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A novel strategy for optimal placement of locally controlled voltage regulators in traditional distribution systems

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A R T I C L E I N F O

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A B S T R A C T

In this paper, an approach for placement of voltage regulators (VRs) in traditional distribution systems by considering a local controller model is presented. The main aims of this paper are controlling the voltage level in its permitted range and decreasing the costs imposed to the distribution system companies, such as costs that stem from power losses, VRs' investment and maintenance. Genetic algorithm (GA) has been used as a tool to determine the number, location and rated power of VRs. Since in traditional distribution systems, tap position determination of VRs is achieved by local controllers, local controller model is established to determine tap operations. A 70-bus distribution system is considered to prove the value of the presented approach. Effectiveness of the proposed approach and ineffectiveness and infeasibility of conventional approaches are presented in numerical studies. The presented approach allowed to eliminate voltage violation in all load conditions and a reduction of power losses of about 6% for the maximum load level.

1. Introduction

The VR placement is not a new topic for researchers, but from broad prospective, seeking more feasible approaches along with finding the best solution for this issue are still persistent motivations of researches. Maintaining the voltage magnitude within standard ranges, besides energy losses reduction benefits, persuade utilities to utilize voltage regulators (VRs) in distribution systems. The need to have an acceptable voltage drop will be more intensified when loads are at their maximum value and the length of feeders is long. VRs in distribution systems are employed as an alternative to fulfill both technical and economic aspects and, in most cases, they eliminate the requirement of conductors resizing, network reconfiguration and the implementation of new feeders [1]. Before taking advantage of VRs, some factors should be taken into account to obtain their optimum usage. The required number, location, rated power and tap position of VRs should be meticulously designated. Some researches that have been done about this issue are discussed in the Section 1.1.

Worth to mention that as in distribution systems both voltage regulators and capacitor banks are considered to solve distribution problems, a comparison has been added here. It is clear that capacitor banks and voltage regulators have some advantages rather than each other. For example, in case of overvoltage situations, a voltage regulator can maintain a voltage level by setting the regulation ratio lower than 1. In other words voltage regulators have been designed to control voltage in both overvoltage and under voltage situations while capacitor banks can be mainly useful in under voltage situations to boost the voltage level. So, from the voltage control point of view, voltage regulators are more beneficial than capacitor banks. In case the main problem of a distribution company is related to high power losses, capacitor banks can be more effective than voltage regulators as they can decrease reactive power flow in the distribution feeders. From economic aspects, investment costs of VRs are higher than capacitor banks (in the same scale) especially when it comes to compare a VR to a fixed capacitor. The point is that the needs of distribution companies specify the selection of VRs or capacitor banks in a system.

1.1. Literature review

Many papers can be investigated related to capacitor placement [2–6] to satisfy voltage constraints and achieve savings, whereas few works have been done about VR placement [7]. Among various tools employed to solve VR placement problem, the most commonly used in previous works are optimization methods and two-step algorithms.

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Artificial intelligence (AI) based algorithms are widely used, including genetic algorithm (GA) [1,8,9], particle swarm optimization (PSO) [10] and teaching–learning-based optimization (TLBO) [11], while some other works [7,12,13] are based on two-step algorithms including those aiming at placing VRs to fulfill technical aspects or at decreasing the number of VRs.

Some works have been done to jointly allocate voltage regulators and capacitors (VRCs) [8,14]. This problem was solved by means of mixed-integer linear programming (MILP) in [14] and in [8] GA and optimal power flow (OPF) were used to solve the problem. In [15], GA is utilized to find the best solution for VR placement considering hourly demand. The number of VRs is determined manually and the GA chooses the preferred place for them on an hourly basis. Safigianni et al. [12] proposed a two-step algorithm in order to find the location, number and tap positions of VRs along with minimizing the imposed costs related to investment and maintenance of VRs. At first, the algorithm chose the necessary numbers and location of VRs. Then the algorithm reduced the number of VRs as much as possible, provided that all of the constraints have been fulfilled. Similar to [12], the same approach has been taken into account in [7] with a modified objective function and a different method of VRs reduction.

In [11], different optimization algorithms have been compared to solve VR placement problem considering a multi-objective function. Due to the dissimilarity of objective functions, fuzzy method has been defined to normalize them. Afterward, the optimal solutions are obtained considering the Pareto front. The comparison of the results obtained with a modified TLBO (MTLBO), GA, PSO, and TLBO are also presented. Some deficiencies of [11] are discussed in the following.

- It was noted that the number of VRs is fixed while the optimization method should have a degree of freedom to choose the required number out of maximum number of VRs. As a consequence of fixing the number of VRs, the search area of the optimization algorithm inevitably shrinks. The results will not be reliable enough to be implemented in a distribution system because they may reduce the efficiency of the solutions.
- A wide range of sizes in terms of rated power are available for VRs, and, depends on the network electricity demand and VR's location, distribution companies should be entitled to choose the appropriate size for VRs. If there is a mismatch between VR's size and power demand, a VR definitely malfunctions in overload situations or, in case of over design, extra expenditures will be imposed to the distribution companies. Due to lack of various size consideration for VRs, this is one problem of the approach presented in [11].
- Installation of VRs in distribution systems should be also accomplished for their long-term use. Factors that affect the future utilization of VRs are load forecast and maintenance costs and both of them are ignored in [11].
- In [11], the tap position determination of VRs is done by optimization methods in which the presence of local controllers is neglected. In a traditional distribution system, choosing the tap position is performed by local controllers and ignoring them is the main deficiency of [11].

1.2. Motivations and innovative contributions

Up to now, in VR placement approaches, some initial principals still remained unclear especially about how tap position should be determined or questioning about feasibility of performed papers. After investigating all different approaches in the previous papers about VR placement, some challenges can be pointed out as follows.

(1) In some papers such as [1,11,15], the number of VRs is determined, which means it is given manually to the algorithm hence the search area of the optimization algorithm inevitably shrinks.
(2) Investigated papers are devoted to planning of distribution networks, but most of them ignored load forecast such as [7,11,12,16].
(3) As a VR is an equipment with movement parts (the tap changer), its maintenance should be considered seriously. This issue is one of the reasons for the low inclination of distribution companies to install VRs in distribution networks in comparison to fixed capacitor installation. Maintenance cost of VRs is ignored in some previous works such as [11,14,16].

It is worth mentioning that, in all previous papers; the local controller is omitted and it has been assumed that all necessary information (voltage of downstream buses) is available for optimization algorithm and it can ideally selects tap positions. Due to data access limitation in traditional distribution systems, this assumption is unacceptable and in the presented paper the local controller has been regarded to set tap positions individually. Since each VR acts according to its own data in traditional distribution systems, then the controller set the tap position based on its own voltage magnitude. There is a considerable difference between tap positions which are determined by algorithms (optimization or two-step) and local controller taps that its distinguish will be indicated in the Section 4.3. In this paper, an effort has been made to investigate and solve all of the aforementioned issues. The contributions of this paper are organized in order to answer the above mentioned challenges.

About the first challenge, due to practical limitations, the maximum number of VRs is defined in this paper but the number selection of VRs is carried out by an algorithm considering an objective function and some constraints. In order to solve the challenge number two, the planning length is commensurate with the lifetime of VRs. Because of the increasing trend of power demand, load growth has been considered during the planning length in order to have responsible solutions. As regards with the third challenge, since distribution companies hesitate using VRs due to maintenance considerations, every research in this field should be capable to ensure them that maintenance aspects have been considered. As a result, in this paper total maintenance cost (TMC) has been defined to eliminate utility concerns. The last challenge that is the most important one is solved as follows; instead of selecting the tap position by using optimization algorithms, it is proposed to model the local controller in the solving process used for VR placement. Consequently, similar to the real situation of traditional distribution systems which a VR is equipped with a local controller, tap operations are determined by the local controllers. Also in order to demonstrate the importance of set points for VRs, an investigation of the set point effects on voltage profile is presented in the numerical section.

Hence, the main innovative contributions of the proposed method are highlighted as follows.

(1) Introducing a novel strategy for the placement of voltage regulators in traditional distribution systems.
(2) Establishing the importance of modeling the controller in the VR placement problem.
(3) Confirming the efficiency of locally controlled voltage regulators in terms of cost savings and voltage profile improvement.
(4) Investigating the effect of various conditions of set points for VRs.

Hereafter, in order to simplify the content, traditional distribution systems will be noted distribution systems.

1.3. Paper organization

In the following, the problem of VR placement in presence of local controllers is explained in Section 2. Section 3 is devoted to the problem formulation explaining the objective function and problem constraints. In Section 4, simulation results obtained by proposed and conventional methods are compared and afterward the importance of local controller modeling in the VR placement problem is also demonstrated.