2012 Conference on Smart Electric Grids Technology (SEGT2012)
December 18-19, 2012, Tehran, Iran

Dynamic Control Strategy in Power system Based on Multi-agent System

Alireza Ashrafi[a] , S.Mohammad Shahrtash[b]
[a]alirashrafi@elec.iust.ac.ir , [b]shahrtash@iust.ac.ir
Center of Excellence for Power System Automation and Operation
Iran University of Science and Technology (IUST)

Abstract: *Voltage instability and collapse have been continued to be the major problems in voltage control of power systems for many decades. WAMPAC infrastructures have been introduced and applied in power systems to monitor, protect and control power networks in order to improve stability margins. Also, some control structures have been used to enhance voltage stability. Newly multi-agent system theory has been used in smart grids and control of micro grids. Emerging multi-agent approach and the organization of multi-agent systems make it possible to introduce dynamic structure for control of power system. A new strategy has been proposed in this paper based on multi-agent system and employed for WAMPAC for the purpose of increasing the voltage stability margins.*

Keywords: Multi-Agent System, Organization, Agent, WAMPAC, Voltage Control.

I. INTRODUCTION:

NOWADAYS, power systems are working under more stress than before because of continuous increasing in load demand and also due to more economical issues [1]. In addition, power networks are more widespread than last decades. Occurrence of a contingency or load event may lead power network to voltage instability, force it to catastrophic outages and finally collapse and black out. This is due to low power stability margins rather than before. Accordingly, there is a vital need to more flexible instruments and more reliable and faster strategy to control power system. In this respect, some infrastructures have been introduced to increase stability margins and increase efficiency of power networks such as FACTS and wide area measurement, protection and control (WAMPAC). Those infrastructures help power engineers to take actions faster in order to control power networks and as a result, improve stability margins. WAMPAC infrastructure provides a snapshot from power system at any time, which control center uses these snapshots and percepts the state of power system.

On the other hand, some approaches have been used to control power system more effectively. In this area, a decentralized structure has been replaced by a hierarchy structure in two or three layers under the name of secondary or tertiary structure voltage/VAR control strategy. Accordingly, another approach has been merged in artificial intelligence in recent years called multi-agent approach or Multi-agent System (MAS). MAS paradigm divides a complex problem to some easier sub-problems and delegates each sub-problem to an autonomous agent to deal with; while all agents are in coordination, collaboration, and cooperation in order that they can converge their solution to the main solution [2]. In other words, agents operate in cross-related program to achieve the main goal [3]. Agents are in cooperation, coordination, and collaboration through negotiation and their arrangement and data flow have been affected by organization applied in the system. In this context, a complex system may be composed of some MASs each of which possesses some agents [4].

There are some similarities between MAS and power system construction like as dispersion of their components, independently acting of their components as well as having relation, and complexity in behavior [3]. These similarities and also autonomy, flexibility, extensibility, and being robust are some beneficial behavior of multi-agent approach which encourage power engineers to use MAS in power system applications [5]. In addition, MASs provide a modeling approach by offering a way of viewing the world [5]. An agent system can intuitively represent a real-world situation of interacting entities, and give a way of testing how complex behavior may emerge [5].

There are a few published papers in this area, up to now; where in [4] a four buses power system equipped with some voltage controller components as AVR, SVC, and STATCOM is supposed. These voltage controller components, as three agents are placed in two MASs in order to clear voltage violations after a contingency occurrence. In fact it is the negotiation between agents and consequently their reactions that clears the voltage violation. Their negotiation is studied based on "request and response" and also based on "local estimation and voluntary action". In [6] four agents (two SVCs and two STATCOMs) are considered in order to eliminate voltage violation in a 39 buses power system. The coverage of each agent is extended from single location to multiple ones in contrast with [4], in order to extend the influence of each agent on the power system. Alternatively, [7] has focused on coordination of some servicing agents capable of supporting reactive power in a power system, where it proposes one Multi-agent System with a *flat organization* which uses directory facilitator to coordinate. An optimal coordination method for MAS based control system in normal operating condition and also in contingencies, is proposed in [7], for enhancing the ability of fast and coordinated voltage and reactive power control. In [8], sensitivity coefficient is used in a radial distribution feeder to dispatch reactive power in order to support voltage; while each distributed generator is considered as an agent. All these agents together with one of the monitored nodes as a moderator agent form a Multi-agent System. In addition, [9] has proposed a flat organization for wide area back up protection which some agents create a temporary team to remove fault.

In this paper a study has been performed on the organization of multi-agent systems employed for voltage control in power system. The organization is based on negotiation between agents and topology of power system.

At the rest of this paper and in section II, an introduction about multi-agent systems has been presented; also, organization of multi-agent systems and their organization have been stated in II. Section III is dedicated to control strategies and then section IV is about results of the simulation and a comparison has been done between the organizations. Finally conclusion has been presented in V.

II. MULTI-AGENT SYSTEM:

A. Introduction:

By definition, an agent is a software or hardware entity capable of taking some actions autonomously and also able to communicate with other agents located adjacent to it [2]. Each agent is delegated to do a task while is in cooperation, coordination and collaboration with other agents. In other words, agents are entities that simulate rational behaviors and have the capability to communicate through a network to achieve their goals in a particular domain [10]. Obviously, every agent must be able to perceive some part of the environment and be able to alter that by taking some actions [2]. In other words, environment must be observable to any agent and this observability may be achieved by some sensors or through computing program and also by communication channel and messaging [5]. Figure.1 has shown an agent in its observable environment and an agent which is able to change the environment by some actions.

Generally, agents are divided in two categories:

- **Cognitive agents**
- **Reactive agents**

Reactive agents are some agents without any intelligence in making decisions, they take decision just by a change in their environment. These agents are used where fast speed in actions is required. On the other hand, cognitive agents have a level of intelligence, where after a change in the environment, they make decisions based on their intelligence and take some actions on this basis. Actually, cognitive agents are the brain of an MAS.

A multi-agent system is composed of two or more agents [5]. In this area, cooperation of agents located in an MAS make the environment to be adjusted with the intentions of designer. Clearly, communication and negotiation between the agents placed in an MAS and also between two MASs, define the role of each agent to achieve its goals.

B. Organization:

Optimization of the decision making process in multi-agent systems is very challenging due to the fact that each agent needs to take into account other agents in the system [11]. An approach to cope with large scale systems is to organize agents towards a common goal where each agent interacts with the other agents according to a network topology [11].

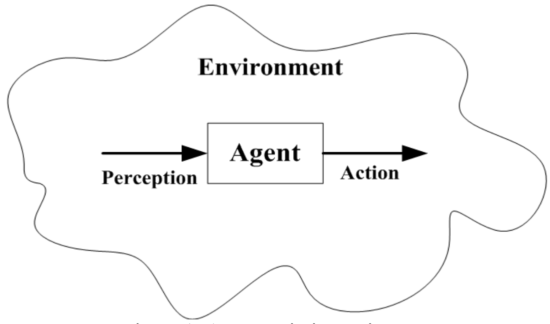

Figure 1: An agent in its environment.

An organization of multi-agent system is the collection of roles, relationships and authority structures which govern MAS behaviors [12]. All multi-agent systems possess some or all of these characteristics and therefore all have some forms of organization, although it may be implicit. Like human organizations, such agent organizations guide how the members of the population interact with one another [12].

In addition, organization might influence on authority relationships, data flow, resource allocation and coordination patterns. These parameters can help groups of simple agents to exhibit complex behaviors or a complex system can be modeled by simple agents [12]. In other words, a number of simple agents can reduce the complexity of their system by settling an appropriate organization.

Since an organizational structure can affect the behavior of the system, organization must serve the purpose of system designer. In other words, the organization of a system can have significant impact on short and long-term performance depending on the characteristics of the agent population, scenario goals and surrounding environment [12].

Generally, each approach has different characteristics which may be more suitable for some problems and less suitable for others. Organization can be used to limit the scope of interactions, provide strength in numbers, reduce or manage uncertainty, reduce or increase redundancy or formalize high level goals which no single agent may be aware of [12]. On the other hand, organizations can affect computational or communication overhead, reduces overall flexibility, and increase an additional layer of complexity to the system [12].

There are different organizations in literature each of which may be used based on considered application. In other words, there is no single type of organization that is suitable for all situations. Some types of organizations are Hierarchy, Holarchy, Team, and some other which have not been considered in this paper.

- **Hierarchy organization:**

Hierarchy or hierarchical organization is perhaps the earliest example of structured, organizational design applied to multi-agent system and also to control large systems. In this organization, agents are conceptually arranged in a tree-like structure while higher agents in the tree have a more global view than those located in lower levels [12]. Indeed, task decomposition trees are a popular way of modeling individual agent plan recipes; a hierarchical organization can be thought of as an assignment of roles and interconnections inspired by the global goal tree [12].

- **Team organization:**

An agent's team consists of a number of cooperative agents which have agreed to work together toward a common goal. The agents in a team attempt to maximize the utility of the team (goal), and not just their own utility [12]. In other words, agents are expected to coordinate in some fashions such that their individual actions are consistent with and supportive of the team's goal. Within a team, the type and pattern of interactions can be quite arbitrary [12]. The roles of each agent in a team may change over time in response to planned or unplanned events [12]. By providing agents with a representation of shared tasks and the means by which cooperation should progress, the agents were able in accurately reasoning about interactions by employing team level knowledge [12]. Usually, team organization is used to provide the structure and coordination needed by agents to address interdependent goals in dynamic environments [12]. But also, authors of this paper believe that the goal assigned to a team, defines team intentions.

- **Holarchy organization:**

This organization is a self similar organization that is composed of agents each of which is created by one or more agents [12]. Each agent in holarchy organization is called a holon which is composed of two words of "hole" meaning "whole" and "on" meaning "part" in Greek language. Each holon exists simultaneously as both a distinct entity from a collection of subordinates and as part of larger entity [12]. This notion of hierarchical, nested structure does accurately describe the organization of many systems such as business, manufacturing, biological, urban traffic, and social systems [11, 12].

The distinct characteristic of a holarchy organization is the partially-autonomous holon. The degree of autonomy associated with an individual holon could differ for them in different levels or even between similar holons at the same levels [12]. However, the level of autonomy is neither complete nor completely absent, as these extremes correspond to either a strict hierarchy or an unorganized grouping, respectively [12]. It would not be incorrect to conclude that a holarchy is a particular type of hierarchy. If the definition of hierarchy is allowed to be relax to contain some amount of cross-tree interactions and local autonomy, the two styles share many of the same features and can be used almost interchangeably [12].

III. CONTROL STRATEGY

A. Holarchy organization

This paper supposes that bus agents as cognitive agents which are able of monitoring their voltage and also capable of sending and receiving of message from other bus agents and reactive agents. Transformer tap changers as Tap agents and capacitors/reactors as Cap agents are assumed to be the reactive agents which percept their setting and if possible take action in the request of a bus agent. By using holarchy organization, the communication channels must be able to transmit messages among bus agents and also commands between bus agents and reactive agents. Employing a multi-agent voltage control system with “bus agents” as cognitive agents and transformer tap changer/capacitors as reactive agents, the proposed control strategy is structured as follows:

- ✓ Each bus agent measures the voltage by an installed PMU. This paper has used the need of each bus to reach the normal voltage by (1).

$$Need_i = 0.95 - \text{Its Bus Voltage Magnitude} \quad (1)$$

- ✓ The negotiation between the agents is done via communication channels and messages are transferred through them. This paper does not care about communication limitations in transmitting messages between the bus agents.
- ✓ Owing to the fact that, changing transformer taps may lead to voltage collapse in power system, at those situations tap changers’ actions must be limited. So this paper proposes that when tap changing lead to decreasing voltage of a bus agent, that bus agent will force that reactive agent to undo its action and then locks the reactive agent, by sending a message.
- ✓ The negotiation takes place among those buses which have some common resources (reactive agents). This has been considered due to multi-agent system definition and also in order to decrease communication traffic.
- ✓ In the stage of performing the optimization, the limitations and/or capabilities of reactive agents have been considered. These limitations contain the step and maximum value of capacitor/reactor banks and the step and position of tap changers in transformers.

Then the steps in control strategy are proposed as:

Step0: First, some MASs must be defined. The authors have experienced this step in [3], i.e. 41 MASs have primarily been assigned in the network. In each MAS, there are one bus agent together with a few number of reactive agents while each reactive agent may belong to more than one MAS. Reactive agents placed in an MAS have obviously larger sensitivity coefficient than others (which implies lower electrical distance and therefore more contribution) on helping corresponding bus agent of MAS [3].

As a result of [3], when just one bus is experiencing under-voltage situation, that bus can activate its assigned reactive agents to remove the voltage violation.

Step1: But, in the case of multiple MASs and wide spread voltage violation in the system, shared interest (i.e. eliminating the voltage violation) and limited resources (reactive agents) lead the cognitive agents (bus agents with experiencing under-voltage condition) to negotiate with each other to rearrange the reactive agents allocation.

In other words, after a contingency occurrence and voltage violation in some buses with intersection in reactive agents, each bus agent and its assigned reactive agents behaves like a holon and engender a group of agents with a flat organization where each agent tries to seize more resources to support itself more; while the sub-organization inside each holon is proposed to be hierarchy.

In the negotiation procedure, shown in Fig. 2, after a contingency occurrence and in the situation that some buses are experiencing under-voltage situation, the holon with lowest amplitude in voltage that needs more support from reactive agents is at a higher priority in seizing all the reactive agents which are located in its MAS (i.e. holon) and also those that are common with other MASs (holons). The next priorities are allocated to buses with next lowest voltage magnitude. Each holon tries to attach the reactive agents to its own MAS which are not seized by the holon with higher priority (as is shown in Fig. 3). In addition, those buses operating in normal amplitude of voltage do not take part in these negotiations and let their reactive agents to be detached.

Step2: After determining the allocation of reactive agents, each holon is composed of a bus agent and some reactive agents in a hierarchy organization. At this step each bus agent estimates how much of its need is covered after the buses with higher priority have seized some of common reactive agents to eliminate their voltage violations.

Step3: At this stage, bus agents make decisions to send requests to reactive agents about either number of steps that must be changed in tap changers or capacitors/reactors must be in/out of service. In order to perform this step, an optimization must be done. The proposed procedure is based on the minimum actions for returning to the normal voltage amplitude. Then, the messages are sent to reactive agents which must be activated.

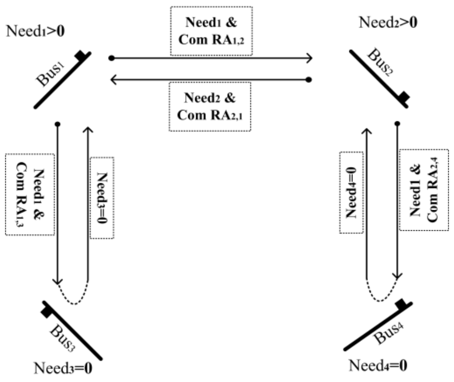

Figure 2: Negotiation procedure between bus agents.

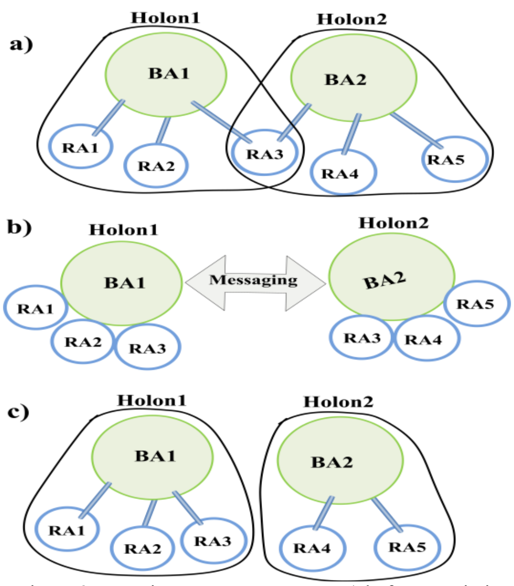

Figure 3: Reactive agents arrangment a) befor negotiation, b) during negotiation c) after negotiation.

B. Team organization

This paper studies team organization in power system in order to control voltage of buses in the network too. In this area, some teams have been created and designed to eliminate voltage violation in power network after a contingency occurrence. Each team is supposed to have a hierarchy organization which is composed of a bus agent and a few reactive agents. Those buses with more vulnerability have more reactive agents in order to have more voltage components to control its voltage and therefore, there are some buses with no reactive agents because of their voltage strength in contingencies.

Since each team possesses a hierarchy organization, bus agent is supposed to be the head of the team and reactive agents located in team stand in the second layer of the team. In addition, as there are limited number of reactive agents in number; so, each team can possess a few number of them. Therefore, an optimization procedure should be follow to assign effective reactive agents to each cognitive agent. This paper has accepted the suggestion of [3] in order to solve the problem of allocating reactive agents to bus agents. [3] suggests applying various N-1 contingencies to power system to find the more vulnerable buses which must be supported more than other buses. Also, sensitivity coefficient of each reactive agent for all busses has been calculated and those with higher sensitivity coefficients will be placed in a team. In other words, a vulnerable bus seizes more effective reactive agents around itself and other buses which are less vulnerable take other free reactive agents to support themselves [3]. Figure. 3(c) shows the team organization applied to control the power network voltage.

C. Conventional control strategy

In this context, conventional control strategy is equal to central control performed by a hierarchy organization in multi agent system which is the simplest organization. A two-layer hierarchy system has been used to achieve voltage control in power network. In this area, an agent in the top of the tree has been supposed to be the central controller which is able to give command to all voltage controller components over the power system. Choosing that central point is a bit challenging, therefore this paper proposes to select a bus with worst voltage condition as the central controller of the system to increase the similarity of this control strategy with those afore-mentioned. As the result of this selection, by performing some actions by central controller of the power network (pilot bus agent), voltages of other buses may be supported. In other words, in this type of organization all of power system has been supposed to be a team widespread over the network.

Whereas this paper has used tap changers and capacitor\reactors as voltage controller components, central controller uses these components to control power network voltages around the network by changing the position of tap changer or the amount of engaged capacitor\reactor bank. The optimization procedure is based on the amount of sensitivity coefficient of each component to central controller (pilot bus). The component with higher sensitivity coefficient is selected to take action(s) in order to support the voltages of power system.

IV. RESULTS AND COMPARISON

Nordic32 as is shown in Fig.4 is the test power system of this paper which is composed of 17 transmission transformers, 20 generator transformers, 9 capacitors and 2 reactors. So, the power network is composed of 37 transformer tap changers as Tap Agents and 11 capacitors and reactors as Cap Agents. Also, all buses except generator buses (41 buses) are considered as Bus Agents. This paper supposes that bus agents as cognitive ones and they are able of monitoring their voltage and also capable of sending and receiving of message from other bus agents and reactive agents. Tap and Cap agents are assumed to be the reactive agents which percept their setting and if possible take action in the request of a bus agent.

In this paper the performances of the three organizations mentioned in the previous sections are explained and results have been shown.

A. Holarchy organization:

By applying the proposed control strategy based on holarchy organization, the result is shown in Fig. 5. This result is drawn for the case that some contingencies have occurred in the system and the voltage of buses 1041, 1043 and L46 have dropped to under-voltage situation. So the bus agents 1041, 1043 and L46 have detected the condition by the aids of PMUs installed on their substations. They calculate their need (actually their distance from the normal limitation) to return to the normal

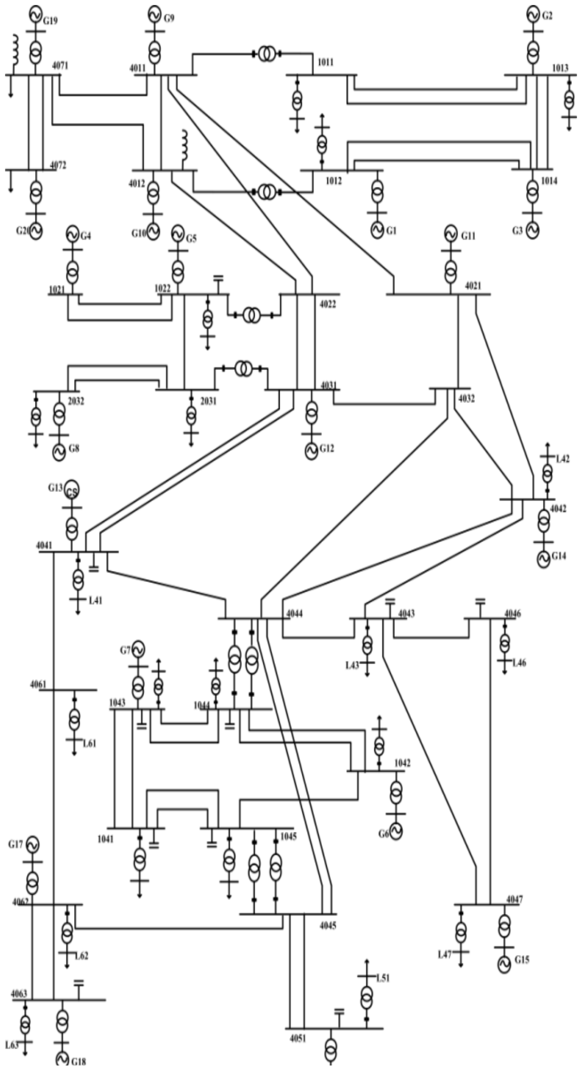

Figure 4: Nordic32 test system [13].

boundary. Based on their needs, the priority has been defined and each bus agent can call its reactive agents in its territory. Then, each bus performs the optimization procedure (Bus agents have the capability of calculation because they are installed in IEDs) and decides to activate which of the assigned reactive agents and their steps for eliminating the voltage violation. The results are shown in Fig. 5.

B. Team organization:

Forcing the same load events to the power network and voltage violation in the afore-mentioned buses stimulates bus agents to attempt in order to eliminate voltage violation. In this area, bus agents 1041, 1043 and L46 which contains some reactive agents in their teams are the actuators to support voltage. Each bus agent calculates the need of its bus voltage to reach the normal voltage condition and then performs the optimization procedure. Consequently, the bus agent sends commands to the team reactive agents to change their setting in order to support the voltage of the bus. The results of team organization are shown in Fig. 6 where buses 1043 and L46 eliminate their voltage violation but bus 1041 cannot perform its mission. The results verify that those teams with enough effective reactive agents are able to support their voltages; but, buses with lack of effective reactive agents cannot support their voltages.

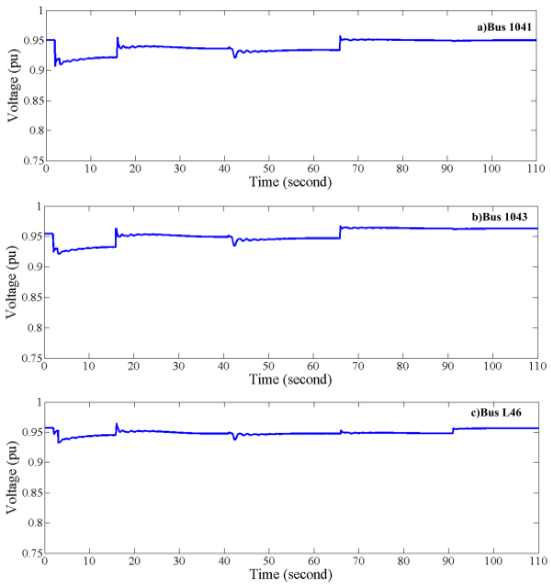

Figure 5: Results of holarchy organization strategy

a) bus 1041 b) bus 1043 c) bus L46.

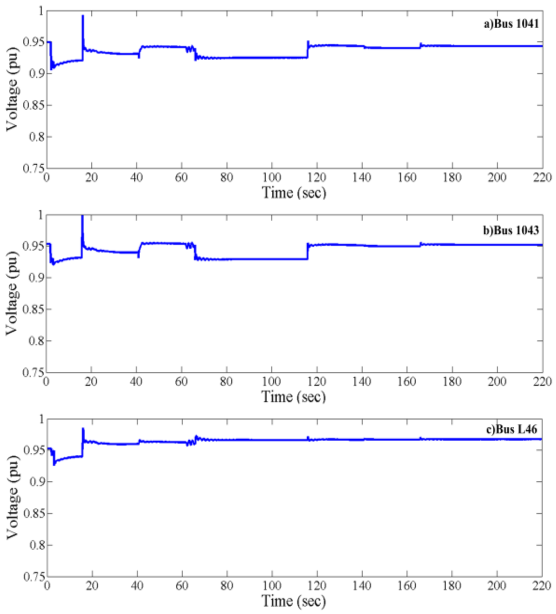

Figure 6: Results of team organization strategy

a) bus 1041 b)bus 1043 c) bus L46.

C. Hierarchy organization(Conventional Strategy):

Finally, in a hierarchy organization an agent located at the top of organization must act as a head of other agents in the lower level. The head agent has more control authoring in comparison with those placed in other layer. In this paper a two layer hierarchy organization has been used where the bus with lower voltage amplitude after contingency occurrence has been selected as the header of organization for power system and all capacitor/reactor banks and transformer taps are located in the second layer to be under the control of this upper level agent. In other words, this organization is as the same of conventional strategy to control the voltage of power system.

The optimization procedure applied in this strategy is as the same of other afore-mentioned organizations. The results of voltage control by performing this strategy are depicted in Fig.7. As is shown in Fig. 7, conventional control strategy supports the voltage of pilot bus (in this simulation, bus 1041 is pilot bus and therefore the head of hierarchy organization), but the actions performed in this strategy may be opposite to the needs of some other buses which the pilot bus has no sense about them. Those actions may lead some buses to voltage drop and even voltage collapse.

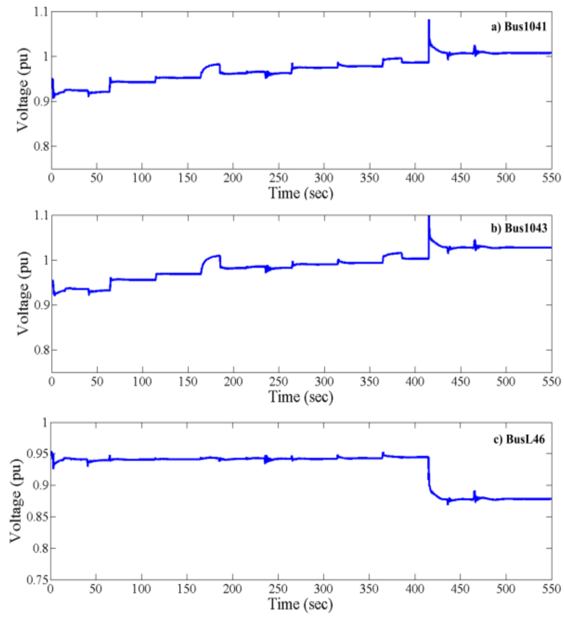

Figure 7: Results of conventional control strategy

a) bus 1041 b) bus 1043 c) bus L46.

V. CONCLUSION

This paper examined three organizations of agents in MAS for voltage control in power systems. Results have shown "Holarchy Organization" has shown best achievement in controlling voltage, which is due to being more compatible with dynamic performance of power system. Also, the performances of MAS have been compared with conventional strategy where the superiority of these systems is approved, at least in the test system.

REFERENCE

[1] Karlsson, D.; Hemmingsson, M.; Lindahl, S.; , "Wide area system monitoring and control - terminology, phenomena, and solution implementation strategies," *Power and Energy Magazine, IEEE* , vol.2, no.5, pp. 68- 76, Sept.-Oct. 2004

[2] Michael J. Wooldridge, " An introduction to multiagent systems", John Wiley & Sons, Published May 2009.

[3] Alireza Ashrafi, Seyyed Mohammd Shahrtash, " Strategy for Arranging Agents in Multi-Agent Systems Employed for WAMPAC ", *The 6th Power Systems Protection and Control Conference*, January 3-4, 2012.

[4] Wang, H.F.; , "Multi-agent co-ordination for the secondary voltage control in power-system contingencies," *IEE Proceedings-Generation, Transmission and Distribution,* , vol.148, no.1, pp.61-66, Jan 2001

[5] McArthur, S.D.J.; Davidson, E.M.; Catterson, V.M.; Dimeas, A.L.; Hatziargyriou, N.D.; Ponci, F.; Funabashi, T.; , "Multi-Agent Systems for Power Engineering Applications—Part I: Concepts, Approaches, and Technical Challenges," *IEEE Transactions on Power Systems,* vol.22, no.4, pp.1743-1752, Nov. 2007.

[6] Hai Feng Wang; Li, H.; Chen, H.; , "Coordinated secondary voltage control to eliminate voltage violations in power system contingencies," IEEE Transactions on Power Systems, vol.18, no.2, pp. 588- 595, May 2003.

[7] Sheng Gehao; Jiang Xiuceng; Zeng Yi; , "Optimal Coordination For Multi-Agent Based Secondary Voltage Control In Power System," Asia and Pacific Transmission and Distribution Conference and Exhibition, 2005 IEEE/PES , vol., no., pp.1-6, 2005

[8] Baran, M.E.; El-Markabi, I.M.; , "A Multiagent-Based Dispatching Scheme for Distributed Generators for Voltage Support on Distribution Feeders,", IEEE Transactions on Power Systems, vol.22, no.1, pp.52-59, Feb. 2007.

[9] Xiaoyang Tong; Xiaoru Wang; Jun Tang; , "The Cooperative Modeling of Wide-area Protection Multi-agent Based on Organization," *Power System Technology, 2006. PowerCon 2006. International Conference on* , vol., no., pp.1-6, 22-26 Oct. 2006

[10] Juhwan Jung; Chen-Ching Liu; , "Multi-agent technology for vulnerability assessment and control," Power Engineering Society Summer Meeting, 2001 , vol.2, no., pp.1287-1292.

[11] Monireh Abdoos; Ahmad Esmaeili; Nasser Mozayani; , "Holonification of a Network of Agents Based on Graph Theory," 6th KES International Conference, KES-AMSTA 2012,Dubrovnik, Croatia, June 25-27, 2012.

[12] Horling, Bryan; and Lesser, Victor. "A Survey of Multi-Agent Organizational Paradigms." *The Knowledge Engineering Review*, Volume 19, Number 4, Cambridge University Press, pp. 281-316. 2005.

[13] H. Khoshkhoo, S. M. Shahrtash, " On-line Dynamic Voltage Instability Prediction Based on Decision Tree supported by Wide Area Measurement System" *IET Generation, Transmision and Distribution,2012, doi:10.1049/iet-gtd.2011.0771*