# Strategy for Arranging Agents in Multi-Agent Systems Employed for WAMPAC

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*Abstract*—**Voltage stability continues to be a critical wide-area phenomenon in power systems. WAMPAC infrastructures have improved the voltage stability margin, but for better achievements the margins, Multi Agent System technology has been merged in some studies. This paper proposes an approach to form a Multi Agent System by reactive and bus agents and discusses about the strategy of arranging them to take this advantage in voltage control plan of a transmission network. The principle of the proposed strategy is to give the allocation of reactive agents according to their effectiveness in supporting the voltage of the bus. Also, the criterion for the number of agents to be called by a bus agent in an under voltage condition due to a contingency is presented.**

***Keywords-Agent allocation; Multi-agent systems; Voltage control; Wide-Area Monitoring Protection and Control (WAMPAC)***

## I. INTRODUCTION

TODAYS, power network needs faster and more reliable control strategy in order to support voltage during a contingency occurrence rather than past decades. This necessity is due to that power systems are operating under more stresses with lower margins to the stability limits. Such instabilities might cause voltage instability and consequently tripping out of some components which may lead to catastrophic outages and/or voltage collapse. Avoiding these catastrophic outages, needs to new technologies be studied and employed in power systems.

Multi Agent System (MAS) is an active branch of Distributed Artificial Intelligence which divides a complex problem to some easier sub problems and solves them independently and also correlated. In other words, a complex and giant system is composed of some MASs capable of achieving a complex goal in relation with each other while achieving such a goal independently is more difficult. MAS consists of some "agents" which are allocated and arranged in a cross-related program to achieve the specified goal. An agent is defined as an entity which is capable of autonomous action in some environments in order to meet its design objectives [1].

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. These similarities between MAS and power system, and also the ability of multi agent system in solving complex problems encourage power engineers to use MAS approach/structure in power system in order to make improvements in voltage control.

Employing MAS in power systems and especially in voltage control is infancy. However there are a few published papers in this area, up to now; where in [2] 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 has occurred. 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 [3] 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 [2], in order to extend the influence of each agent on the power system. Alternatively, [4] 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. An optimal coordination method for MAS based control system in normal operating condition and also in contingencies, is proposed in [5], for enhancing the ability of fast and coordinated voltage and reactive power control. In [6], 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 which all of them and one of the monitored nodes as a moderator agent form a Multi Agent System.

In none of the above mentioned papers, there is no study in order to determine the "effective agents" whose action can effectively support a voltage violation in transmission power system. In other words, there is not enough reports in finding out the "effective agents" which are capable of eliminating the voltage violation in a specific transmission bus. This paper has reported studies performed to notice this point and give a strategy for arranging the agents in a hierarchy in different MASs for improved voltage control in a power transmission system.

This paper is organized in the following way. First, Multi Agent System is briefly introduced in section II. Next, section

III is dedicated to simulation and results in order to determine the effective agents. The simulations are performed on Nordic32 power system as the test network. Finally conclusion is presented.

## II. MULTI AGENT SYSTEMS

An agent is a software or hardware entity that is situated in some environment and is able to autonomously react to changes in that environment [1]. In other words, agents are entities that simulate rational behavior and have the capability to communicate through a networking environment to achieve their goals in a particular domain [7]. It is supposed that at least a part of environment is observable to an agent and an agent can alter its environment by taking some actions [8]. This observability may be achieved through some sensors, or by computing programs, and also through system calls and messaging [8]. As is shown in Fig. 1, an agent must percept its environment in the hope that take some appropriate actions based on its intelligence and ability.

Generally, agents are divided into two categories:

- Reactive Agents
- Cognitive Agents

Reactive agents are some simple agents which act very fast and have no ability to make reasoning about its task. In other words, reactive agents percept their environment and act instantaneously based on their environment condition.

Agents which are able to make reasoning and/or decide about some perception as it is sensed are called cognitive agents. Cognitive agents are the brain of an intelligent system.

A multi agent system is simply composing of two or more agents [8]. In such an area, cooperation, collaboration, and coordination of agents in an MAS make the environment to be aligned to the intentions of agents designers. Voltage controller components like transformer taps, capacitor banks, and reactors are distributed all over the power network and can be assigned as agents. These components/agents may operate independently based on their measurement and/or be controlled by a central decision making system. Alternatively, and as mentioned these may operate in a cooperation and/or coordination with each other. For example, [6] has supposed each distributed generator in a distribution feeder as an agent which is accessible by a messaging system and they are coordinated by an agent called moderator agent. In [5] Static Var Controllers and generators are considered as agents to control power system voltage. Transformer tap changers and capacitor banks are set as agents in [9-10], in order to eliminate voltage violations versus load changing in a simple power system. Also it has proposed two layer reactive control system which is composed of “voltage control” and “reactive power control” sub problems for the purpose that more coordination being achieved during voltage violation eliminating.

The occurrence of a contingency in a power system might lead some network buses to under-voltage situation. During this abnormal condition, bus agents activate (call) installed reactive agents which are capable of supporting them in clearing the condition. Consequently, when voltage violation

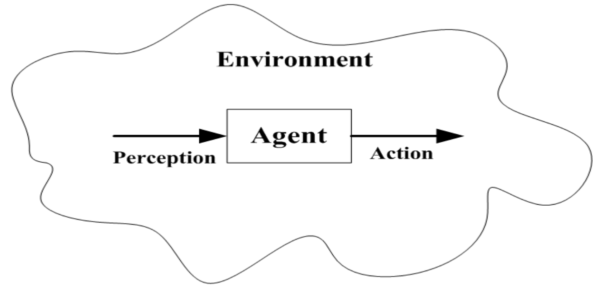

Figure 1: An Agent in its Environment

is detected in a bus by a bus agent, it calls effective reactive agents to provide remedial action in supporting the bus voltage. In such a condition, a question may arise that which reactive agents are capable of supporting bus agent to eliminate the voltage violation in the corresponding bus. In other words, among a lot of voltage controller components/agents distributed in a bulk power system, which components have more effects on voltage violation elimination in a specific bus. This is the question answered in this paper by using the Sensitivity Coefficient.

## III. SIMULATION AND RESULTS

In this paper, Nordic32 is the test power system as shown in Fig. 2. Nordic32 is composed of 17 transmission transformers, 20 generator transformers, 9 capacitors, and 2 reactors. This system consists of 37 transformer tap changers as Tap Agents, 9 capacitor banks as Cap Agents and also 2 reactors as Reactor Agents which totally form “reactive agents”. Also, all buses except generator buses (41 buses) are considered as Bus Agents.

This study supposes that “bus agents” are cognitive ones and have the ability to monitor their voltage. Bus agents can percept their environment by measuring their corresponding bus voltage and are able to make decision based on their perception; finally they act on the power system by calling the reactive agents to support them.

The reactive agents are supposed to support the requested reactive power from bus agents. These agents can percept their environment by sensing their internal states (steps of capacitor, reactor, or tap steps of transformer) and also by receiving messages from bus agents. Finally, they take action on the power network by changing their setting (i.e. changing the amount of capacitor/reactor in service or changing the transformer tap).

### *A. Assigning Reactive Agents to a Bus Agent in a Contingency*

The first objective of this paper is to investigate “effective reactive agents” which should be called by a bus agent, in a bus voltage violation due to a contingency. As mentioned, the method followed is Sensitivity Coefficient. Obviously, these sensitivity coefficients and any results based on them is valid for the specified contingency in the specified operating condition.

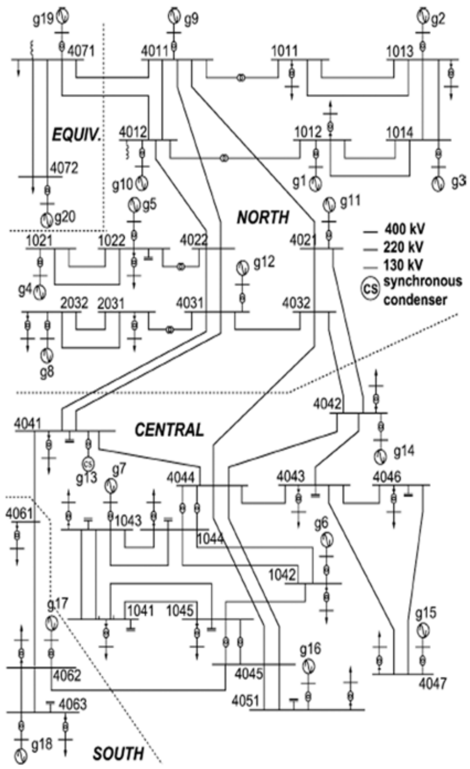


Figure 2: Nordic32 Power System

Numerous simulations are performed to find out the sensitivity of each bus voltage to amount of reactive power generated/consumed by each capacitor/reactor in service and also to the each transformer tap value. In each simulation, an N-1 contingency has occurred and the voltage magnitude of each bus is monitored in order to find out the buses which are in under-voltage situation (this step is supposed to be performed through dynamic simulations). In the next step, by performing a load flow, keeping the contingency, the sensitivity coefficients are again calculated.

These sensitivity coefficients, which imply an electrical distance between any reactive agent and any bus agent, are good indicators of the effectiveness of a reactive agent in supporting any specified bus agent. Clearly, if during a contingency, a bus experiences voltage drops, it is the reactive agents with larger sensitivity coefficients (effective reactive agents) that should first be called in order to support calling bus agents. Calling fewer reactive agents proposes faster coordination between bus agents resulting in deciding faster during voltage drop and faster elimination of the voltage violation.

As shown in Table 1, sensitivity coefficients of some bus voltages w.r.t. some transformer taps and the reactive power of some capacitors after a contingency and voltage decrease of those buses are calculated. As a result, MASs composed of a cognitive agent (bus agent) and some reactive agents are determined based on the effectiveness of reactive agents on supporting the cognitive agent. In other words, the effective reactive agents can be assigned to any specific bus agent which will be called during an under voltage condition in the specified contingency situation.

For example, based on Table 1, bus agent 1041 and reactive agents tap-trG 4047, tap-trG 4021, tap-tr1045-4045(p1 and p2), Cap1043, Cap1041, Cap1045, and tap-trG 4041 compose a Multi Agent System. Also, bus agent 1043 and reactive agents tap-trG 4047, tap-trG 4041, tap-tr1044-4044 (p1 and p2), Cap1043, Cap1041, and Cap1044 compose another Multi Agent System. Therefore, when an under voltage condition is detected by a bus during a contingency, each bus agent calls its assigned reactive agents to support the situation.

The effectiveness of Cap1045 reactive agent on both buses 1041 and 1043 has been shown in Fig. 3. Clearly, the effect of Cap1045 on the voltage of bus 1041 is more than its effect on bus 1043 due to its larger sensitivity coefficient as is shown in Table 1.

Table 1: Sensitivity Coefficient of Agents on Buses

| Contingency | Bus | Sensitivity coefficient | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| trG1042[a] | | Tap-trG 4047[b] | tap-trG 4021 | tap-trG 4062 | tap-tr 4051-51 | tap-tr 4043-43 | Cap 1044[c] | tap-tr1045-4045(p1)[d] | tap-tr1045-4045(p2) | tap-tr1044-4044(p1) | tap-tr1044-4044(p2) |
| | **1042** | -0.0040 | -0.0025 | -0.0019 | -0.001 | -0.0007 | -0.0007 | 0.0009 | 0.0009 | 0.0025 | 0.0025 |
| | **1041** | -0.0040 | -0.0025 | -0.0021 | -0.0012 | -0.0006 | 0.0001 | 0.0019 | 0.0019 | 0.0017 | 0.0017 |
| | **1044** | -0.0042 | -0.0026 | -0.0017 | -0.0009 | -0.0007 | 0.0002 | -0.0009 | -0.0009 | 0.0038 | 0.0038 |
| trG1043 | | tap-trG 4047 | tap-trG 4041 | tap-trG 4021 | tap-trG 4062 | Cap1045 | Tap-tr1044-4044 (p1) | tap-tr1045-4045(p2) | tap-tr1045-4045(p2) | Cap1043 | tap-tr1044-4044(p2) |
| | **1043** | -0.0034 | -0.0033 | -0.0015 | -0.0011 | 0.00009 | 0.0028 | 0.0011 | 0.0011 | 0.0004 | 0.0028 |
| | **1041** | -0.0033 | -0.0032 | -0.0015 | 0.0013 | 0.00015 | 0.0018 | 0.002 | 0.002 | 0.0003 | 0.0018 |
| | **1044** | -0.0035 | -0.0029 | -0.0015 | -0.0007 | 0.00006 | 0.0039 | -0.00017 | -0.00017 | 0.0001 | 0.0039 |
| Line 4046-4047 | | tap-trG 4041 | tap-trG 4047 | tap-trG 4031 | Cap1045 | Cap4043 | Cap4043 | tap-tr1044-4044 (p1) | tap-tr1044-4044(p2) | tap-tr1045-4045(p1) | tap-tr1045-4045(p2) |
| | **1041** | -0.0026 | -0.0021 | -0.0018 | 0.00012 | 0.00005 | 0.00005 | 0.0018 | 0.0018 | 0.002 | 0.002 |
| | **4043** | -0.0018 | -0.0045 | -0.0017 | 0.00004 | 0.00008 | 0.0001 | -0.0004 | -0.0004 | -0.0002 | -0.0002 |
| | **4046** | -0.0018 | -0.0042 | -0.0017 | 0.00004 | 0.0002 | 0.00009 | -0.0004 | -0.0004 | -0.0003 | -0.0003 |

a. trG1042 means Generator Transformer installed on bus 1042
b. tap-trG4047 means tap changer of trG4047
c.Cap1044 means Capacitor which is installed on bus 1044
d. tap-tr1045-4045 (p1/p2) are two parallel transformer

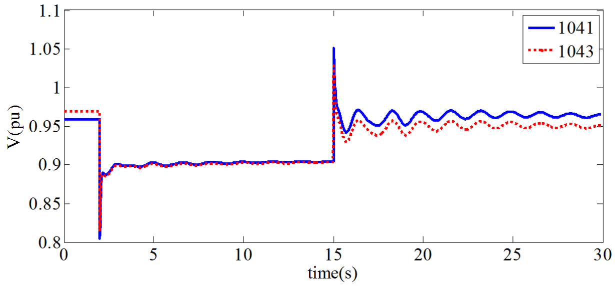

Figure 3: The effect of Cap1045 on voltage of buses 1041 and 1043.

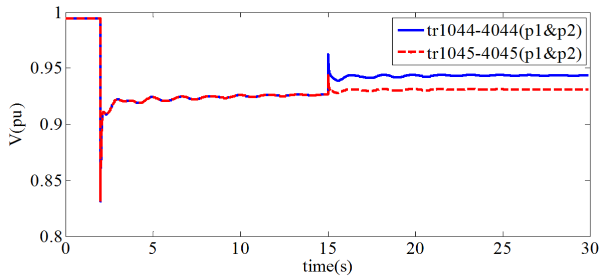

Figure 4: voltage of bus 1043 due to change of two reactive agents

Also, Fig. 4 has shown the effect of two reactive agents on bus 1043. It is shown that voltage of bus 1043 is under the influence of reactive agent "tr1044-4044(p1&p2) " and the effect of "tr1045-4045(p1&p2)" on this bus is negligible, in agreement with the sensitivity coefficient shown in Table 1.

### *B. Assigning a Bus Agent to a Reactive Agent in a Contingency*

Furthermore, and as a second objective of this paper, a study has been performed to distinguish more vulnerable buses in a contingency, in order to find out which bus agent should the reactive bus be attached, while more than one bus agent is calling it.

As mentioned before, some reactive agents are placed in more than one multi agent system. In such a condition, a higher priority must be applied to a bus which is a clue of vulnerability in order to allow it to call more reactive agents from the common set of agents. In other words, a bus which is more vulnerable must be prior to any other buses to call more reactive agents to eliminate its voltage violation.

A plenty of contingencies have been considered in Nordic32 while all transmission buses voltage have been monitored to extract more vulnerable buses. In order to determine the vulnerable buses, the average magnitude of bus voltage and its standard deviation have been extracted. These parameters help the designer of MASs to allocate reactive agents to a specific bus in an under voltage situation. The proposed strategy is to attach a common reactive agent between two or more bus agents, to the bus agent with lower average magnitude and with larger standard deviation.

As shown in Table 2, bus 1041 is more vulnerable than bus 1043 because its average during contingencies is lower than average voltage of bus 1043, while standard deviations of both buses are nearly equal. Therefore, bus 1041 must have higher priority rather than bus 1043 in calling reactive agents in the purpose of voltage drop elimination.

Table 2: Average and Standard Deviation of Bus Voltage

| | 1041 | 1042 | 1043 | 4043 |
|---|---|---|---|---|
| Average | 0.9236 | 0.9633 | 0.9487 | 0.941 |
| Standard deviation | 0.1437 | 0.1419 | 0.1547 | 0.1436 |

## IV. CONCLUSION

In this paper a strategy for relating bus agents and reactive agents in a hierarchy inside MASs is proposed. The strategy is based on the sensitivity coefficients obtained from comprehensive simulations, resulting in introducing effective agents for supporting most vulnerable buses in a contingency analysis. Also, the proposed method for selecting the more vulnerable bus agents is based on their average and standard deviation in voltage magnitude.

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