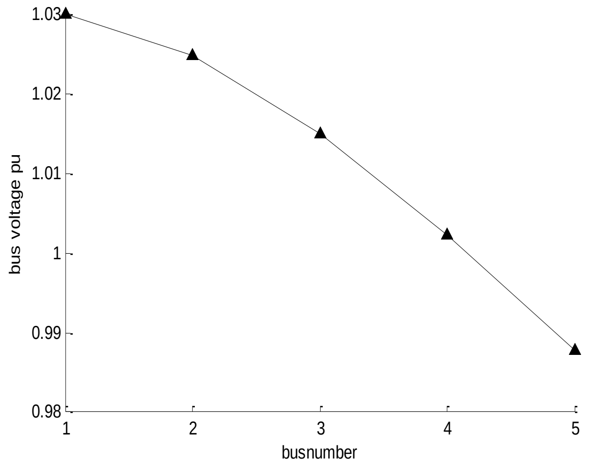


Fig. 5 Voltage Profile Without DG Connected.

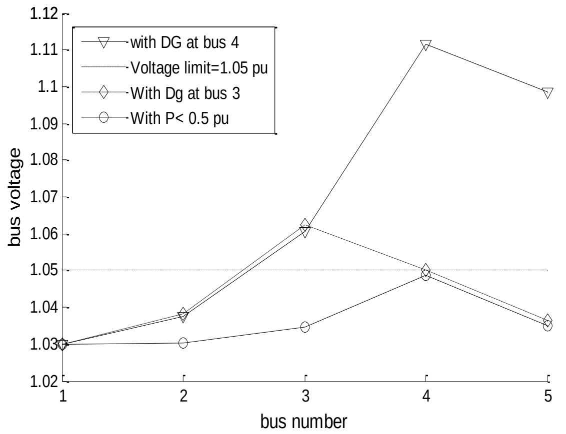
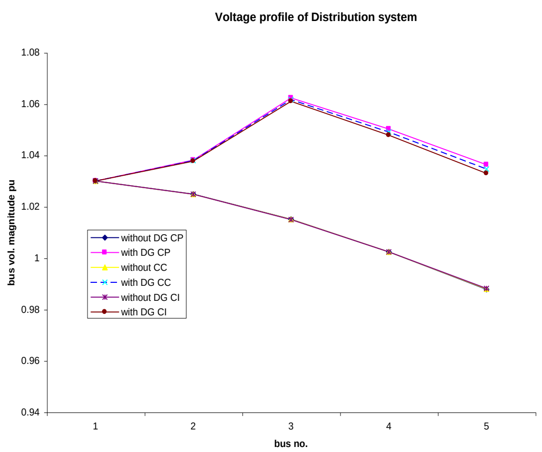


Fig. 6 Voltage Profile with DG Connected.

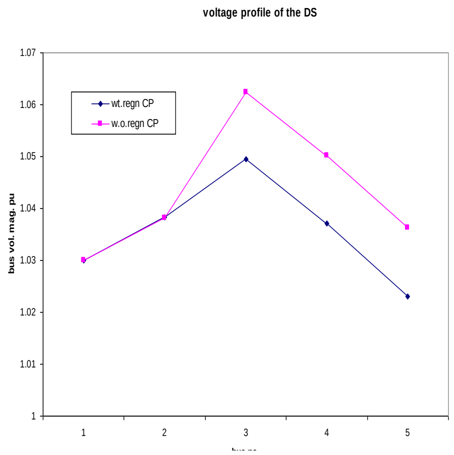
The voltage profile of the system depends very much on the type of load models. The effect of different load models considered in this work on the voltage profile of the system is shown in Figure 7. All the voltage profiles are within the margins when the DG is not connected. In all the models the voltages at buses 3 and 4 are outside the statutory limits when DG is connected to bus number 3. There is a marginal change in the voltage profile for each type of the load models.



Legends:
1. Without DG CP
2. With DG CP
3. Without DG CC
4. With DG CC
5. With DG CI
6. With DG CI

Fig. 7 Voltage Profile of DS Without Regulation.

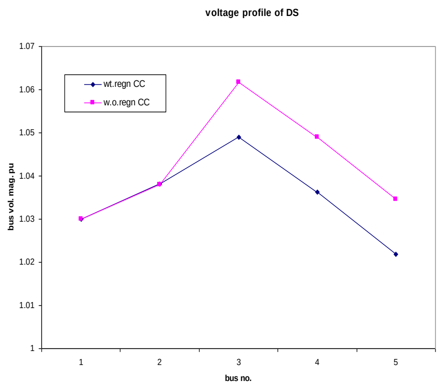
In order to bring the voltages at all the buses within the statutory limits, two algorithms are developed with SVR and SVR with LRC/LDC voltage regulation methods considering the effect of DG and VDLs. The simulation is carried out and the voltage profile is obtained for the test DS with DG connected and considering the load as CP. Using the algorithms proposed the voltage regulation is carried out and voltage profile is obtained for the same system with DG and CP load as shown in Figure 8. Similarly, the voltage profiles are obtained for CC and CI load models as shown in Figure 9 and Figure 10 respectively. With the proposed methods, the voltage profile of the system is improved and the voltage regulation is achieved by bringing the bus voltages within the limits.



Legends:

1. With regulation CP
2. Without regulation CP.

Fig. 8 Voltage Profile of Test DS with Regulation for CP.



Legends:

1. With regulation CC
2. Without regulation CC.

Fig. 9 Voltage Profile of Test DS with Regulation for CC.

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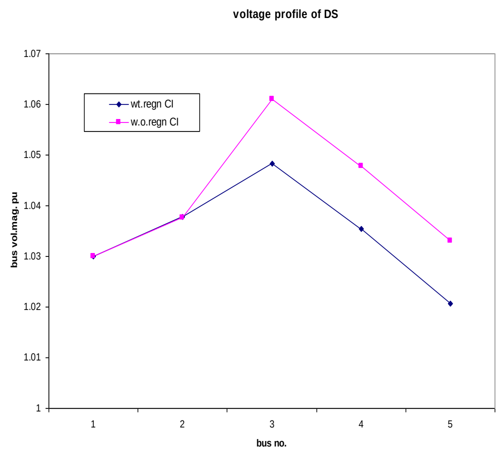
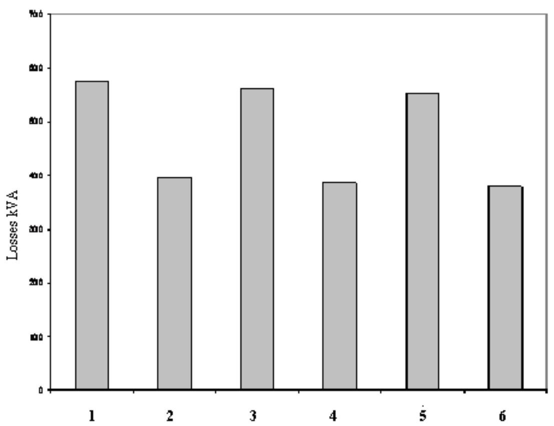


Fig. 10 Voltage Profile of Test DS with Regulation for CI.

Legends:
1. With regulation CI
2. Without regulation CI.

The losses of the test distribution system without regulation and with regulation for different load models are compared in Figure 11. The losses in kVA (including both kW and kVAR) for different load models are found to be 576 and 396 for the CP model, 564 and 387 for the CC model, 552 and 379 for the CI model, without regulation and after voltage regulation respectively. It is found that the losses are a minimum when the load is considered to be a constant impedance model.

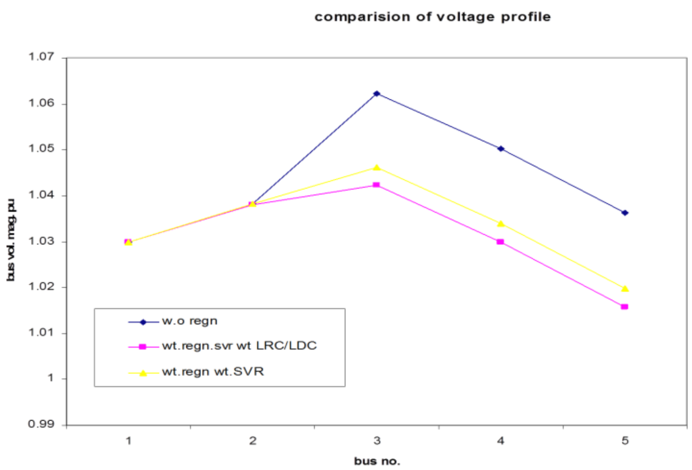


Captions:
1. Without regulation CP
2. With regulation CP
3. Without regulation CC
4. With regulation CC
5. Without regulation CI
6. With Regulation CI.

Fig. 11 Comparison of Losses of Load.

The voltage profiles of the test DS without regulation and with regulation by using method 1 (SVR alone) and method 2 (SVR with LRC/LDC) voltage regulation methods are compared in Figure 12. Although the voltage profiles are improved with both the proposed methods, the voltage profile with method 2 is found to be more accurate and promising than with the method 1 since the voltage profile variation is very less from source end to load end in the method 2.

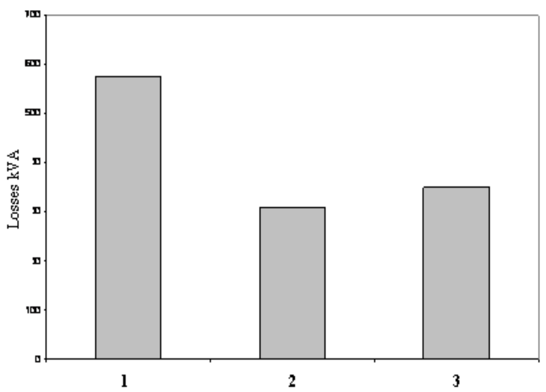
The voltage profiles of the test DS without regulation and with regulation by using method 1 (SVR alone) and method 2 (SVR with LRC/LDC) voltage regulation methods are compared in Figure 12. Although the voltage profiles are improved with both the proposed methods, the voltage profile with method 2 is found to be more accurate and promising than with the method 1 since the voltage profile variation is very less from source end to load end in the method 2.



Legends:
1. Without regulation
2. With regulation SVR with LRC/LDC
3. With regulation with SVR

Fig. 12 Comparison of Voltage Profiles.

The losses of the test DS without regulation and with regulation by using method 1 and method 2 are compared in Figure 13. The losses in kVA are found to be 576, 350, and 310 for the cases without regulation, with regulation by method 1 and with regulation by method 2 respectively. The losses are reduced with both the methods and are found to be minimum with the method 2 proposed in this work. So, it can be concluded that with method 2, losses are minimum and we get a better voltage profile. So method 2 is better than method 1.



Legends:
1. Without regulation
2. With regulation SVR with LRC/LDC
3. With regulation with SVR

Fig. 13 Comparison of Losses

Simulation Results of Optimal Volt/Var Control Using GA

The proposed methodology is applied on the distribution system shown in Figure 4. The control variables considered are as listed in section 4.1.

The objective function considered for this work is discussed in Section 4.4. In this work, the GA parameters with a population size 50, crossover probability 0.8, and mutation probability 0.1 are used. The algorithm proposed has been discussed in section 5.2. The value of the fitness function plotted against generations using the proposed method is shown in Figure 14. This approach takes less than 10 iterations to find optimal values.

Generationwise variation of different objective functions is plotted in Figure 15a. It is observed that the optimal values obtained are acceptable since there is no constraint violation. Tuning of weights is the key issue while solving the volt/var control optimization problems. If the weightage factors are not properly assigned, the solution obtained may not be the optimal one, which is evident from Figure 15b.

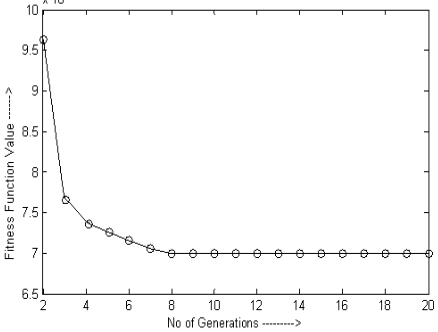


Fig. 14 Fitness Function versus Generation.

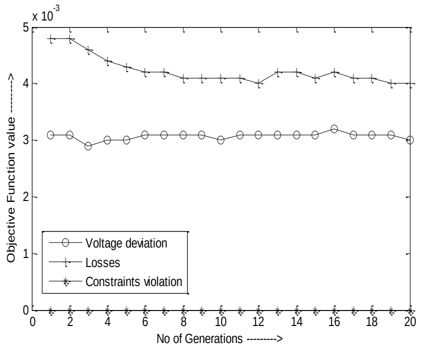


Fig. 15a Variation of the Objective Functions versus Generation.

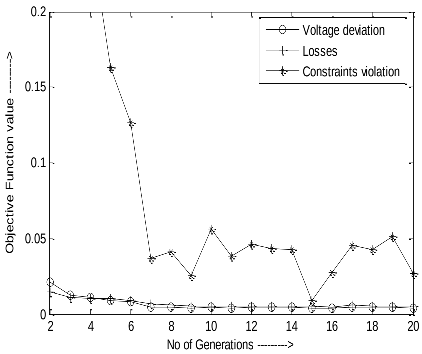


Fig. 15b Variation of the Objective Functions versus Generation (Effects of Weights).

It is observed from the Figures 14 and 15a that the optimal solution is obtained with proper assignment of the weightage factors. The tuned weightage factors are 1, 2, and 3 for W_1, W_2, and W_3 respectively. It is also observed from Figure 14 that the proposed method takes very few number of generations to converge.

Voltage profile of the test system with the proposed method is plotted in Figure 16. It is observed that with this method, the voltage profile is improved to a very large extent and the voltages at all the buses are well within the statutory limits.

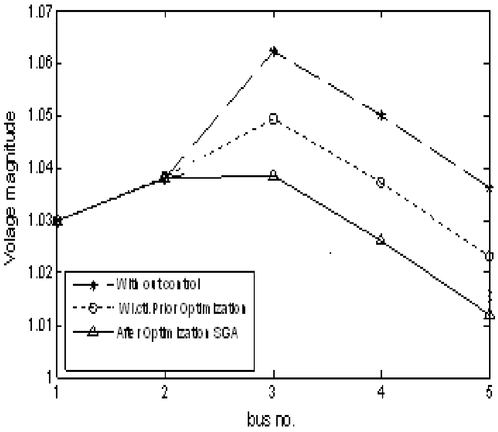


Fig. 16 Voltage Profile of the Test System.

The values of the objective functions without voltage regulation, with the voltage regulation prior to optimization, and optimization using (GA) weightage factors are compared in Table II. It is observed that with the proposed method, the values of the objective functions are optimal.

TABLE II Values of Objective Functions

	ΣVoltage deviation (pu)	**Total losses (kVA)**
Without control	0.0101	576.1
Prior to optimization	0.0091	537.1
Proposed method GA	0.0052	310.0
With only Voltage deviation	0.0050	390.0

The losses are found to be 390 kVA and 310 kVA by considering only the sum of voltage deviation alone and considering both voltage deviation and losses in the objective function respectively. Therefore, when the multi-objective functions are considered, the losses are less when compared to the objective function with voltage deviation alone and without losses is considered.

The sum of voltage deviations and losses are compared in Figure 17 and Figure 18 respectively. In Figure 17, voltage deviations of the test system for the cases without control, with control prior to optimization, and after optimization using GA are compared. In Figure 18, losses in kVA (including kW and kVAR) of the test system for the cases without control, with control prior to optimization, and after optimization using GA are compared. The sum of voltage deviations and losses are found to be 0.0052 pu and 310 kVA respectively with the proposed method. It is observed that with the proposed method, both sum of the voltage deviations and losses are minimized.

The optimal values of the control variables, resistance, and reactance settings of LRC/ LDC, reactive power output of DG, and tap position of SVR are found to be 0.29772 pu, 0.31494 pu, 0.09227 pu, and 3 respectively.

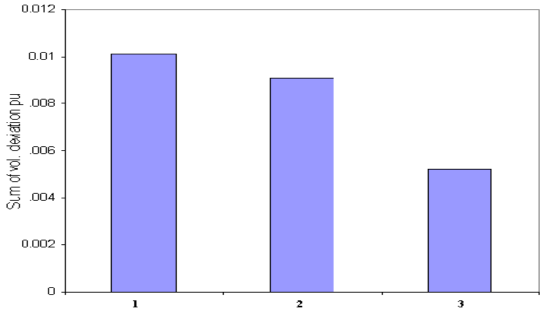


Fig. 17 Comparison of Sum of Voltage Deviations.

Captions:
1. Without control
2. With control prior to optimization
3. After optimization with GA

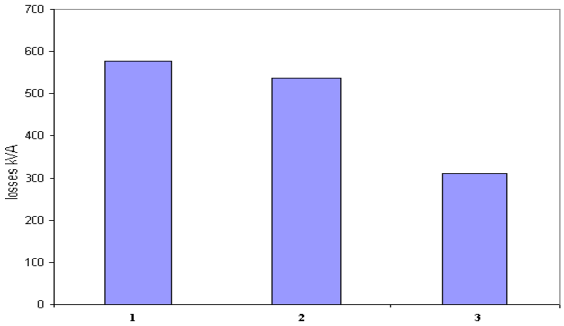


Fig. 18 Comparison of Losses.

Captions:
1. Without control
2. With control prior to optimization
3. After optimization with GA

CONCLUSIONS

Voltage regulation of a radial distribution system with a DG and with VDLs is considered in the first part of this paper. Two voltage regulation methods using SVR and SVR with LRC/LDC function are proposed for the volt/var control in a DS with a DG and with VDLs. With the proposed methods, the voltage profile of the test DS is improved and losses are decreased. The proposed methods are simple, effective, and easy to implement. The losses in kVA for different load models are found to be 576 and 396 for the CP model, 564 and 387 for the CC model, 552 and 379 for the CI model, without regulation and after voltage regulation respectively. The losses are found to be at minimum with CI load models. Since the variation in voltage profile is less from source end to load end in method 2 compared to method 1, it can be concluded that the results are better and promising with method 2 compared to method 1. This can become a major step towards achieving power quality in a distribution system.

GA based approach is proposed in the second part of this paper to solve the multi-objective volt/var control problem of a DS with DG. The optimal set points of volt/var controls in the DS with DG are found with the proposed approach. This technique takes very few iterations to converge. The sum of voltage deviations and losses are found to be 0.0052 pu and 310 kVA respectively with the proposed method. The losses are found to be 390 kVA and 310 kVA by considering only sum of voltage deviation alone and considering both voltage deviation and losses in the objective function respectively. Therefore, when the multi-objective functions are considered, losses are less when compared to the objective function with voltage deviation alone and without losses. With the proposed method, the voltage profile has improved and losses have decreased. This method is found to be simple and easy to apply in finding optimal set points of resistance and reactance settings of LRC/LDC, reactive power output of DG, and tap position of regulator. The optimal values of the control variables, resistance and reactance settings of LRC/LDC, reactive power output of DG, and tap position of SVR are found to be 0.29772 pu, 0.31494 pu, 0.09227 pu, and 3 respectively. Therefore, the proposed method is very much suitable for solving the multi-objective volt/var control optimization problem of a DS with DG, which is a leaping step towards distribution system automation, very much necessary for modern distribution systems.

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