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Optimal volt/var control of distribution system using multi objective particle swarm optimization

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ABSTRACT

This paper presents a novel method for solving multi-objective Volt/Var control of radial distribution system. The Volt/Var control is formulated as a multi-objective optimization problem which consists of the following objectives: minimization of real power loss, minimization of total voltage deviation and minimization of number of OLTC's and capacitor operation and voltage fluctuations for a day-ahead in Distribution system. The Proposed MOPSO Algorithm is used to find the optimal settings of control variables such as On-Load Tap Changer (OLTC) and shunt capacitor. The proposed MOPSO algorithm is tested on a standard IEEE 33-bus and 69-bus distribution system.

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1. INTRODUCTION

The main objective of optimal Volt/Var control is to ensure proper coordination between all the shunt capacitor and On Load Tap Changing transformer (OLTC) in order to maintain proper voltage profile and optimal reactive power flow in the distribution system to minimize the real power loss, voltage deviation and to reduce the operation of OLTC's and capacitor banks [1].

In the recent years, the Optimal Volt/Var control for Distribution systems are classified into offline control and real time control, the offline control involves optimal dispatch calculations based on the day-ahead load forecasts [2-3], whereas the real time control involves the optimal dispatch based on real time monitoring and measurements. Moreover, the real time control is very difficult as it requires automation and more about hardware and software support [4].

Nowadays, multi-objective optimal Volt/Var control focuses on power loss, voltage deviations, number of OLTC's and capacitor operations [5-7]. Recently, many mathematical optimization algorithms like linear programming, gradient approach were [8-9] applied for solving optimal Volt/Var control problem, but the disadvantages with these approaches is due to its complexity and heavy computational burden and also since Volt/ Var control is a multi-phase decision making problem it becomes a discrete and a nonlinear problem for every hour of study.

In order to overcome the above illustrated drawbacks, Heuristic Methodologies have been under research for solving Volt/Var control problem [10-13].

In the past few decades, heuristic algorithms such as Genetic Algorithm (GA), Ant colony optimization, honey bee mating optimization, Binary ant colony Optimization(BACO), Evolutionary Programming (EP), Differential Evolution (DE) were used for solving Volt/Var control problem. The above stated heuristic algorithms have overcome the drawbacks in the traditional methods, but also have certain limitations, that is they easily get trapped in the local optima and premature convergence would occur. In order to focus on a better convergence, the problem formulation was formulated as multi-objective optimization problem for different power system problems [14-15].

In this paper a Multi Objective heuristic optimization algorithm based on Particle Swarm Optimization (MOPSO) was developed [16-26] and validated on an IEEE 33 & 69 bus distribution system and found to overcome the above illustrated drawbacks and hence this paper concentrates on finding the optimal setting of control variables for achieving optimal Volt/Var control.

2. PROBLEM FORMULATION

Optimal Volt-Var Control refers to the process of maintaining the voltage and reactive power in the distribution system. The system voltage and reactive power are related to each other, since the voltage drop is because of reactive power flow over a line has large inductance. Because, as reactive power flows over an inductive line, that line sees a voltage drop. Thus Optimal Volt/ Var emphasized devices have the ability to control and maintain the voltage drop by injecting reactive power into the grid are those thatpurposely inject reactive power into the grid to maintain the voltage drop, in addition to equipment that more direct control voltage.

On-Load Tap Changing Transformers (OLTC) are used to maintain the voltage within the limits. Shunt capacitors inject reactive power at the location it is placed in the distribution system. Reactive power injected into the distribution network boosts the voltage by mitigating reactive power demand. Shunt capacitors are added to distribution networks to boost voltage levels. In the present work the optimal Volt/ Var control problem is formulated as a multi-objective optimization problem which are listed below:

2.1. Minimization of Real Power Loss

The objective of optimal Volt/Var control problem is Minimization of Real Power Loss while satisfying its various equality and inequality constraints.

$$\text{Minimize F1} = \sum_{i=1}^{N} P_{loss,i} \tag{1}$$

Where, N represents the 24 hours in a day, PLoss,i denotes the loss at time i.

2.2. Minimization of Voltage Deviation

The Minimization of voltage deviation improves the voltage profile of the system, thereby enhancing the security and quality of the system. The objective function is given as,

$$\text{Minimize F2} = \sum_{i=1}^{N} \left| \Delta V_{2,i} - 1 \right| \tag{2}$$

Where,

$\Delta V_{2,i}$ is the voltage deviation of the main transformer secondary at the time of i.

2.3. Minimization of Voltage Violations

Minimization of Voltage violations avoids bus voltages reaching their maximum limits,

$$\text{Minimize F3} = \frac{1}{N_L} \sum_{h=1}^{N_L} \sum_{i=1}^{N} \left| V_{h,i} - V_{h,i-1} \right| \tag{3}$$

Where, Vh,i is the voltage at bus-h at time i and NL is the total number of load buses.

2.4. Minimization of OLTC Operations

The minimization of OLTC operation increases its life expectancy and reduces its higher repairing cost,

$$\text{Minimize F4} = \sum_{i=1}^{N} \left| TAP_i - TAP_{i-1} \right| \tag{4}$$

Where, TAPi is the OLTC tap position at the time i.

2.5. Minimization of Shunt Capacitors Operations

The objective function is given by,

$$\text{Minimize F5} = \sum_{k=1}^{C_T}\sum_{i=1}^{N}(C_{K,i} + C_{K,i-1}) \tag{5}$$

Where, CK,i is the status of capacitor at time i and CT is the total number of shunt capacitors that is present in the system and $\oplus$ denotes exclusive OR operation.

2.6. Constraints

The objective functions are subject to power balancing equality constraint and following inequality constraints,

i) voltage constraint:

$$V_{\min} \le V_{h,i} \le V_{\max} \tag{6}$$

ii) Line flow constraints

$$S_{TX,i} \le S_{TX,rat} \tag{7}$$

Where, Vmin and Vmax are the minimum and maximum voltage limits, STX,i is the apparent power flow in the substation transformer at time i, STX,rat is the substation transformer rating.

3. MULTI-OBJECTIVE PARTICLE SWARM OPTIMIZATION ALGORITHM (MOPSO)

The evolutionary algorithms that were used to solve multi-objective optimization has shown significant advancement in the last few years, giving rise to newer algorithms. Particle Swarm Optimization (PSO) is a heuristic algorithm inspired by the choreography of a bird flock.

PSO seems to be suitable for solving multi-objective optimization problem because of its speed of convergence that the algorithm is presented for single-objective optimization. In this work, we present a modified Multi-Objective Particle Swarm Optimization (MOPSO), which allows the PSO algorithm to be able to solve multi-objective optimization problems. Our current work is an improvisation of the algorithm, in which we have added a constraint-handling mechanism and a mutation operator [13-14] that considerably improves the exploratory capabilities of the original algorithm [13, 15-16].

Multi-objective optimization problem have two or more objectives to be solved simultaneously. The Pareto front concept describes the optimal trade-off possibilities between the objectives. The Optimal VVC problem has two objectives; the main objective is to minimize the real power loss and at the same time minimizing the voltage deviations, voltage fluctuations and the number of OLTC and shunt capacitor operations have to be minimized.

The performance of MOPSO is improvised by the use of an external archive of non-dominated solutions found in previous iterations. The Cauchy Mutation (CM) operator improves the exploratory capabilities of the algorithm, and prevents premature convergence [15]. However, it should be noted that the use of CD of each solution, as a diversity operator by NSGA-II was able to produce a better distribution of the generated Non-dominated solutions, compared to the results generated by MOPSO that uses an adaptive grid [15] in maintaining the diversity of the generated solutions. The computation time of the PSO algorithm is less compared to that of the EA. This fact suggests that the PSO has been extended to solving multi-objective optimization problems, by incorporating the mechanism of DCD computation in the global best selection, and the deletion method of the external archive of non-dominated solutions, whenever the archive is full. The DCD operator, together with a CM operator, maintains the diversity of Non-dominated solutions in the external archive.

3.1. Algorithmic Steps

The algorithm of MOPSO consists of following steps:

Step1: For i=1 to M, where M is the population size

a) Initialize the particles *p[i]*

b) Initialize the velocity of the particles *v [I] =0*

c) Evaluate the fitness function of each particle
d) Find the personal best (*Pbest [I]*) value of the particles
e) Find the global best (*gbest [I]*) value among all the particles

Step2: Initialize the iteration counter $iter = 0$
Step3: Store the position of the non-dominated vectors into the external archive A.
Step4: Repeat the steps:

a) Compute the DCD values of each of the non-dominated solutions in the archive A, where DCD is given by,

$$DCD_i = \frac{CD_i}{\log\left[\frac{1}{z_i}\right]}$$

Where CDi is calculating using,

$$CD_i = \frac{1}{m}\sum_{k=1}^{m}\left| f_{i+1}^{k} - f_{i-1}^{k} \right|$$

Where m is the number of objectives, f_{i+1}^{k} is the kth objective of the $i+1^{th}$ individual and f_{i-1}^{k} is kth objective of the $i-1^{th}$ individual after sorting the population. zi is calculated using the equation,

$$z_i = \frac{1}{m}\sum_{k=1}^{m}\left(\left| f_{i+1}^{k} - f_{i-1}^{k} \right| - CD_i \right)^2$$

Step5: compute the new velocity and position.
Step6: Repeat the step until maximum iterations is reached.

4. NUMERICAL RESULTS

4.1. IEEE 33 and 69 Bus System

MOPSO approach is tested on the standard IEEE 33 and 69 bus Distribution system. The line data, bus data, generator data and the minimum and maximum limits for the control variables are referred from [13] and appendix. There are in total 168 control variables since the load changes for every hour there are 7 control variables hence for a day the total number of control variables becomes 168.

The IEEE 33-bus and 69-bus Distribution system shown in Figure 1 and Figure 2 respectively has 168 control variables, i.e 1 OLTC tap setting and 6 shunt capacitors at buses 1, 8, 13, 17, 28 for the 33 bus distribution and at 1, 43, 47, 58, 64, 66 for the 69 bus distribution system.

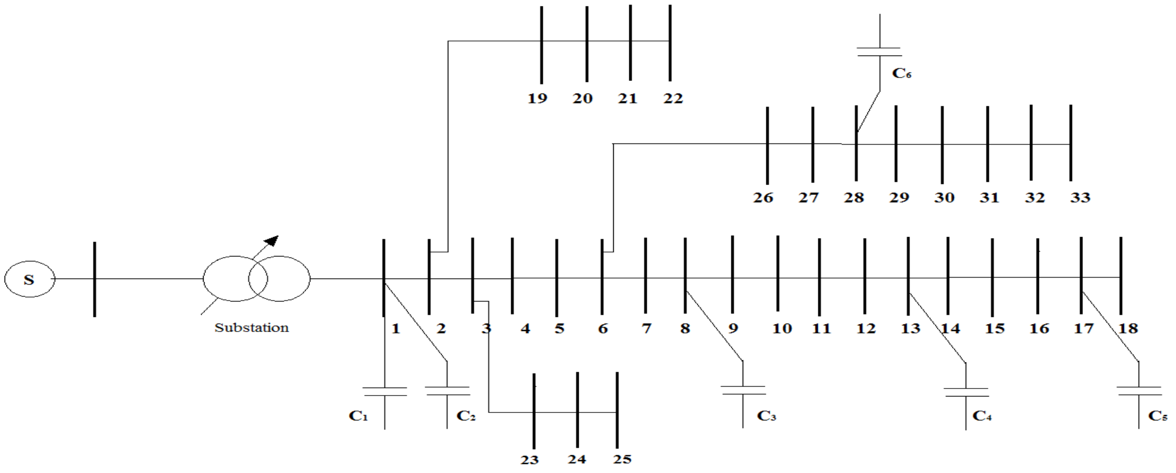

Figure 1. IEEE 33- bus distribution system

In this study, 10 test runs in the 33 and 69-bus Distribution system was performed to solve VVC problem.The appropriate values of C1 and C2 is set to 1.5 and 3 and the Inertial factor is varied from 0.3 to 0.9, it is generally higher at the beginning and decreases gradually.T denotes the total number of iterations. The Maximum iteration number is taken to be at 100 in all cases.

4.1.1 Case 1: Considering Minimization of Real Power Loss and Total Voltage Deviations

The load pattern for 24 hours a day for the 33 bus system is given in Figure 1 and the voltages at the respective buses for the base case of 33-bus system is given in Figure 3 and Figure 4.

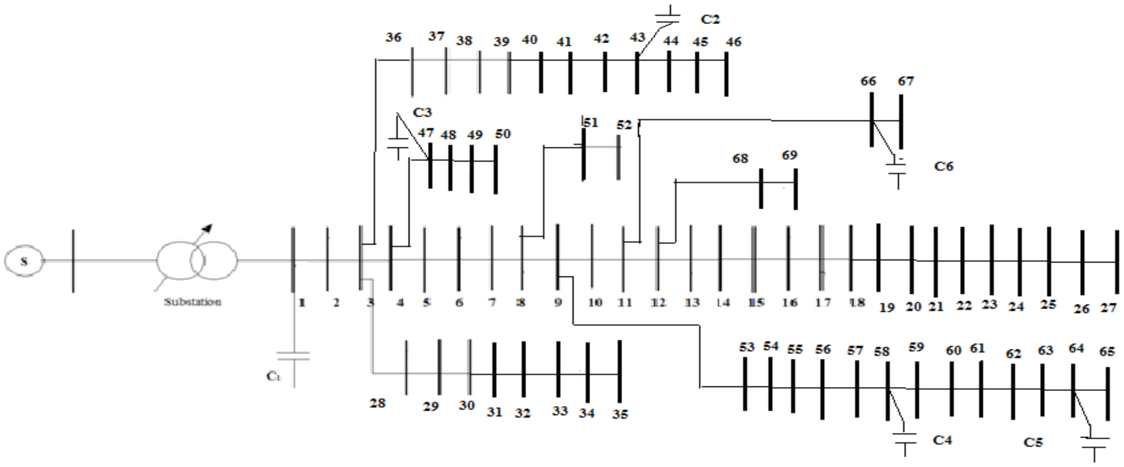

Figure 2. IEEE 69 - bus distribution system

The proposed approach is applied to obtain Pareto-curve for minimization of Real power loss and total voltage deviation. The obtained values are the total power loss is 1.885 p.u and the peak power loss is 0.143 p.u, the obtained total voltage deviations is 0.2476p.u and its respective Pareto graph is shown in Figure 5 and Figure 6 for the 33-bus system and for an 69 bus distribution system the obtained real power loss 3.0785 p.u and voltage deviations 0.3635 p.u are and its respective Pareto graph is shown in Figures 7 and 8.

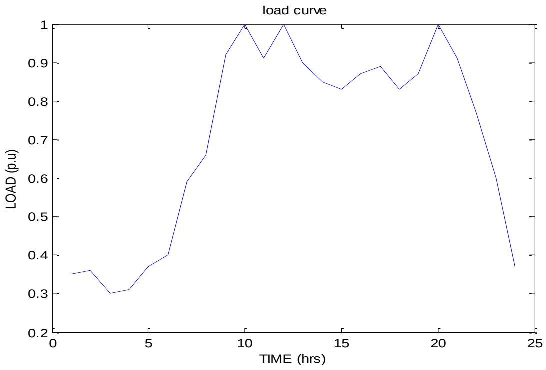

Figure 3. Load curve pattern for 24hrs for 33 - bus distribution system

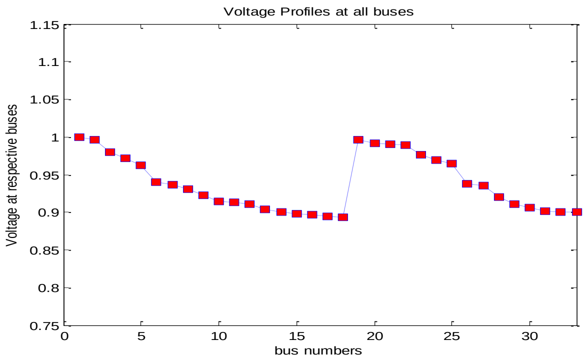

Figure 4. Voltages at respective buses for 33 - bus distribution system

4.1.2 Case 2: Considering Minimization of Real Power Loss and Total Voltage Fluctuations

The obtained total Real power loss is 1.886 p.u and the total voltage fluctuation is 0.2 p.u, for 33-bus system and for the 69-bus system the obtained values are total energy loss is 3.0785 p.u, the total voltage fluctuation is 0.1989 p.u. The obtained Pareto-curve for real power loss and voltage fluctuations for 33-bus and 69-bus system is given in Figure 5 and Figure 6.

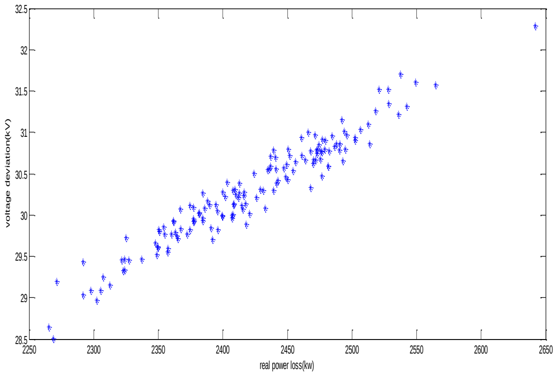

Figure 5. Total Real power loss and voltage deviation for 33-bus system

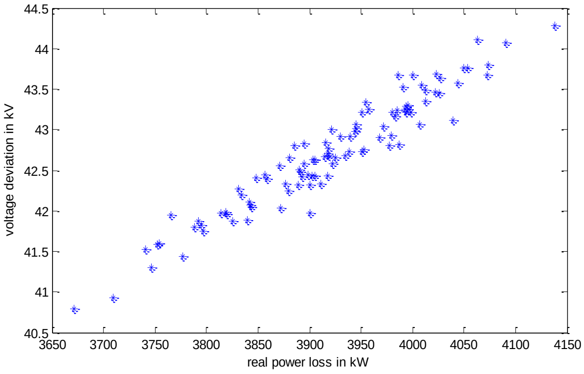

Figure 6. Total Real power loss and voltage deviation of 69 - bus distribution system

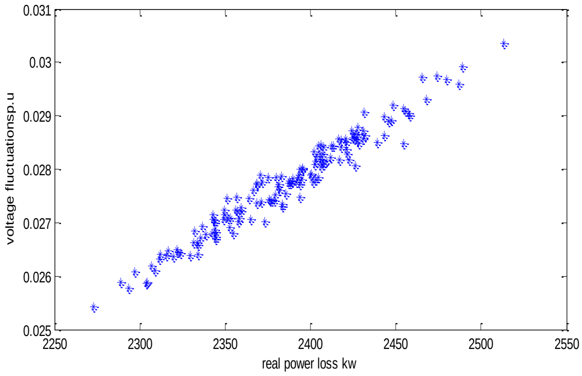

Figure 7. Total Real power loss and Voltage fluctuations of 33-bus system

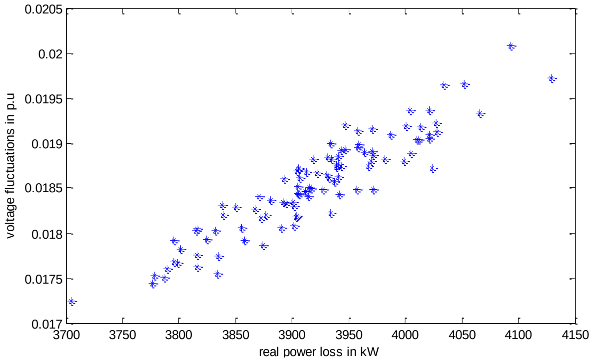

Figure 8. Total Real power loss and Voltage fluctuations of 69 - bus system

4.1.3 Case 3: Considering Minimization of Real Power Loss and Number of OLTC Operations

The obtained total Real power loss is 1.905 p.u and the number of OLTC operations is 16, for 33-bus system and for the 69-bus system the obtained values are total energy loss is 3.0785 p.u, the number of OLTC operations is 13. The obtained Pareto-curve for real power loss and number of OLTC operations for 33-bus and 69-bus system is given in Figure 8 and Figure 9. Total Real power loss and number of OLTC operations for 33-bus system as shown in Figure 10.

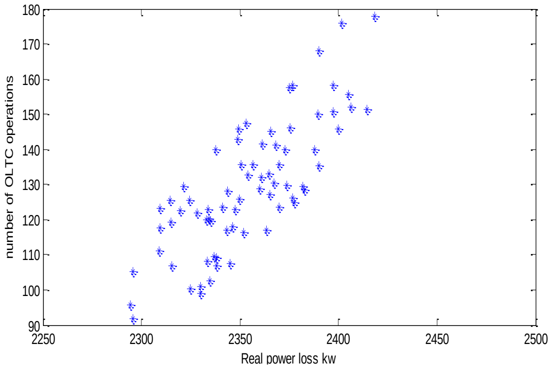

Figure 9. Total Real power loss and number of OLTC operations for 33-bus system

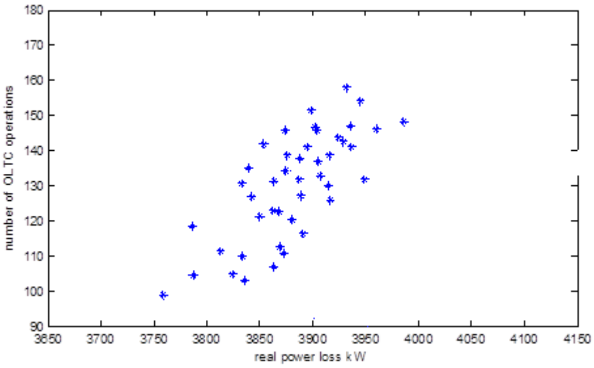

Figure 10. Total Real power loss and number of OLTC operations for 33-bus system

4.1.4 Case 4: Considering Minimization of Real Power Loss and Number of Shunt Capacitance Operations

The obtained total Real power loss is 1.905 p.u and the number of shunt capacitance operations is 6, for 33-bus system and for the 69-bus system the obtained values are total energy loss is 3.0785 p.u, the number of OLTC operations is 4. The obtained Pareto-curve for real power loss and number of OLTC operation for 69-bus system is given in Figure 10.

Thus the above approach for solving VVC problem seems to more efficient and less time consuming and hence considered advantageous when compared to conventional methods. This approach seems to be more advantageous compared to the weighted aggregation by resulting in a most compromised set of solutions.

5. CONCLUSION

A novel method for solving multi-objective Volt/Var control (VVC) of radial distribution system is proposed in this paper. The problem of VVC control was formulated as a multi-objective optimization by minimizing the real power loss, total voltage deviation, number of OLTC's, capacitor operations and voltage fluctuations for a day-a-head in Distribution system. The Proposed MOPSO Algorithm is used to find the optimal settings of control variables such as On-Load tap changer (OLTC) and Shunt Capacitor. The MOPSO algorithm effectively proves its capability of solving VVC with less time consuming and achieved by proper setting of control variables. The proposed MOPSO algorithm has been tested on a standard IEEE 33-bus and 69-bus distribution system.

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Appendix

Table 1. Capacitor Data for the IEEE 33-Bus Distribution System

Capacitor Number	C1	C2	C3	C4	C5	C6
Capacity(kVAr)	300	200	250	300	250	200
Location	1	1	8	13	17	28

Table 2. Capacitor Data for the IEEE 69-Bus Distribution System

Capacitor Number	C1	C2	C3	C4	C5	C6
Capacity(kVAr)	300	250	250	300	250	300
Location	1	43	47	58	64	66