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Optimal Coordinated Voltage Control Method for Distribution Network in Presence of Distributed Generators

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Abstract:
Now-a-days, integration of new devices like Distributed Generation, small energy storage and smart meter to distribution networks introduced new challenges and also that require more sophisticated control strategies. This project proposes a new technique called Optimal Coordinated Voltage Control (OCVC) to solve the multi-objective optimization (MOO) problem. It is accomplished with the objective of minimizing the voltage error at generators & pilot buses and the reactive power deviation. In this paper, the OCVC is done by using Non-dominated Sorting Genetic Algorithm II (NSGA-II) to find the optimal values of voltage of the generator and On Load Tap Changer (OLTC). It offers an optimal participation of reactive power of all devices available in the network. This proposed approach is tested in IEEE 33 and IEEE 69 Node test systems with unbalanced loading scenarios and the results of OCVC are presented.

Keywords: Distributed Generation, Multi-objective optimization, Non-dominated Sorting Genetic Algorithm II, Optimal Coordinated Voltage Control, On Load Tap Changer.

I. INTRODUCTION

Due to fast industrialization and growth of residential and commercial sectors, the electrical energy requirements have increased considerably over the last decades. In this condition, renewable energy becomes a very significant factor in the electrical distribution system. This type of generating unit is known as distributed generation (DG), and these generators will supply a large portion of demand and many of them will be directly connected to the distribution network. The limiting factor of DG capacity is the amount of energy given by the DG.The direction of power flow is depends upon the triggering voltage of DG and the voltage rise is depends on the amount of energy added by the DG.

II. LITERATURE SURVEY

The electrical energy requirements have increased significantly over the last decades due to rapid industrialization and growth of residential and commercial sectors. In this situation, renewable energy becomes a very important component in the electrical distribution system. This type of generating unit is known as distributed generation (DG), and many of them will be directly connected to the distribution network. DGs and their impact on the voltage the reduction of losses in the active and reactive power and the maximization of the DG capacity have studied by many researchers. A new technique called Optimal Coordinated Voltage Control (OCVC) is proposed for solving a multi objective optimization problem in order to reduce the voltage deviation and reactive power deviation in distribution network and also to minimise the voltage error at generators [1]. OCVC uses Pareto optimization to find the optimal values of voltage of the generators and OLTC. In this work the objectives are kept as it is. The OCVC is to be done by using Non-dominated Sorting Genetic Algorithm II (NSGA-II) to find the optimal values of voltage of the generator and (OLTC). It proposes an optimal participation of reactive power of all devices available in the network. An efficient algorithm is proposed to solve the multi-objective (MO) voltage control problem in distribution networks [2]. In which two optimization techniques are used as: Fuzzy logic and Pareto optimization to find the optimum value of the reactive power of the distributed generation (DG) and to find the voltage of pilot bus respectively. The author does not consider the voltage errors of generator. In this work it is to be done by using NSGA II by multi objective optimization problem. The Coordinated Voltage Control principle is used in the distribution system to manage the reactive power deviation and to improve the system voltage profile [3, 11]. In which the generator bus voltage errors are not considered. In this paper it is minimised along with minimisation of reactive power and voltage deviation in distribution network. The Optimal coordinated voltage control uses NSGA II to solve these multi objective problems. Based on model predictive control and tree search a coordinated system protection scheme (SPS) against voltage collapse is presented [4]. It optimally synchronize dissimilar and discrete controls such as tap changer, generator, and load shedding controls in presence of soft and hard constraints on controls as well as current and voltages in the network. An optimal Reactive Power Dispatch problem (ORDP) is to minimize real power transmission losses of the network while maintaining the system voltage profile in an acceptable range, with the control variables such as the voltages of generators, transformer tap ratios and reactive power generation of VAR sources [5]. A novel secondary voltage regulation (SVR) strategy for Treating voltage controllers as autonomous control agents based on multi-agent theory is presented for improving the performance of secondary voltage control actions under different system operating states. According to the principle of the multi-agent technology, the framework of this new type of control scheme is described and the optimal coordination methods are investigated in [6]. The various evolutionary algorithms Modified Non dominated Sorting Genetic Algorithm -II, and multi-objective particle swarm optimization (MOPSO) for solving ORPD problem [5] and Non dominated Sorting Genetic Algorithm –II for solving multi objective [5, 7]. NSGA II has revealed a good performance in comparison with other multi-objective evolutionary algorithms. Loss minimisation and cost minimisation are the main objectives [7]. Voltage deviation and reactive power deviation minimisation are the main objective in this paper. A new OLTC voltage control strategy proposed for use on networks where DG is connected that the level of bi-directional power flowing is considered as in the control scheme [8]. This paper describes the novel OLTC voltage control technique and shows its enhanced performance using the simulation studies. The novel OLTC voltage control technique to put up the potential use of Smart Grids are used to improve the methods are discussed. The authors have made a comparison in distribution networks, between uncoordinated and coordinated voltage control, without and with DGs involved in the voltage control [9]. The result indicates that using DG in the voltage control will reduce the losses, the number of OLTC operations and will decrease the voltage fluctuation in distribution network. An online voltage control strategy for a realistic distribution system containing a synchronous machine-based renewable DG unit and other voltage regulating devices are discussed [10]. The proposed strategy ordering the operations of different regulating devices while maximizing the voltage regulation support by the DG by minimizes the operational conflicts. The most essential conditions loss to improve the voltage profile and to minimize the total active power[12] is based on the optimal sizing and placement of DG units in radial distribution network. In this paper, a new technique called Optimal Coordinated Voltage Control (OCVC) to solve this multi-objective optimization problem. It is accomplished with the objective of minimizing the voltage error at generators & pilot buses and the reactive power deviation. The OCVC is done by using Non-dominated Sorting Genetic Algorithm II (NSGA-II) to find the optimal values of voltages of the generator and (OLTC). It proposes an optimal participation of reactive power of all devices available in the network. This proposed approach is tested in IEEE 33 and IEEE 69 Node test systems with unbalanced loading scenarios and the results of OCVC are presented.

III. PROBLEM FORMULATION

The reactive power production, voltage in a distribution network at some selected buses (pilot buses) and the generator's voltage deviation are tied together. Any variations in voltage at pilot buses will cause variations the reactive power production and generator voltage. Therefore, this problem can be formulated as an optimization problem as explained below.

3.1. Objective Functions

3.1.1. Voltage at Pilot Bus

CVC in distribution networks tune the voltage at pilot buses. In a mathematical form, the problem can be written as follows:

$$F_1 = \sum_{i\in p} \lambda_i \left[K\left(V_i^{ref} - V_i\right) - \sum_{K\in G}.\Delta V_K\right]^2 \quad (1)$$

Where,

P Sets of pilot

G Generator buses indices

V_i^{ref} Set-point voltage

V_i Actual voltage

ΔV_k Voltage deviation at bus i,

λ_i Weighting factor

kRegulator gain

3.1.2. Reactive Power Production

The reactive power production ratio deviation is the second objective. In OCVC, it represents the management of the reactive power of DG in the regulated area. This objective is modelled as follows:

$$F_2 = \sum_{i\in G} \lambda_i^q \left[K\left(q_{ref} - \frac{Q_i}{Q_i^{max}}\right) - \sum_{K\in G} \Delta V_k\right]^2 \quad (2)$$

Where,

G Set of generator buses indices

Q_i Actual reactive power generations at bus i

Q_i^{max} Maximum reactive power generations at bus i,

$$q^{ref} = \sum_{i\in G} Qi / \sum_{i\in G} Q_i^{MAX} \quad (3)$$

q^{ref} Uniform set-point reactive power value within the regulated area.

λ_i^q Weighting factor

k Regulator gain

3.1.3. Voltage at Generators

CVC in distribution networks adjust the voltage at the X generators. The mathematical model for the third objective is as follows:

$$F_3 = \sum_{i\in G} \lambda_i^V \left[K\left(V_i^{ref} - V_i\right) - \Delta V_i\right]^2 \quad (4)$$

Where,

G generator buses indices,

V_i^{ref} Set-point voltage

V_i Actual voltage

ΔV_i Voltage deviation at bus i,

λ_i^v Weighting factor

k Regulator gain

3.2. Constraints

3.2.1. Optimization Constraints

The constraints above are considered as technical and economic issue of the distribution network. The voltage limits, voltage drop, reactive power and the weights are the main constraints.

3.2.2. Voltage Constraints

The voltage constraints of pilot and generator buses voltages are used to determine the safe operation values of distribution network. The acceptable range of steady state voltage deviation in distribution network is considered within ±5% of the operating voltage at DG.

$$\left.\begin{aligned} V_i \in \left[V_i^{min}; V_i^{max}\right] for\ i\ \in\ P \cup G \\ |\Delta V_i| \le \Delta V_i^{max}\ for\ \mathrm{i}\ \in G \end{aligned}\right\} \quad (5)$$

3.2.3. Reactive Power Constraint

In this work, the control and efficient management of the reactive power are the main objectives. Therefore, the control of the production of the reactive power of the DG is very important. In an acceptable power factor for the DG is of ±0.91.

$q^{ref} = \sum_{i\in G} Q_i / \sum_{i\in G} Q_i^{max}$ (6)

Where,

$$|Q_i| \leq Q_i^{max}$$

3.2.4. Weights Constraints

The weights of the objectives are important because they give priority to an objective that depends on the conditions of operation. These weights are related as described in relation.

$$\lambda_i + \lambda_i^q + \lambda_i^v = 1 \quad (7)$$

$\lambda_i, \lambda_i^q, \lambda_i^v$, are weighting factors for bus i

The optimization problem ensures an optimal voltage profile of the distribution network. The optimization solution results in a single value that reflects a compromise in all objectives. The weighting factors are managed in real time using fixed values depending on the voltage value at the pilot bus. They coordinate the different areas of the distribution network to obtain the optimal values of the voltage and reactive power.

3.3. Pilot Bus Identification

Monitoring and the control of the voltage level at the pilot bus allow the control of the voltage in that area. Then, the voltage at the pilot bus must reflect the voltage profile of the entire control area. A simple method called barycentre to find the pilot bus is illustrated below. This method requires the following three steps.

Step 1: Compute $V_{bar} = \sum_{j=1}^{N} V_i$

Step 2: Find $\Delta V_i = V_{bar} - V_i$

Step 3: Choose the bus number with min |ΔVi| as the pilot bus.

In this paper, this method is used. The networks (IEEE 33 and 69 Nodes) used in this work, have loads in some buses. If we put out sequentially these loads, we will produce N variations of the voltage at the buses. If we sum up these N variations of the voltage, we will getV_{bar}. The next step is to obtainΔV_i. Finally, we choose the minimum value of the pilot bus has the corresponding index i.

3.4. On-Load Tap Changer

OLTC are normally located in the transformer between transmission and distribution network and they are quite common to maintain the voltage in Medium voltage network. Normally, the highest voltage point of the network is the sending-end bus bar and the voltage is decreased along the feeder due to line impedance and loads. The typical mathematical model of the voltage drop is as follows,

$$\Delta V = V_1 - V_2 \approx \frac{R_L P_L + X_L Q_L}{V_2} \quad (8)$$

Where P_L, $Q_L$are the active and reactive power of load, Q_L, $X_L$are respectively the line resistance and reactance; V_1, V_2 are the sending-end voltage and load bus voltage respectively. Due to the structure and properties of the distribution networks the most effective way of regulating the voltage is OLTC. The OLTC changes the voltage by alternating the turns ratio of the primary side and secondary transformers. When a DG is connected to the distribution network, the voltage drop is approximated as follows,

$$\Delta V = V_1 \_ V_2 \approx \frac{R_L(P_L - P_{DG}) + X_L(Q_L - (\pm Q_{DG}))}{V_2} \quad (9)$$

Where,P_{DG},$Q_{DG}$are the active and reactive power of DG. The extent of voltage regulation (DV) is limited by the number of positions and the step size between positions. In the characteristics of our OLTCs are displayed.

IV. SOLUION METHODOLOGY

4.1. Non-Dominated Sorting Genetic Algorithm II

The Non-dominated Sorting Genetic Algorithm II is a one of the efficient algorithm to solve Multiple Objective Optimization (MOO) algorithm and it is an algorithm developed from Genetic Algorithm for multiple objective function optimizations. To improve the adaptive fit of a population of candidate solutions by a set of objective functions to a Pareto front constrained is the objective of the NSGA algorithm. The algorithm uses an evolutionary process with replacements for evolutionary operators including selection, genetic crossover, and genetic mutation. Based on the ordering of Pareto dominance, the population is sorted into a hierarchy of sub-populations. The Pareto front, and the resulting groups and similarity measures are used to promote a diverse front of non-dominated solutions is evaluated based on Similarity between members of each sub-group. In this work, Matlab (gamultiobj function) is used to find minimum of multiple functions using genetic algorithm and obtain the Pareto frontier. For each set of solutions, Decision Maker (DM) calculates the minimum of the sum of the three objectives (minimum of losses); the set of solutions that have the minimum is selected.

$$F = min \sum_{j=1}^{N} \lambda_i f_j \quad (10)$$

Where F is the minimum sum of the objectives of the set of solutions N is the number of objectives; λ_i is the weight of the objective j; f_j is the objective j of the MO function. OCVC includes the OCVC includes the use of DM; in this study the fitness solution was used but various options are possible. The use of OCVC could be advantageous in relation to the

Step 1: Define input variables; the algorithm acquires the network values. The network will have two disturbances. The first is the input of the DG to the network. The second disturbance is the input of the large load on the pilot bus.

Step 2: The objective functions and constrains are calculated. OCVC calculates the three weights corresponding to F1, F2 and F3. The results of the distribution power flow namely bus voltages, line currents, real and reactive power are those which form the three objectives of the optimization problem.

Step 3: When the voltage in the pilot bus is not around the set point, NSGA II optimization finds a set of solutions of the voltages at the pilot bus (Vp optimal), the reactive powers (qref optimal) and the voltages in the generator (Vg optimal). Decision Maker (DM) calculates the fitness solution.

Step 4: According to the voltage at the pilot bus, the optimal reactive power and the voltage in the generator, the control action is executed. For this, a dynamic control of OLTC ensures compliance with the upper and lower voltages. In each time using Eq. (8), the voltage in the OLTC is calculated.

Step 5: With the data from step 4, OCVC calculates new values for the distribution network.

Step 6:If the values of the pilot bus voltage(Vp) , generator bus voltages (Vg) and the reactive power references(qref) are within the limits go to 7, if not, return to step 1.

Step 7: End. development of a flexible system for network operator, by applying different settings at the decision stage, according to specific circumstances.

4.2. Optimal Coordinated Voltage Control (OCVC)

In OCVC, the three objectives are always competing. When the voltage in pilot bus is within the fixed range, the objective 1 decreases its value. Therefore, the objective 2 (reactive power) becomes more important. The weights are related to the optimization process and will be responsible to maintain this priority. Conversely, when the voltage in pilot bus is outside the acceptable range, objective 1 and objective 3 increase the value and become the most important objectives. In this case, OCVC optimizes the voltage of the generators and OLTC available on the network. When the voltage begins to be within the limits defined, OCVC changes the priority. The new objective is to reduce the losses. OCVC has the advantage of using all the available sources of reactive power in the network and calculates the optimum value and reduce the losses, so λ_i^q increases its value in MO function.

The OCVC solves all the different objectives of the optimization problem separately and that OCVC changes the weights all the time to achieve the objectives of the minimization of losses and maximization of all the reactive power sources. OCVC proposes a multilevel approach for optimal participation in reactive power balancing of DG connected to the distribution network. In OCVC, the weights vary according to availability of resources in the network. The optimal values of OCVC maintain the voltage at optimal values with lower losses. The Joule losses are smaller in OCVC due to the optimal management of reactive power in the network. In this case, OCVC optimally coordinates the delivery of reactive power to obtain low losses. The solution obtained of the three objectives in the multi objective function is the one that produces the smallest possible losses. In this work the OCVC is evaluated in three different cases they are, in first case the network is maintained in normal load condition and for second case the new disturbance is created in a network by adding a DG of capacity 1045.8kw at the location of 31st bus for IEEE 33 bus system and for IEEE 69 bus system a dg is added at the location of 65th bus with the capacity of 1169.1kw.In case 3 a new load with a capacity of 150% of a normal load at the particular location is added in a network at pilot bus to create disturbance in a network.

4.2.1. Algorithm of OCVC

The priority for OCVC is to maintain the voltage within a specific range around the set point using all available resources in the network. From eqs. (4.1-4.2) & (4.4), we see the three objectives on voltages on the pilot buses F1 and on reactive power F2 and voltages on the generation buses F3. Furthermore, Eq. (4,7) is responsible for maintaining an optimal relationship in the objectives.

V. RESULTS AND DISCUSSION

Our analysis method has been implemented on two IEEE distribution test systems. These are IEEE 33 Node Test Feeder and IEEE 69 Node Test Feeder.

5.1. IEEE 33 Bus System:

The results of OCVC based on NSGA II optimization for IEEE 33 radial bus system is listed below. The results has three different cases they are,

1. Normal load
2. DG added
3. Load added

CASE 1- In this case the distribution network is in normal load condition.

CASE 2- In this case the disturbance is created in a distribution network by adding a DG with a capacity of 1045.8kw at the location of 31st bus in the network.

CASE 3- In this case the disturbance is created in a distribution network by adding a new load at the location of pilot bus with capacity of 150% of the normal load at the particular location.

Table.1. Pilot Bus for IEEE 33 Bus System

BUS SYSTEM	PILOT BUS
IEEE 33	18

Table.2. weights variations of IEEE 33 bus system for different cases.

Parameters	Normal load	DG added	Load added
λ_i	0.6835	0.7128	0.7117
λ_i^q	0.1563	0.1377	0.1504
λ_i^v	0.1595	0.1486	0.1377

Where,

λ_i - Weighting factor for pilot bus voltage.

λ_i^q - Weighting factor for reactive power production.

λ_i^v- Weighting factor for voltage at generators.

Table.3. Results of OCVC FOR IEEE 33 Bus System For Different Cases

Parameter	Normal load	DG added	Load added
F	0.00121	0.00460	0.00837
F1	0.00059	0.00460	0.00836
F2	0.00000	0.00000	0.00000
F3	0.00062	0.00000	0.00000

Where,

F - Summation of F1,F2,F3.

F1 -Voltage deviation at pilot bus in PU.

F2 -Reactive power deviation in MVAR.

F3 - Voltage deviation at generator bus in PU.

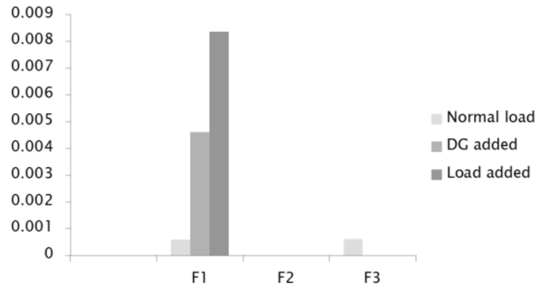

Figure.1. Plot of objective functions for ieee 33 bus system

Figure1. Show the comparisons of the objective functions for different cases in IEEE 33 bus system.

5.2. IEEE 69 Bus System

The results of OCVC based on NSGA II optimization for IEEE 69 radial bus system is listed below. The results has three different cases they are,

1. Normal load
2. DG added
3. Load added

CASE 1- In this case the distribution network is in normal load condition.

CASE 2- In this case the disturbance is created in a distribution network by adding a DG with a capacity of 1169.1kw at the location of 65th bus in the network.

CASE 3- In this case the disturbance is created in a distribution network by adding a new load at the location of pilot bus with capacity of 150% of the normal load at the particular location.

Table .4. Pilot Bus for Ieee 69 Bus System

BUS SYSTEM	PILOT BUS
IEEE 69	65

Table.5. weights variations of ieee 69 bus system for different cases.

Parameters	Normal load	DG added	Load added
λ_i	0.4999	0.7785	0.5683
λ_i^q	0.2547	0.1086	0.2125
λ_i^v	0.2464	0.1129	0.2189

Table.6. Results Of Ocvc For Ieee 69 Bus System For Different Cases

Parameter	Normal load	DG added	Load added
F	0.00118	0.00010	0.01004
F1	0.00047	0.00007	0.00160
F2	0.00000	0.00000	0.00843
F3	0.00071	0.00003	0.00000

Where,

F - Summation of F1,F2,F3.

F1 - Voltage deviation at pilot bus in PU.

F2 - Reactive power deviation in MVAR.

F3 - Voltage deviation at generator bus in PU.

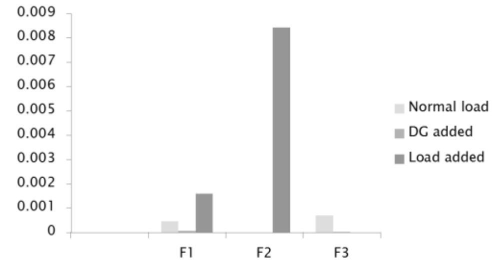

Figure. 2. Plot of Objective Functions for IEEE 69 bus system

Figure 2. Show the comparisons of the objective functions for different cases in IEEE 69 bus system.

VI. CONCLUSION

In this work, a new technique based on the NSGA II optimization has been presented and applied to Multi-Objective optimization voltage problem. It has been proposed as multilevel optimization with the participation of active and reactive power of the DG connected to the distribution network. For this purpose, we used the NSGA II to solve all the different objectives of the Multi-Objective problem separately with dynamic weights. OCVC performances are better than those of OLTC. OCVC eliminates the entire voltage problem, including the DG's over-voltages. The voltage problem has been solved. The proposed idea was tested in IEEE 33 and IEEE 69 bus system. OCVC could be an interesting way to reduce or eliminate future investments in classical voltage and reactive power regulation. This paper shows that the optimal integration of DG in distribution network can help to maintain the voltage within the limits and reduce losses.

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