



# Coordinated Volt/VAr control for real-time operation of smart distribution grids



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## ABSTRACT

This paper proposes a new approach to the development of coordinated Volt/VAr control for real-time operation of smart distribution grids. The methodology intended for the coordinated Volt/VAr control conveys the minimization of the voltage violations and also a better distribution of the number of commutations among the control equipments. The control algorithm developed centrally coordinates the equipment actions in the conditions where the local control does not act properly. The adjustments are performed in the voltage regulator, in the capacitors banks and in the reactive power injected by the inverters of the distributed generation. The coordinated control strategy uses the fuzzy logic combined with a heuristic algorithm, which has implementation simplicity and suitable performance for real-time applications. A numerical example is presented aiming to clarify the procedure of the proposed control algorithm. Furthermore, the algorithm performance is verified through a modified IEEE 34 node test feeder under distinct operating conditions.

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## 1. Introduction

The voltage and reactive power control (Volt/VAr control—VVC), from a distribution system equipment, is essential for maintaining suitable voltage levels in all buses of the distribution feeder, considering the most diverse system operating conditions [1]. The VVC has showed new in the context of advanced distribution systems automation (DA) and distribution management system (DMS) [2] for real-time applications [3].

Traditionally, in the distribution system operation, voltage and compensation problems are solved through off-line analysis and local adjustments in the control devices, with automatic actions from the comparison between pre-adjustments and devices measurements [4–6]. For several times, these control actions are not coordinated, due to the lack of management systems and communication between the system equipments, creating an ineffective control in terms of operation safety.

The possibility of on-line adjustments through equipments with communication and interaction with other Volt/VAr equipments refers to sophisticated control approaches, which can uses DMS and

supervisory control and data acquisition (SCADA). These control approaches commonly known as local, decentralized, centralized and hybrid controls structures and are characterized by a management system and a central control, which is in charge of the decision taking functions in different levels, as showed in Fig. 1.

Recently, new benefits have been presented with VVC, providing support to the smart grids. The main benefits of this control are: technical losses reduction through voltage optimization, demand management, voltage maintenance after self-healing, dynamic voltage control with power electronics based equipments such as distributed generation through renewable source [7], electrical vehicles chargers [8], distributed static VAr compensators (D-STATCOM) [9,10], and solid-state transformers (SST) [11,12].

VVC is an emerging solution that can be added to the power electronic devices in the electrical grids, especially the inverters used in the distributed generators, which can process active and reactive powers injected at point of common coupling (PCC) [9]. Electronic devices have been suggested as a way to promote reactive power control, necessary to the voltage regulation maintenance [9–13], and so they can operate as an additional tool to the VVC implementation, mainly due to its capacity of varying the reactive power fast.

The active power injection carried out through the Distributed Energy Resources (DER), such as distributed generation (DG) and energy storage systems (ESS), can cause the overvoltage in peri-

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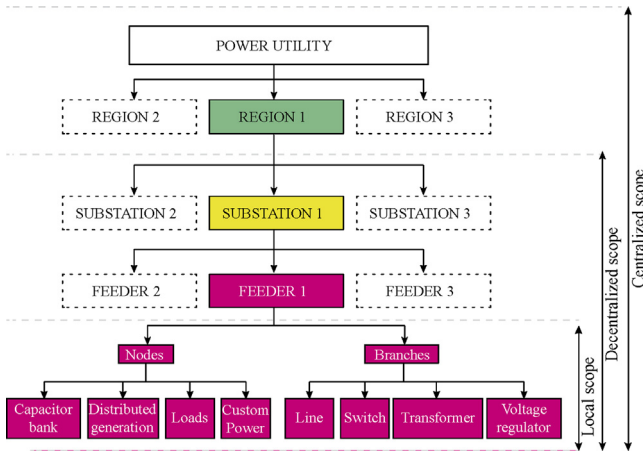


Fig. 1. Hierarchical Volt/VAr control structure.

ods of low energy consumption [14,15]. The overvoltage is one of the main limitations for greater participation of DG in distribution networks. This way, the VVC can be an alternative to the increase of the participation of the DG in the distribution networks, since the active and reactive power management can be smartly coordinated by external control in order to eliminate both undervoltage and overvoltage violations in the distribution networks.

Several techniques have been proposed aiming coordinated actions with VVC. In [16,17] the Dynamic Programming (DP) is used as a VVC strategy, where the DG actively participates in the control actions along with other devices, reducing the voltage variations in the loads. A hybrid approach is used in [18] with the primal-dual interior-point method (PDIPM) to treat the discrete variables as continuous ones and with the genetic algorithm (GA) for VVC control. Other methods such as heuristic technique [19,20], evolutionary algorithm (EA) [21], simulated annealing (SA) [22], fuzzy logic [22], have also been used to solve the VVC problem. Especially, the use of fuzzy logic has showed to be one of the most successful techniques among the modern technologies for on-line control system applications [22–24]. The fuzzy inference systems (FIS) present the main advantage: the ability to solve non-linear problems and to analyze qualitative information, which is associated to the process that is being controlled [25], with high efficiency in terms of computer effort to find viable solutions [26].

Therefore, this paper presents the development of a new approach for a real-time coordinated VVC using fuzzy logic. The main contributions of this paper are the VVC algorithm based on the effectiveness and availability of equipments, the coordinated VVC including conventional and power electronic equipments and the flexibility of the algorithm to adjust this one to the system changes, with functions that can be enabled/disabled in concern to the objective of the operation. The proposed technique coordinates the control actions among the devices considering the physical limits and the number of commutations, aiming not to prioritize a specific equipment and, consequently, to preserve the lifetime of the devices. Moreover, the method can use the information from supervision systems of equipment remotely controlled in the system, allowing the automatic action of these devices, applying the smart grids concepts.

## 2. VVC problem formulation

The coordinated VVC consists in a searching problem to find a centralized solution to produce systemic optimizing effects in the distribution networks, which is not possible with only local actions without coordination between the devices. In this sense, the systemic optimization is achieved in the DMS with coordinated VVC

algorithm that receives information from the remote terminal units (RTUs) of each equipment. The VVC algorithm executes the optimization and transmits new control information back to RTUs of the field devices.

The equipments used in the proposed coordinated operation are the conventional ones, such as voltage regulators and capacitors banks, and equipments based on power electronics, such as reactive static compensator for distribution networks (D-STATCOM), inverters used in grid-connected distributed generators and distribution transformers with electronic commutation.

The coordinated VVC can also be applied to the energy storage systems, since the reactive power control in the storage devices is performed through the inverters. This way, the reactive power control will occurs such as it is implemented with the D-STATCOM and DG.

### 2.1. Real-time application requirements

The real-time implementation of coordinated VVC needs the following requirements [27–29]:

- Three-phase unbalanced power flow to optimize and validate the operation.
- Centralized control system with DMS and support for SCADA.
- Real-time data record of the advanced metering infrastructure (AMI) in the field equipment.
- Remotely controllable devices with commutable controllers.
- Efficient and modern communication system.

An important feature of the real-time coordinated VVC is the need of a highly reliable communication system and that allows a high-speed and increased bandwidth communications for data acquisition and control [28,30]. Additionally, these characteristics can affect the VVC control performance, such as network availability and communication delays, which are critical requirements [31]. The proposed methodology can be implemented by the distinct existing solutions of communication systems (GPRS, RF Mesh Network, LPWAN). The LPWAN (low power wide area network) communication network is being used in a pilot project from RGE Sul power utility, in the southern part of Brazil, mainly due to low cost and low data consumption, that this proposed VVC strategy will be implemented.

### 2.2. Objective functions and constraints

The optimization objectives of the proposed VVC are used to minimize the voltage violations in the network nodes and to minimize the standard deviation between the number of equipments commutations to correct these violations, as follows:

$$\min Nv_{T,t} = \sum_i Nv_{i,t}, \quad t = 0 \dots 23h \quad (1)$$

$$\min Nc_{SD,t} = \sqrt{\frac{\sum_{eq=1}^n (Nc_{eq} - \bar{Nc})^2}{n-1}} \quad (2)$$

where  $Nv_{T,t}$  is the total number of voltage violations in the network at time  $t$ ,  $Nv_{i,t}$  is the voltage violation in the node  $i$  at time  $t$ ,  $Nc_{SD,t}$  is the standard deviation between the number of equipments commutations in the network at time  $t$ ,  $Nc_{eq}$  is the number of commutations of the equipment  $eq$  used to correct the voltage violations and is the average of the number of the equipment commutations.

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