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Optimal Voltage Control Method for Unbalanced Distribution System with PV and Phevs Using Artificial Bee Colony Algorithm

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Abstract: *The penetration of photovoltaic (PV) systems has been increased worldwide. The output power generation of photovoltaic (PV) has an intermittent nature due to cloud transients. Consequently, distributed PV systems with their intermittent feature can seriously affect the voltage regulation in distribution systems. In this paper, an optimal voltage control (OVC) method for unbalanced distribution networks (UDNs) with PV and plug-in hybrid electric vehicles (PHVs) is proposed. In this paper, a method is proposed to mitigate voltage fluctuations due to PV by simultaneously optimizing the reactive power of the PV inverters and charging/discharging power of the plug-in hybrid electric vehicles (PHEV). This OVC method considers different types and configurations of voltage regulators, and three-phase and single-phase step voltage regulators (SVRs). The use of this new objective yields a high reduction in the voltage fluctuations. The artificial bee colony (ABC) algorithm is utilized to optimally solve the real-time optimization problem while considering the constraints of the distribution system, PV inverters, and PHEVs. The simulation results on the 33-bus distribution system demonstrate the effectiveness of the proposed method for mitigating the voltage fluctuations during a high fluctuating generation profile of PV.*
Keywords: *Unbalanced distribution networks, Voltage fluctuation, distribution system, Photovoltaic (PV) and artificial bee colony ABC algorithm.*

Introduction: Recently, the usage of plug-in hybrid electric vehicles (PHEVs) has been increasing worldwide. The batteries in PHEVs can have positive impacts on distribution systems, including peak load shaving and voltage regulation. In addition, such devices can be helpful to mitigate the voltage fluctuations with intermittent PV output [1]. During high PV power generation and low load demand, the battery of PHEV can be operated in the charging mode to absorb the extra power. On the contrary, the battery of PHEV could operate in the discharging mode during low PV generation and high load demand. The charging and discharging ability of a large number of PHEV batteries can greatly regulate the power of supply and reduce voltage fluctuations.
Nowadays, the integration of renewable energy resources in distribution networks (DNs) has been increased rapidly. The installation of distributed generations (DGs) in DNs has a lot of benefits like reducing the feeder congestion, decreasing losses, and improving the system efficiency. However, increase the penetration of DGs, in particular PV and wind system, causes a lot of technical problems in distribution systems which affects the power quality and the network reliability. Renewable energy resources, such as wind power and photovoltaic (PV), greatly contribute to the existing and future electricity generation. PV is considered a fast-growing renewable energy source. The introductions of PV to distribution systems greatly affect their performance. On the one hand, there are several benefits from the integration of PV in distribution systems, such as power loss reduction, voltage profile improvement, and reliability enhancement [2].
The aim of the paper is to formulate a three-phase voltage control strategy for UDNs. In turn, the proposed OVC method considers the unbalanced features of the DNs and the different configuration of voltage regulation devices. Moreover in this paper, an efficient method is introduced to mitigate the voltage fluctuations with PV. The reactive powers injected/ absorbed of the PV inverters and charging/discharging power of the PHEVs and are simultaneously optimized for minimizing voltage deviation from its last moving average value. The use of this new objective yields an effective solution to the voltage fluctuation problem. The artificial bee colony (ABC) algorithm is used as an optimization tool to solve the optimization problem of fluctuation mitigation.
Literature Survey: Different studies for treating the voltage regulation problem in UDNs have been performed. In [3], a solution for voltage regulation problems in UDNs has been proposed based on different strategies and the coordination between OLTC and SVC using a two-stage approach. Ref. [6] has developed a network reconfiguration technique as an effective solution for voltage problems caused by PV sources due to moving clouds in UDNs, the developed technique is based on a proposed voltage variation sensitivity analysis, the method took in account different features of the UDNs like line configuration, different phase loading, PV fluctuations, and phase sequence. A distributed voltage control scheme for the UDNs has been proposed in [5],

where a cooperative protocol has been developed considering the DG source and the transformer tap changer as controlled agents to achieve the best performance.

Voltage regulation in DNs with high penetration of renewable DGs is an important issue, and it represents a difficult challenge to the network operator. The traditional voltage control devices, e.g., on-load tap changer (OLTC) transformer, SVRs, and switched capacitors, should have an effective and cooperative voltage control algorithm to overcome the voltage violations and keep the voltage within the standard limits [7]. In recent years, with increasing the integration of DGs in the DNs, the use of multi-agent systems (MAS) is increased to control the system operation and solve the problems of the DNs. The MAS is a control system consisted of a number of controlled agents. An agent is a system which can take a control action and affects its environment based on the data collected by sensors, and it can act autonomously. MAS can be classified based on the control architecture in three different categories, a) centralized control, b) decentralized control, and c) distributed control. In the centralized control system, the control centre collects information from all DN agents and calculates the optimum control action for each agent based on the collected data. The performance of the centralized control method is affected by the reliability and the speed of the employed communication system. This means that the high performance operation will be costly and more complicated to overcome the communication failure and increase the overall system efficiency [8].

Recently, a decentralized control strategy for MAS in DNs has been widely used. In this approach, each agent can act autonomously and control itself by a local control system based on local information, and also, it can perform as a distributed control scheme if the available information is shared between the neighbour agents. Distributed and decentralized control schemes are not required complicated communication links, and their performance is not affected by faults in the communication system, and they can offer flexible control schemes for the DNs with DGs. Since, the DNs contain three-phase structures; the study of voltage regulation problems with three-phase model of the UDN will be more practical. Also, the increasing of the installed capacity of the customer single phase rooftop PV without proper control schemes in UDNs can increase the unbalance features of the UDNs.

Proposed Method

Control Strategy

OVC strategy: The control of voltage regulation devices in UDNs with high PV penetration needs an effective management strategy to avoid voltage fluctuations and oscillations of the regulator taps. The proposed control strategy will depend on “index S” method. The “index S” method will be updated to meet the different configurations and models of UDNs components. The voltage regulation devices in UDN have different configurations in each agent area based on its type and method of connection; therefore, developing “index S” for UDN will help a lot to avoid voltage violation and tap oscillations problems.

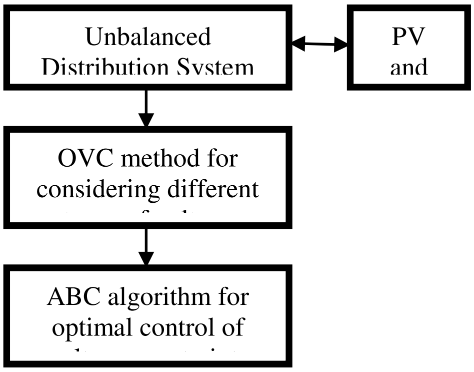

Fig. 1: Flow Diagram of Proposed Method

Formulation of OVC method: The optimal control strategy aims to minimize the three phase voltage violation function f_{abc} as follow:

$$min \int_0^\infty f_{abc}(v)dt \text{ -------- (1)}$$

The formulation of the voltage violation function f_{abc} depends on the available number of phases and regulator and loads configuration in each controlled area f_{abc}can be written as:

$$f_{abc}(v) = f_a(v) + f_b(v) + f_c(v)$$
$$= \frac{1}{2}\sum_{p=a}^{c}\sum_{j=1}^{M_p} w_j^p \cdot \left(v_j^p - v_r\right)^2$$

------ (2)

Where, f_a, f_b, *and* f_c represent voltage violation functions for phase a, b and c respectively; $v_j^p = \left[v_1^p \cdots v_{M_p}^p\right]$ represents the phase voltage vector at *Mp* observation points and $p \in \{a, b, c\}$; $w_j^p = diag\left[w_1^p \cdots w_{M_p}^p\right]$ are weight coefficients. The node voltages of the UDNs are affected by the tap positions ***n*** and the load parameters$L$, and it can be calculated by the simplified power flow equation:

$$v = f(L, n) \text{ -------- (3)}$$

If the tap position changes by $\Delta n(t)$ the voltage violation function in (2) will change by $\Delta f_{abc}(t)$ as following:

$$f_{abc}(v(t+1)) = f_{abc}(v(t)) + \Delta f_{abc}(t)$$

------- (4)

$$\Delta n(t) = \text{R.Z} \text{ --------- (5)}$$

Where R is regulator step size, and $Z(t)$ is the tap status described as follow:

$$Z(t) = \begin{Bmatrix} +1(tap\ increase) \\ 0(no\ tap\ change) \\ -1(tap\ decrease) \end{Bmatrix} \text{ ------- (6)}$$

The change in voltage violation function will be as follow:

$$\Delta f_{abc}(t) = \left[\frac{\partial f_{abc}}{\partial V}\right] \cdot \left[\frac{dV}{dn}\right] \cdot R \cdot Z(t)$$

$$S_{abc}(t) = Z(t) \text{ ----- (7)}$$

Where $S_{abc}(t)$ is identified as index S, $\left[\frac{dV}{dn}\right]$ · is the voltage/tap sensitivity matrix calculated from (3), and *N* is the number of the voltage regulators. From the previous equations, it is noticed that decreasing in the voltage violation function is subjected to minimizing $\Delta f_{abc}(t)$ as follow:

$$min\ \Delta f_{abc}(t) = f_{abc}(v(t)) + min \text{ ----- (8)}$$

As noticed from (8), the most effective term in the objective function is the index S.

ABC Algorithm

ABC optimization algorithm is used in this paper to solve the objective function ABC is one of the most recent meta-heuristic optimization algorithms. The classical ABC consists of two necessary components (i.e., food sources and agents). The possible solutions are represented by food sources and the food sources are selected and preferred based on numerous properties such as taste, richness, and proximity. Base on colony decision, balancing the process of utilization of current food sources and reconnaissance of new food sources is governed. Usually, the food sources that produce higher values for the fitness function are prioritized. On the other hand, Agents are grouped as employed agents and unemployed agents based on their functionality. The unemployed agents are further divided into two sub-groups, namely, onlookers and scouts. Each one of them (employed agents and unemployed agents) corresponds to a different search task. The main flow can be described as follows.

Firstly, all the bees are randomly initialized in a possible solution area. The minimum and maximum limits of the search space are represented by *min* and *max*, respectively. The food source number is N_{FS} then the D-dimensional vector as $Y_k = (y_{k1}, y_{k2}, \cdots y_{kD})$ indicates the k^{th} food source's location and y_{kl} represents the l^{th} variable of Y_k, $k = 1, 2, \cdots, D$. The initialization updating equation can be expressed as:

$$y_{kl} = min_{ij} + (max_{ij} - min_{ij}) \times rand(0,1) \text{ ---------- (9)}$$

Where $rand\ (0,1)$ is a real number selected randomly and uniformly from the range of $(0,1)$. Secondly, the possible food sources will be utilized by combining the previous experience and information of a randomly selected neighbor bee as follows:

$$z_{kl} = y_{kl} + rand\ (-1,1) \times (y_{kl} - y_{ml})$$

---------- (13)

Where z_k is the candidate solution of *k* and z_{kl} denotes the l^{th} variable; m denotes the number of a neighbour bee in [1, *NFS*]; $rand\ (-1,1)$ is a uniformly distributed real value randomly selected in the interval of [-1,1]. If a minimum optimization problem is assumed, the fitness value F_k can be calculated as follows:

$$F_k = \begin{Bmatrix} \frac{1}{1+f_k} & if & f_k \geq 0 \\ \frac{1}{1+f_k} & if & f_k < 0 \end{Bmatrix} \text{ ------------ (10)}$$

Where, f_k is the function value of individual k. If the fitness of candidate solution Z_k is better than that of the current solution, the current food source Y_k will be updated by the candidate solution Z_k Otherwise, Y_k will remain unchanged.

Thirdly, the selection probability of each employed bee to use in the onlooker bees is calculated by the following equation:

$$F_k = \frac{F_k}{\sum_n^{NFS} F_n} \text{ -------- (11)}$$

Based on (11), a roulette strategy is used with onlooker bees to select a source for search by using the same updating equation as (10). The adopted strategy in the onlooker bees is the greedy selection strategy. Finally, when a food source stops updating for a sequential iteration, it should be selected as a scout bee and reinitialized in the solution space to replace the previous value of this food source.

Results: In this paper, PV generators are connected to the end of a 10kV traditional radial distribution system, seeing in Figure 2, where the system base power, base voltage, system bus voltage are 10MVA, 10kV, 1.05p.u. Respectively. PV power output level is defined as the ratio of PV active power output to total active power existing in the distribution system. Simulation results are as follows.

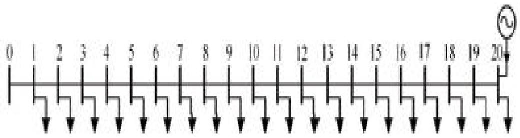

Fig. 2: A 10KV Traditional Radial Distribution System with PV

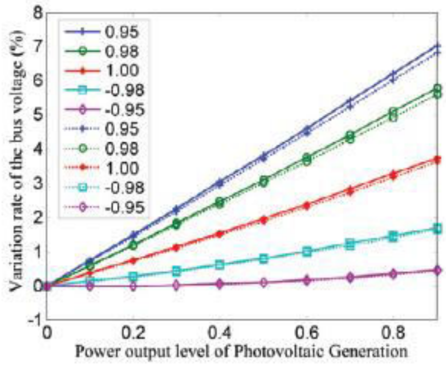

Fig. 3: Different Power Factors and Power Output Levels On The Bus Voltage With PV Generation

Conclusion: In this paper, the voltage violation problems in UDNs with high PV penetration have been mitigated using a proposed three phase's optimal voltage control strategy of ABC algorithm. To do so, the charging/discharging power of PHEVs and injecting/absorbing reactive power of the PV inverter are simultaneously optimized so as to minimize voltage fluctuations. Since the UDNs have different configurations for each regulator area, the proposed OVC method has been developed to control the voltage regulation devices using a multi-agent structure with a decentralized control scheme. The ABC algorithm is used to solve the real-time optimization problem. The results demonstrate that the proposed method can significantly mitigate the voltage fluctuation with OVC strategy of PV system as well as it can mitigate the voltage rise/drop at PCC.

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