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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.

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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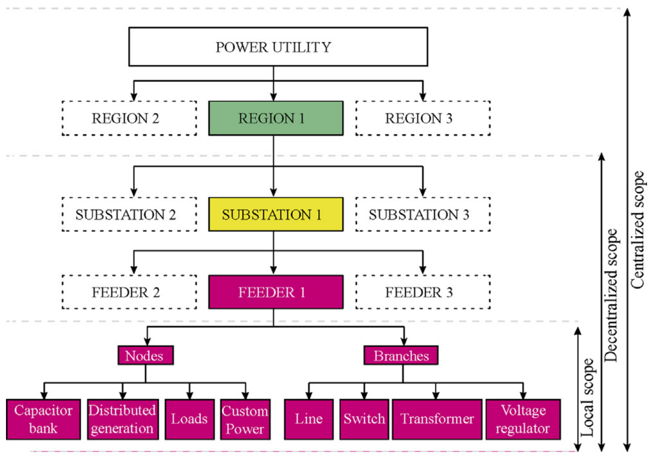

Fig. 1. Hierarchical Volt/VAr control structure.

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 treats 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]:

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

$$\min\ Nv_{T,t} = \sum_{i} Nv_{i,t}, \quad t = 0\ldots 23\text{h} \tag{1}$$

$$\min\ Nc_{SD,t} = \sqrt{\frac{\sum_{eq=1}^{n}\left(Nc_{eq} - \overline{Nc}\right)^{2}}{n-1}} \tag{2}$$

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.

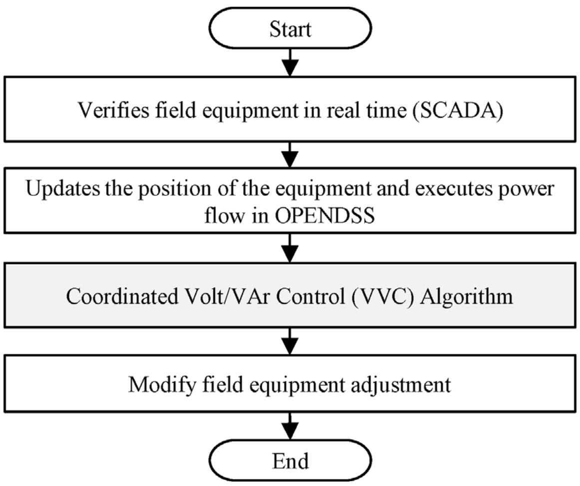

Fig. 2. Architecture of the proposed to the coordinated VVC.

Problem restrictions are:

$$V_{i,\min} \le V_i \le V_{i,\max} \tag{3}$$

$$a_{ij,\min} \le a_{ij} \le a_{ij,\max} \tag{4}$$

$$0 \le Q_{C_i} \le Q_{C_i,\max} \tag{5}$$

$$Q_{\mathrm{INV},\min} \le Q_{\mathrm{INV},n} \le Q_{\mathrm{INV},\max} \tag{6}$$

where V_i are each node voltage, which are delimited in the adequate voltage range $[V_{i,\min}, V_{i,\max}]$, $a_{ij,\min}$ and a_{ij},max are, respectively, the smaller and the larger allowed taps of the transformer and voltage regulator in the branch i–j, $Q_{Ci,\max}$ is the higher value of reactive power capacity allowed in the node i, $Q_{INV,n}$ is the reactive power injected/absorbed by the nth inverter, where $Q_{INV,\min}$ and $Q_{INV,\max}$ depend on the considered inverter purpose. It is important to note that the inverter can be an DG technology, an D-STATCOM or an SST, where the D-STATCOM only process reactive power in distribution networks.

The relationship between the reactive power processing and the energy losses are directly related to the equipment power processing that can control the voltage, the connection point this one, the load profile and the voltage levels of the distribution network. This way, the excessive increase of the equipment reactive power can elevate the energy losses of the distribution network [32]. Operational conditions are verified for each node with the OpenDSS software, which performs the power flow algorithm based on the inverse matrix of node admittances, integrated to the KLUsolve method [33,34].

3. Coordinated VVC algorithm

The VVC algorithm was developed through an integrated interface between MATLAB® and OpenDSS softwares, where the network data can be obtained from SCADA. Fig. 2 shows the global architecture to the proposed coordinated VVC, which verifies the need of action of the coordinated VVC at every 1 h or when some event (load defect/rejection) occurs and acts in real-time, according to the discretized load curve. In this case, it is considered that the local control normally operates between this one hour interval.

At first, there is a reading of the field equipment parameters supplied by SCADA and the adjustments are updated in the OpenDSS software, which performs the network power flow for the received load conditions and equipment adjustments. The MATLAB® software receives the power flow data from OpenDSS and executes the proposed VVC algorithm, which verifies the voltage violations to points out the control actions in equipment adjustment (increase/decrease) to correct the problem.

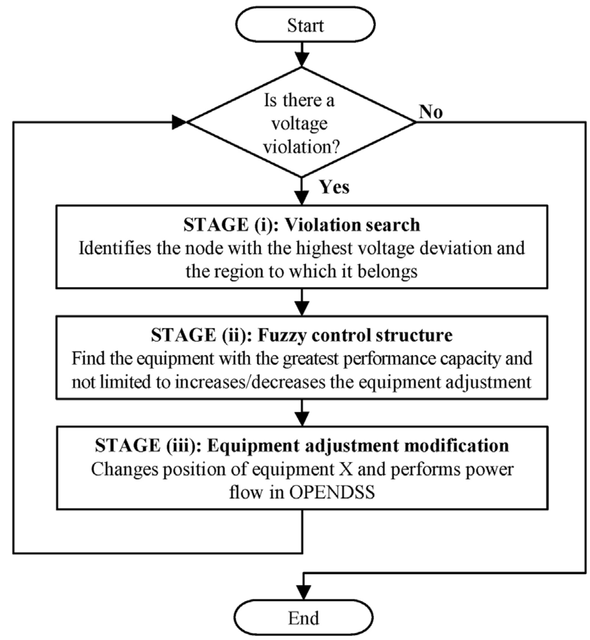

Fig. 3. Main stages of the coordinated VVC algorithm.

The coordinated VVC algorithm is composed by three main stages, that are presented in Fig. 3.

3.1. Stage (i): violation search

At Stage (i) there is a search for voltage violations of the network nodes and the selection of the node with the larger violation.

All violated voltage nodes are identified in the system. The voltage deviations in the nodes are calculated and normalized considering [higher negative deviation, higher positive deviation] in a proportional scale between [−1, 1].

These normalized voltage deviations are used to identify the node with higher violation, similar to the proposals of Refs. [23,24]. In this sense, by correcting the worst violated voltage (higher deviation), other violated nodes will also be able to be corrected, consequently.

3.2. Stage (ii): fuzzy control structure

The coordinated VVC strategy is based on the fuzzy logic and takes into consideration a strip of adequate voltage operation in the node i between the limits of 0.93 p.u. and 1.05 p.u. Voltage values that do not fit in this strip are considered as voltage violations in the node and activate the coordinated VVC algorithm to correct the voltage violations.

Proposed fuzzy control structure uses two cascade fuzzy controllers, as shown in Fig. 4. The first controller (C1) is responsible to generate the *Action Capacity Matrix* (ACM) from two inputs called *Effectiveness Matrix* (EM) and *Commutativity Matrix* (CM). The ACM represents numerically the effectiveness of each equipments adjustments to act in each network node and, at the same time, that does present a low number of commutations. The EM represents numerically the effectiveness of all equipments adjustments for all network nodes. The CM represents the counting of commutations of all equipments aiming to improve the selection strategy of the control equipments.

After the ACM obtainment, the equipment with the most action capability is selected to act in the worst network voltage node that

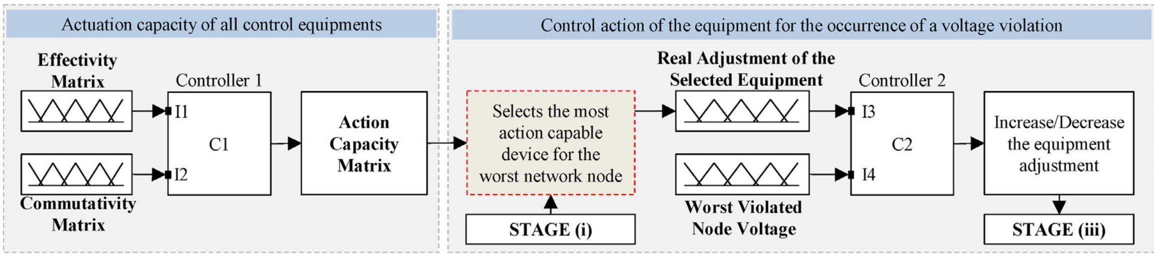

Fig. 4. Flowchart of Stage (ii). Set of fuzzy controllers to the proposed application.

was identified in Stage (i). The second controller (C2) is responsible to return the equipment adjustment to be modified in OpenDSS software and has two inputs called the *Real adjustment of the Selected Equipment* and the *Worst Violated Node Voltage*.

Only the final adjustment value that is obtained after the necessary improvements to correct the violated voltages will be sent to the field equipments, through the procedure described in Stage (iii).

3.2.1. *Fuzzy rules*

The four fuzzy control input variants were divided into five linguistic variants: NB (Negative Big); NS (Negative Small); ZE (Zero); PS (Positive Small) and PB (Positive Big). All of them have the same weight. Rules maps interpreted by each fuzzy control are shown in Tables 1 and 2.

3.2.2. *Effectiveness matrix (EM)*

The VVC algorithm identifies which equipment is the most effective to the voltage violation correction in the system. Unlike already proposed VVC strategies, in this paper the effectiveness of all equipments are calculated only to the node where the worst violation occurs, what conveys the reduction of the computer effort.

From Fig. 5(a) the following steps describe the procedure to obtain the EM:

Step 1—identifies the worst violated node voltage.

Step 2—selects the voltage control equipments and perform the power flow calculus for each adjustment of the equipment. The voltage values in the worst node are stored for each adjustment position.

Step 3—calculates the voltage difference between the actual voltage values obtained in Step 2 and the reference value, resulting in the voltage deviation.

Step 4—calculates the average of the voltages deviations found in Step 3. This process results in the average of the voltage deviations caused by each control equipment in the worst node.

Step 5—normalizes the average of the deviations between [−1, 1] to build the EM, where the matrix have one line and *n* columns, which depends of the number of available control equipments.

3.2.3. *Commutativity matrix (CM)*

The stages that represent CM are presented in Fig. 5(b). Initially, the number of equipments commutations is counted that were used in the voltage violation correction in the previous interaction. These commutations values are normalized in a proportional scale between [−1, 1], where "−1" is the equipment with the fewer number of commutations, and "1" the equipment with the most. The other equipments are represented with proportional values into this gap to obtain the CM.

3.2.4. *Selection of the most capable equipment*

The procedure to select the higher actuation capacity equipment follows the steps showed in Fig. 5(c). Firstly, the equipment with higher acting capacity is selected among the available equipments. Next, the physical limitations of the selected equipment is verified to guarantee that these limitations will not occur in their adjustment position (maximum or minimum), which also depend on the kind of deviance (positive or negative). For example, a negative voltage violation (under 0.93 pu) cannot be corrected from an equipment that is limited in its maximum adjustment and vice

Table 1
Fuzzy rules of C1 to obtain the action capacity matrix.

I2		I1				
		Effectiveness				
		NG	NS	ZE	PS	PG
Commutativity	NG	NS	ZE	PS	PG	PG
	NS	NG	NS	ZE	PS	PG
	ZE	NG	NS	NS	ZE	PS
	PS	NG	NG	NS	NS	ZE
	PG	NG	NG	NG	NG	NS

Table 2
Fuzzy rules of C2 to obtain the equipment adjustment.

I4		I3				
		Real adjustment of the selected equipment				
		NG	NS	ZE	PS	PG
Violated voltage percentage	NG	PG	PG	PG	PS	ZE
	NS	PG	PS	PS	PS	ZE
	ZE	ZE	ZE	ZE	ZE	ZE
	PS	ZE	NS	NS	NS	NG
	PG	ZE	NS	NG	NG	NG

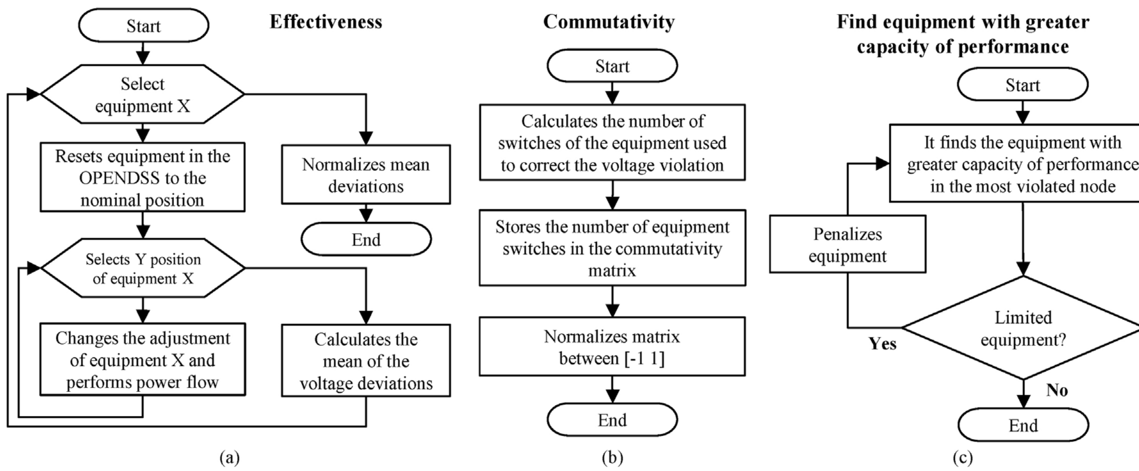

Fig. 5. Flow graphs to obtain the matrices. (a) Effectiveness. (b) Commutativity. (c) Equipment with greater capacity of performance.

versa. The algorithm impose temporarily a penalty withdrawing these equipments from the list of acting equipments, what allows the next equipment with higher acting capacity to be selected. If no solution is found, just the EM is considered to select the equipment.

3.3. Stage (iii): modification in the control equipment

In this stage, the equipment adjustment is modified in OpenDSS, which performs the power flow to verify the voltage corrections in all violated nodes. Since there are still violated nodes, the VVC algorithm is repeated from Stage (i), and the previous adjustment positions of the equipments are maintained until the node voltage becomes adequate.

It is important to highlight that more than one equipment can be used in the correction of a voltage violation in a node. This situation can occur because one equipment can become limited or the commutation of a previously used equipment can change the ACM. In this sense, the algorithm uses the next available equipment, respecting the ACM, and only ends the process when all violated voltages becomes adequate.

In complex conditions, when the algorithm dos not reach the limits defined as adequate, the algorithm increases the voltage limits to guarantee the convergence, as proposed in Ref. [24]. In this case, the algorithm find a solution with the lower increment in the voltage limits.

After doing the procedures previously described, the new adjustment positions are sent to the field equipments through SCADA system.

4. VVC numerical example

A simplified distribution network shown in Fig. 6(a) is used to give a numerical example of the coordinated VVC algorithm. The system has eighteen loads, which are classified as residential and industrial, located in nine network legs. Three control equipments were taken into consideration: two capacitors banks (C1 and C2), where each has six commutation levels of 100 kVAr; and one voltage regulator (R1) with a 0.0625 p.u. step in ±16 adjustment positions. The active and reactive powers of the substation are presented for each phase, respectively, in Fig. 6(b) and (c).

The numerical example of the coordinated VVC is presented in Table 3, which have the results of EM, CM and ACM for each hour. It can be observed that the voltage violations in the system occur in accordance to the load curves shown in Fig. 6(b) and (c), which presents a more expressive amplitude from the hour 7:00.

At hour 7:00, there are voltage violations in buses 9 and 10. The bus 10 is most critic one. This way, equipment R1 was selected due to its higher effectiveness in the bus 10. Besides that, as there are no voltage violations previous to this time, CM is null, what makes ACM equals to EM. The worst violation in the hour 8:00 occurs in bus 10. It can be observed in ACM that C1 and C2 present the same action capacity and still were not used in the system. In this case, the algorithm choose the equipment C2, prioritizing the EM values. At hour 9:00, there are voltage violations in the buses 8, 9 and 10, where C1 is selected even with low effectiveness, but low usage in the system. At hour 15:00, there is again voltage violation in bus 10. At this moment, where C1 have four commutations. In this case, the algorithm select R1, because this one have a higher ACM value in compared to C2. At hour 19:00, the worst voltage violation is identified in bus 8, where C2 was selected.

The voltage profile in the bus 10 is shown in Fig. 7 because it has the worst voltage violations. In this result, the voltages obtained after the coordinated VVC adjustment are compared to the voltages obtained before the VVC adjustments at the same time. Thus, the previous modifications in a certain equipment are kept in the next hour.

The main contribution of this paper is related to the commutativity strategy to achieve the commutations balance between the

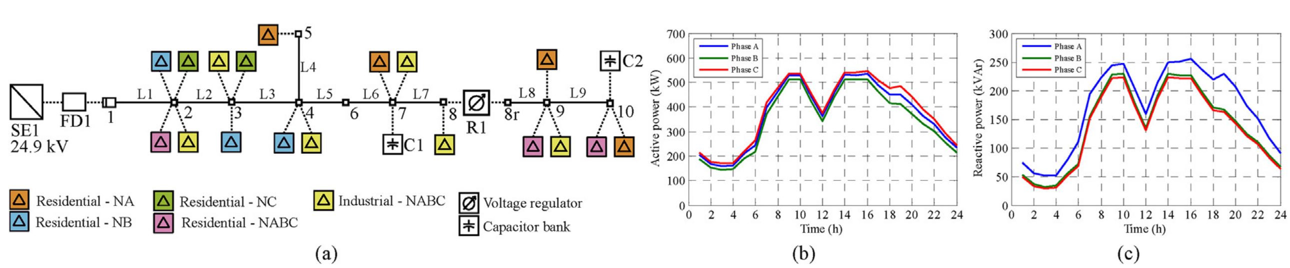

Fig. 6. Distribuition test network. (a) Network topology. (b) Active power behavior. (c) Reactive power behavior in substation.

Table 3
Numerical example of the coordinated VVC algorithm for 24 h.

Hours	Violated buses	Worst node	Effectiveness			Number of Commutations			Action capacity			Selected equipment	Increase/decrease			Voltage in the worst node	
			C1	C2	R1	C1	C2	R1	C1	C2	R1		C1 (kVAr)	C2 (kVAr)	R1 (step)	Before (p.u.)	After (p.u.)
1–6	There is no violation of voltage levels																
7	9 and 10	10	−1	−0.7517	1	0	0	0 → 2	−1	−0.7517	1	R1	0	0	1 → 1.0125	0.922	0.932
8	9 and 10	10	−1	−0.7497	1	0	0 → 2	2	1	1	−1	C2	0	0 → 200	1.0125	0.927	0.933
9	8, 9 and 10	10	−1	−0.7472	1	0 → 4	2	2	1	−1	−0.3158	C1	0 → 400	200	1.0125	0.925	0.933
10–14	There is no violation of voltage levels																
15	10	10	−1	−0.7494	1	4	2	2 → 4	−1	1	0.004	R1	400	200	1.0125 → 1.025	0.929	0.939
16–18	There is no violation of voltage levels																
19	8, 9 and 10	8	−1	0.4354	1	4	2→5	4	−0.03	−1	1	C2	400	200 → 500	1.025	0.924	0.933
20–24	There is no violation of voltage levels																

Where the symbol "→" represents that the equipment adjustment was modified.

devices used in the VVC strategy. Fig. 8(a) and (b) shown the evolution of the number of commutations with the CM disabled and enabled, respectively. Thus, due to the use of the effectiveness and commutativity strategy, a reduction of C2 use in terms of commutations is obtained when the C1 capacitor starts to be processed. This balances the use of devices in the voltage violations correction.

5. VVC case study and results

The distribution network used as study case corresponds to a modified IEEE 34 bus system [35] with nine control equipments. Three new capacitors banks (C1, C3 and C4), a reactive static compensator for distribution systems D-STATCOM (D1) and a distributed generator (DG1), as well as a transformer (T1) with electronic commutation were inserted. The active and reactive power profile of the substation is presented in Fig. 9(a) and (b), respectively.

The system was classified into two action regions of the VVC, as shown in Fig. 9(c). The characterization of the control regions was defined according to the preservation of the voltage regulators (R1 and R2), since they are the most effective equipments that act in the most of grid buses. Thus, the equipments R1, C1, C4 and DG1 acts in region 1 and the equipments R2, T1, C2, C3 and D1 acts in region 2.

The tap adjustments of R1 and R2 are the same used in the numerical example as well as the reactive power steps for C1 to C4. The equipment T1 has an electronic tap adjustment with five steps of 0.05 p.u. The reactive power injected/absorbed by the inverter is limited according to the standard NBR16149, which limit the reactive power injected/absorbed between ±43.58% of the rated active power (0.9 lagging/leading power factor). The D-STATCOM reactive power limits was considered as ±1 kVAr.

5.1. Voltage profile analysis—performance evaluation

According to the Electrical Energy Distribution Procedures in the National Electric System (PRODIST Module 8) established by the National Agency for Electrical Energy (ANEEL, Brazil), the suitable voltage limits are considered between 0.93 p.u. and 1.05 p.u. for the systems supplied between 1 kV and 69 kV.

The three-phase voltages behavior in the maximum demand that occurs at hour 19:00 for all system buses is presented in Fig. 10(a) with CM disabled, i.e. with just the EM enable, and in Fig. 10(b) with CM and EM enabled. Both results are showed before and after the VVC application.

It is possible to note that the voltage profile presented in Fig. 10(a) presents a slight rise when compared to the voltage profile presented in Fig. 10(b). This characteristic occurs due to the CM activation, which reduces the use of the most effective equipments (R1, R2 and T1).

Fig. 11(a) and (b) respectively present the voltage profiles in buses 12 and 29 over 24 h. The bus 12 is a single-phase branch with a typical rural load shape and has the worst violations in region 1. The bus 29 is a three-phase branch with a typical industrial load shape and has the worst violations in region 2. The voltage profiles of these nodes was were corrected to within the suitable voltage range between 0.93 p.u. and 1.05 p.u. in the 24 h through the use of different electrical network equipments, selected by the proposed VVC technique.

5.2. Commutativity performance and comments

The commutativity performance is verified to demonstrate that the use of different equipments allow to reduces the number of equipments commutations. Fig. 12(a) shows the equipments commutations just with EM enabled and Fig. 12(b) with EM and CM

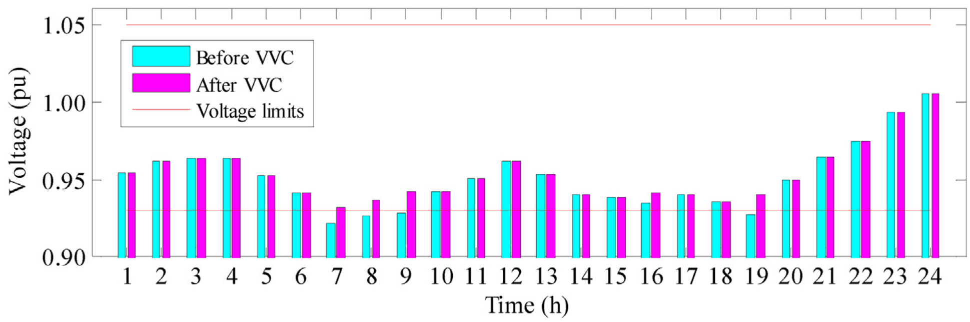

Fig. 7. Voltage behavior in bus 10 before and after the VVC.

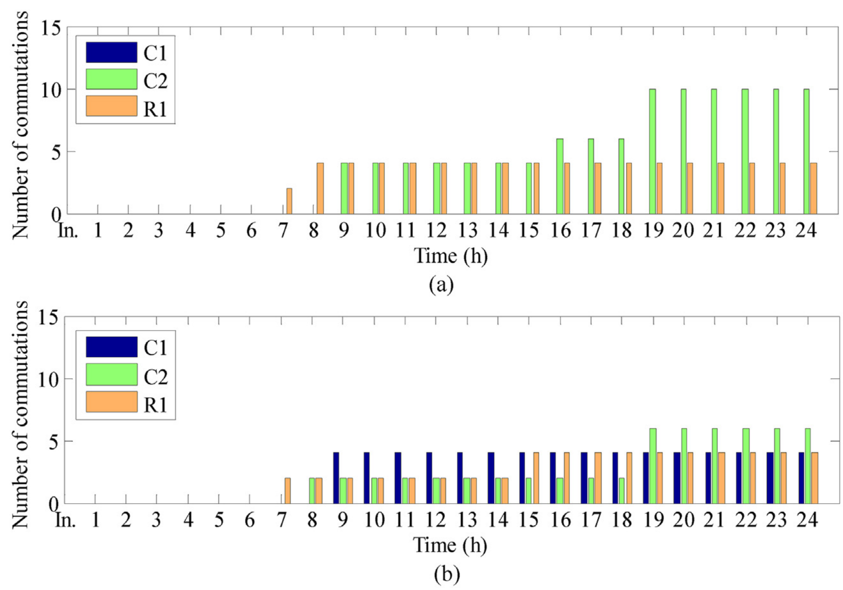

Fig. 8. Evolution of commutations in the system with (a) EM enabled and CM disabled and with (b) EM and CM enabled.

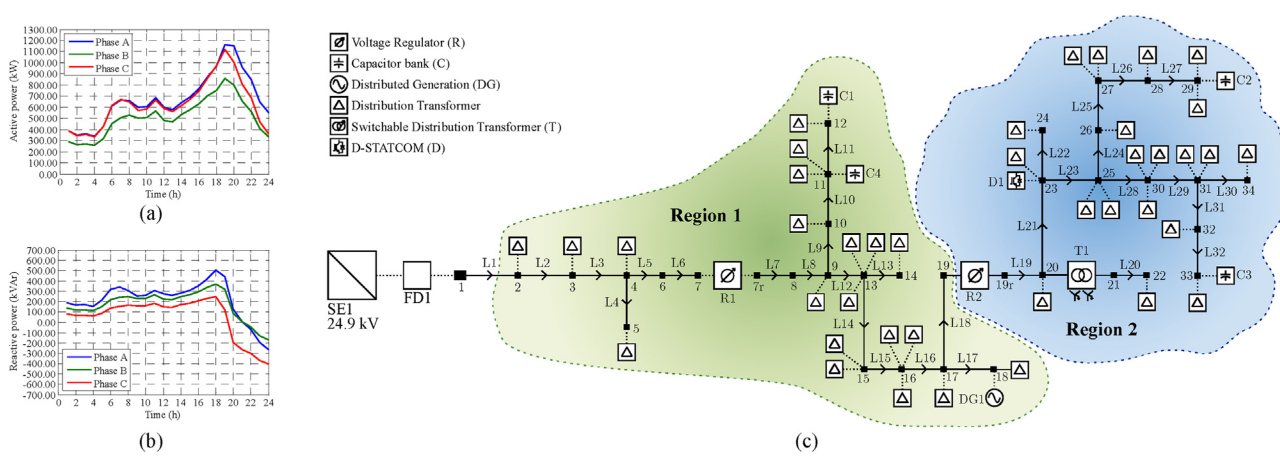

Fig. 9. Modified IEEE 34 node test feeder. (a) Active and (b) reactive power curves in the substation. (c) Network topology.

enabled. In the first result, the most effective equipments (R1, R2 and T1) are used to guarantee a suitable voltage profile. In the second one, the correction of region 1 is obtained by using R1, C1 and DG1, and demonstrates a great commutations balance of these devices. Likewise, the corrections made by R2, C2, C3 and D1 were also satisfactory, by adjusting the voltage levels in region 2.

An important characteristic is the balance among the equipments commutations in the same region, for instance, in region 1, distributed generator DG1 and capacitor bank C1 begin to be used instead of R1. The same feature occurs in region 2, where D-STATCOM begins to be used instead of R2 to guarantee suitable voltage levels.

The fuzzy logic approach provides a good performance in the voltage corrections, where the controller adjusts the equipments according to the need of the respective regions. These regions can

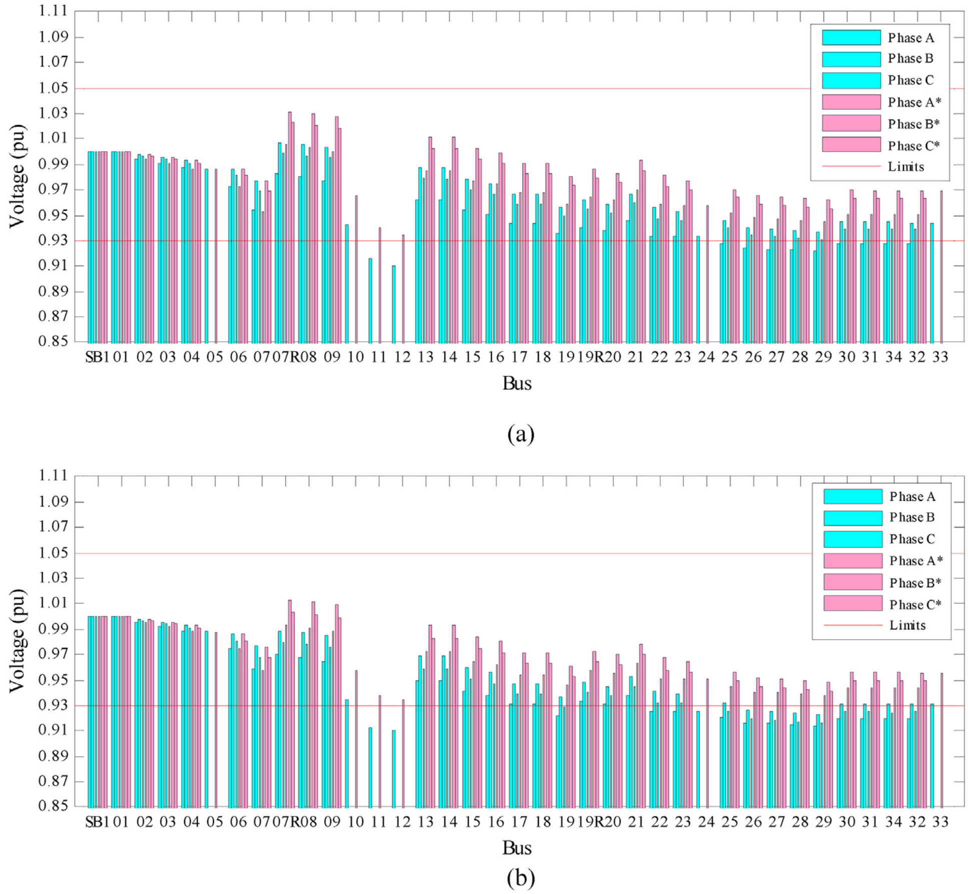

Fig. 10. Voltage behaviors to the maximum demanding time (19 h) before (phases ABC) and after (phases A*B*C*) the coordinated VVC application (a) with CM disabled and (b) with CM and EM enabled.

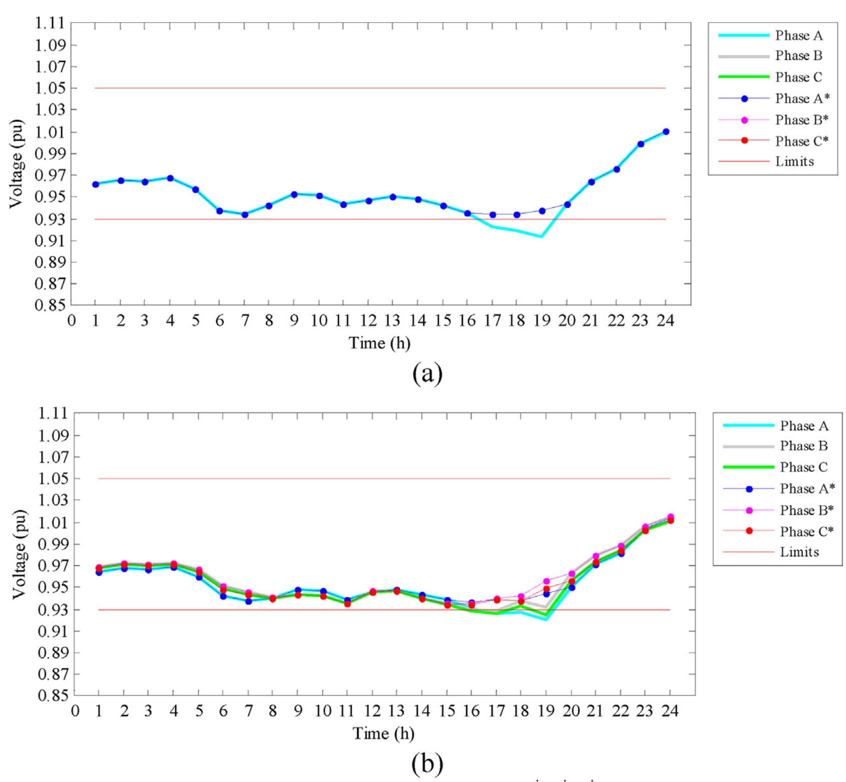

Fig. 11. Voltage profile before (phases ABC) and after (phases A*B*C*) the coordinated VVC application in (a) Bus 12 and in (b) Bus 29.

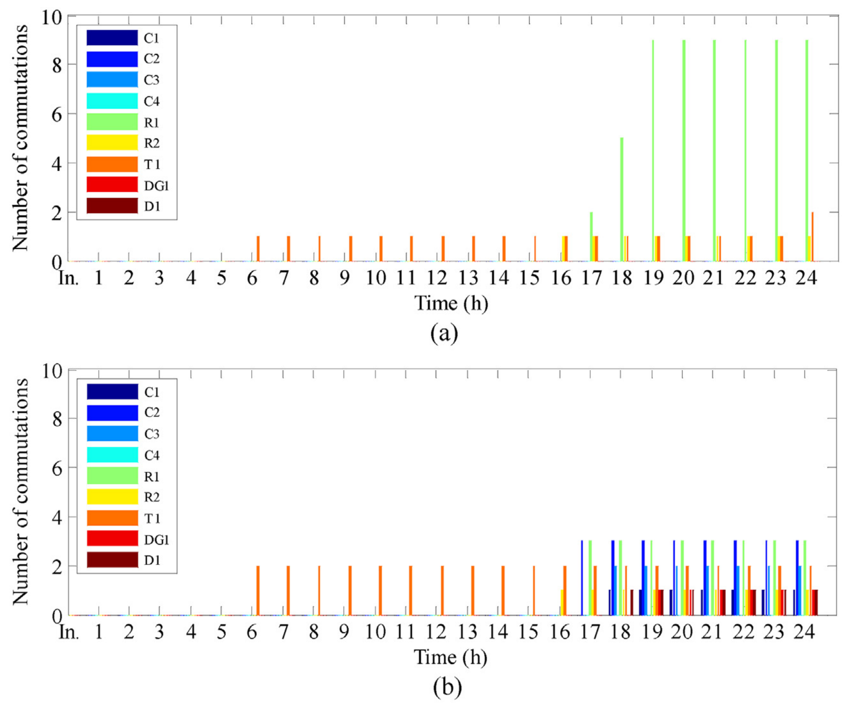

Fig. 12. Behavior of the equipments commutation along 24 h with (a) EM enabled and CM disabled and with (b) ME and CM enabled.

be modified to preserve other equipments, which depends on the technical operational goals.

The use of the proposed VVC methodology makes possible new operational objectives of the distribution networks in a smarter concept, such as the commutativity and effectiveness in the equipment selection. Also, these functions can be enabled just in some regions aiming to comply local operational goals.

6. Conclusion

This paper has presented a novel and efficient strategy of real-time VVC for distribution networks aiming automatic and coordinated action to produce a smarter systemic control effect in the distribution network. Also, the proposed VVC possibilities the coordinated action of conventional equipments, such as voltage regulators and capacitor banks, along with devices that are based on power electronics, such as the transformers with electronic commutation and the inverters (D-STATCOM and distributed generation).

It is noted that solutions with balance in the number of equipment commutations contributes to higher equipment lifetime and lower maintenance of this one, which is obtained through the commutativity function. Strategies that use only effectiveness can prioritize the action of the same equipment, which becomes undesirable, as there is a diversity of available VVC equipments. In this sense, the methodology presented is promising for the VVC of distribution networks both with conventional equipments and power electronics.

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