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A predictive agent-based scheme for post-disturbance voltage control

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ABSTRACT

In this paper a predictive scheme for dynamic voltage control is proposed, which maintains voltage security (both voltage stability and voltage profile) of power system, in a wide area manner. The proposed algorithm, upon detecting any voltage violation (both under- and/or over-voltages), employs organized multi-agent system (OMAS) in order to coordinate the employment of reactive power devices in returning voltage magnitudes of all buses to the acceptable range and steady behaviour. In order to achieve high benefits of power system response, each agent takes advantage of a predictive scheme, which is based on the corresponding bus voltage trend. By this predictive characteristic, each agent coordinates its command for remedial action with the prediction of bus voltage destination. Moreover, this predictive characteristic is extended to consider incoming remedial actions (or to compensate the latency in activation of previously decided remedial actions). These predictive characteristics lead to making a smooth waveform and reducing the number of needed remedial actions. The performance of the proposed scheme against different scenarios in Nordic32 test system is presented, where the results illustrate effectiveness and robustness of the proposed scheme.

1. Introduction

Wide area monitoring, protection, and control (WAMPAC) is a platform for control strategies, having a global management on power system disturbances with more effective contributions, if well-organized indeed. WAMPAC can prevent the spread of large disturbances by processing system-wide information gathered from all/selected local points. Indeed, WAMPAC became enabled when synchronized measurement technology (SMT) found its application in phasor measurement units (PMUs). These devices provide voltage and current phasor and frequency information, synchronized with high accuracy to a common time reference produced by a global positioning system. More key reasons for implementation of WAMPAC systems have been addressed in [1,2].

By employing wide area monitoring under conventional centralized control approach [3,4], although a pseudo real time data measurement gathered from dynamics of power system is created, the weakness of these schemes in maintaining resiliency in power system remains. Moreover, the traffic in data transferring to a unit control center and high dependency on this control center is additional problem of these approaches.

Besides, in recent years, a distributed control strategy named as multi-agent system (MAS) has been introduced by artificial intelligence researchers. By employing MAS, a complex problem is split to some easier sub-problems and each sub-problem is delegated to an agent; while agents of an MAS are in communication, cooperation, and coordination [2]. With the development and complement of the MAS theory, many power engineers have attempted to apply it to power system control schemes in recent years.

Hitherto, by employing MAS in the field of voltage control (mainly under-voltages), various schemes have been proposed. In [2], an MAS under WAMPAC framework has been introduced, in order to simulate the cooperation and coordination of agents in eliminating under-voltages against power system disturbances. In [5], by applying MAS in a small test system, an optimal control issue has been formulated and an index has been presented to provide coordination of tap changer transformers. In [6], an agent based algorithm for integrated volt/var control has been presented which provides distributed intelligence for smart grid. The voltage regulator and shunt capacitor controlled by intelligent agents collaborate to determine optimal setting for maintaining the system voltage profile and reducing the switching of shunt capacitors. In [7], an MAS-based scheme has been proposed to prevent long term voltage instability induced by cascading trips. In this scheme an optimal emergency control strategy has been derived based on sensitivity analysis. In [8], a multi-agent based hierarchical control has been presented, in order to maintain secure voltages in autonomous micro grid. In [9], a multi-agent receding horizon control (RHC) has been introduced to prevent voltage collapse in a multi-area power system; where each agent preserves its local information and communicates with its neighbours to find an optimal solution. Also, in [10], a

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novel multi-agent-based voltage control scheme has been presented, which dynamically adapts the settings of control devices (such as AVR of generators, on-load tap changers- OLTCs, and FACTS) to optimize operational objectives (such as maintain voltage stability, improve voltage profile, and reduce transmission power loss). In [11], an agent based distributed reactive power management scheme has been proposed to improve the voltage stability of energy distribution systems with distributed generation units. In [12], a multi-agent control system (MACS) has been proposed to eliminate the congestion of feeders and amend voltage violations by coordinating the operation of reactive power control sources and/or reconfiguring the distribution network. In [13], a multi-agent system based decentralized coordinated control scheme has been constructed to deal with the complex energy management problem of DGs. Finally, in [14] a secondary voltage regulation strategy based on multi-agent theory has been presented for improving the performance of secondary voltage control actions under different system operating states, where the concept of virtual control agency has been proposed to adapt the emergency dynamic control environment.

A brief comparison of the previously published methods and the one in this paper has been given in Table 1.

This paper follows the fundamental concepts of [2] in applying MAS for dynamic voltage control of power systems. But it innovates in proposing a voltage control scheme with the following novel features (rather than [2] and other schemes):

- Predictive, as it decides to take remedial actions according to:
  - ○ relying on the prediction of bus voltage destination via its trends in recovery of voltage magnitudes, whenever they are helpful (i.e., following a disturbance, there are bus voltage magnitudes, that after an under-shoot and/or over-shoot, return back to the permissible voltage limit; because of automatic actions of AVRs. Identification of these situations and relying on voltage trends for restoration of voltage magnitudes manages any request for remedial actions);
  - ○ notification of incoming remedial actions (i.e., at each time instant, there may be remedial actions to become activated now or in the future, upon the requests in the past. Identification of these actions, which are in the queue, and predicting their contributions on bus voltages, again, manages any request for remedial actions);
  - ○ double-sided in controlling voltage magnitudes, i.e. taking actions against over-voltages as well as under-voltages.
  - ○ efficient, as it is able to control voltages, dynamically, with lower number of actions, more effective and higher speed in achieving acceptable results, and more powerful in controlling against stressful disturbances.

The rest of this paper is structured as follows. In Section 2, the basic concepts, including MAS and dynamic voltage control, are described. The proposed approach is introduced in Section 3. The simulated power system and the results are explained and discussed in Section 4. Finally, at the end, conclusions are presented.

2. Basic concepts

In this section, the basic concepts of MAS and dynamic voltage control are described.

2.1. Multi-agent system (MAS)

Multi-agent systems are composed of devices with sensing, communicating, interacting, and computing elements, named as agents. The agents can be divided into two categories including Intelligent Agent (IA) and Reactive Agent (RA) [15]. IAs are systems with two important capabilities. First, they should contain appropriate software, capable of deciding for themselves what they need to do in order to satisfy their design objectives. Second, they should be capable of interacting with other IAs. The main features of an IA are communication, cooperation, coordination and negotiation. In power networks, the host computers in substations can behave as IAs and their collection in one of the common forms of organization (in this wok Holarchy organization was employed [16]) constitutes a multi-agent system. Actually, an MAS is a collection of IAs in companion with RAs; where the former ones cooperate and coordinate to solve a particular problem by controlling RAs, i.e. managing the actions assigned to RAs [17].

In this study, IAs are assumed to have the capability of receiving voltage phasors, analyzing received data, taking rational decisions, and sending commands to OLTCS, reactors, and capacitor banks. These are called Bus Agents (BAs). BAs can also make negotiations with other BAs, i.e. how each of agents tries to convince the others to help it in achieving its assigned goals. In this work, a scenario-based negotiation among BAs is applied, where a priority index is introduced and at each time the assigned value to each BA defines the priority of its commands, through which a clear and reliable agreement will be achieved in allocating and managing RAs.

Then, commands of BAs, for retaining power system integrity, are applied to each of RAs under its control. These commands, i.e. managing the positions of taps of OLTCs (with considering the inherent delays in tap changing [18]) and connectivity of reactors and capacitor banks, are delivered to and conducted by Tap Agents and Cap Agents, respectively. These agents are in the category of RAs.

The proposed organized multi-agent system (OMAS) is supposed to be built in companion with WAMPAC infrastructure, as shown in Fig. 1. Generally, there are phasor measurement units (PMUs) that measure

Table 1
Comparison of the reviewed schemes.

Schemes	Abilities					
	Reacting against sudden changes	Double-sided voltage control	Considering delays	Attempts to reduce remedial actions	Attempts to reduce settling time	Employing simple control devices
[2]	√	–	–	–	–	√
[5]	–	√	–	–	√	√
[6]	–	–	√	√	–	√
[7]	√	–	√	–	–	–
[8]	√	√	–	–	–	–
[9]	√	–	–	–	√	√
[10]	√	–	–	–	√	–
[11]	√	–	√	–	√	–
[12]	√	√	√	–	–	–
[13]	–	–	–	–	√	–
[14]	√	√	–	–	–	–
This paper	√	√	√	√	√	√

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