IoT Based System of Energy Compensation in Smart Power Grid

A. ZITOUNI[1] and H.BENTARZI[1]

[1] Laboratory Signals and systems, Institut Génie Electrique et Electronique, Université M'hamed Bougara Boumerdes, Boumerdes/Algeria, lss@univ-boumerdes.dz

Abstract **– In this research work, a new approach of energy compensation system using IoT in smart grid has been proposed. Where, multi-agents that can communicate with each other to share information are used, distribute energy and control the voltage level. Multi-agents make the link between flexible resources. They are an emerging technology for decentralized computation and data storage, secured by a distributed consensus mechanism. For testing this approach, a standard IEEE 9 bus power grid has been used that gives a good result.**

Keywords **– Energy Compensation; Distributed energy resources; IoT; Multi-agents; IEEE 9 bus power grid.**

I. INTRODUCTION

IN the literature, the energy management of smart grids is based on centralized approaches [1, 2]. However, the researchers start to reshape it by using distributed energy resources (DERs). DERs are compensated for providing energy services by an aggregator or a utility: a central authority that is trusted to act fairly in scheduling generators, satisfying loads, and rendering payments [3].

DERs are often remotely controlled by the Internet of Things. When they are used intelligently, these DERs can reduce cost, improve reliability, and integrate renewable resources in the electric grid — features which have led regulators to introduce policies promoting their adoption.

In this research work, a new approach of decentralized energy management for smart grid has been proposed. Where, micro-grids and aggregators are used as smart agents that can communicate with each other to share information, distribute energy and control their own energy consummation. Aggregators make the link between flexible resources. Multi-agents are an emerging technology for decentralized computation and data storage, secured by a combination of cryptographic signatures and a distributed consensus mechanism.

II. DISTRIBUTED ENERGY RESOURCES (DERs)

With smart grid, the planning, investment, and operation of the distribution system change dramatically. Historically, utility investment in distribution systems ensured circuit capacity was adequate to deliver power from the bulk grid to the customer. Now, customer-owned solar PV delivers power to the distribution system, and DR from customers provides energy and capacity reduction at the bulk grid level. A host of other distributed resources, including fuel cells and energy storage, provide power that is injected at the low-voltage level and may create reverse power flows on the grid, moving power away from the customer. Platforms are being designed to host DERs at lower voltage levels to explicitly supply customers at the distribution level and to wholesale markets.

An immediate objective is to monetize the option value of DERs, which translates to more flexible DER uses in multiple markets. Multiple opportunities have emerged, and more will result as DER needs increase across the grid. We examine both the voltage context and future opportunities to provide greater understanding of these new resources.

Distributed resources can reduce peak demand, which can eliminate or defer new transmission and distribution capacity, and decrease total energy costs. Enhanced on-site peaking generation resources also improve the security and hence the reliability.

III. IOT APPROACH IN SMART GRID

In its universal meaning, IoT (Internet of Things) depicts the notion of inter-relating the virtual world of computers with the real world of physical objects [4, 5].

Everything in IoT Smart grid (SG) is based on networking because the grids must capable of sensing (through their sensors) and reacting (through their actuators); thus, creating smart environments surround them, this can be via the integration of communication networking, the internet, sensors (PMUs), smart meters and remotely controlled switches, hardware (embedded systems) and software technologies. IoT helps SG systems to support various network functions throughout the generation, transmission, distribution and consumption of energy by providing the connectivity, automation and tracking for such devices.

The IoT focuses on the realization of three main concepts, namely things-oriented, Internet-oriented and semantic-oriented. The things oriented concept involves smart devices, such as RFID tags, sensors, actuators, smart meters, the Global Positioning System (GPS) and NFC. The Internet oriented concept enables communication among smart devices through various communication technologies, such as ZigBee, Wi-Fi, Bluetooth and cellular communications and connects them to the Internet. The semantic oriented concept realizes a variety of applications with the help of smart devices [6].

Connecting things to the Internet involves the devices to use an IP (Internet Protocol) address as distinctive identifier. IPv4 is definitively bushed owing to its insufficient address range against to the huge address range requirements that leads to unavoidable passage from IP v4 to IP v6 [4].

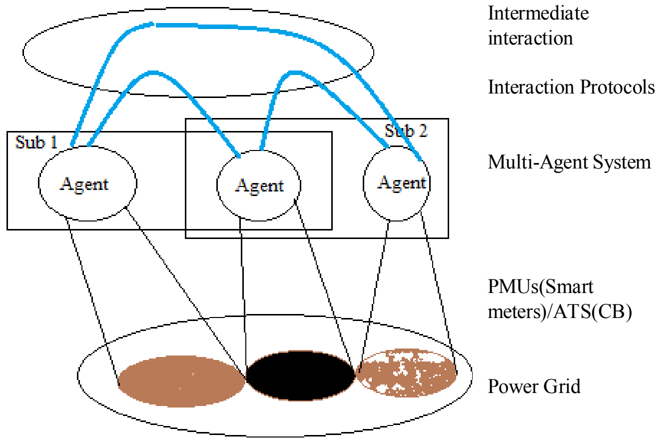

Figure 1: Multi-agents system structure.

A multi-agent system (MAS or "self-organized system") is a computerized system composed of multiple interacting intelligent agents [7-9]. It can be divided to many different sub-systems as shown in Fig.1. One agent can play one or more roles. All agents coordinate with subsystems. Interactions among agents with the power grid can be ensured by the remote terminals unit (RTU)s and smart actuators such as RES and SVC via communication network or internet. The role of the smart agent determines the part of the power grid in which can receive and send the data.

IV. ENERGY MANAGEMENT IN SMART GRID

Centralized or decentralized energy management may be used in smart grid. However, the centralized scheme has a clear drawback; a failure in one of the control centers might result in the total collapse of the system. Therefore, it is highly desirable to have enough intelligence and redundancy throughout the system to survive failures.

Our approach proposes a multi-agent system consists of several Bus Agent (BAGs) and energy compensation Agent (CAGs) capable of regulating voltage and keeping it within the permissible limits, based on local information. This being a way of decentralizing the information, because the loss of information can lead to a cascade of overloads that can lead to voltage collapse. The decomposition of problem (P) into m sub-problems is considered, with most of the equality or inequality constraints from electric grid are expressed in terms of only few variables and local variables come from a small geographic area. Each sub-problem (assigned to one agent) contains a part of the objective of (P) and some of its constraints.

The agents will work on their sub-problems asynchronously. Agents can be used to improve the control devices, relays, Flexible AC Transmission Systems (FACTS) devices or voltage regulators. The later is treated in our case study.

The connection between software entities and automation subsystems are fixed (generally defined at design-time), but the systems should deal with unanticipated requests.

V. VOLTAGE REGULATION BASED ON MULTI-AGENTS

The application of smart agents to the power grid is new research field. In the power grid, the voltage level can be affected by different causes such as the load variation or the grid reconfiguration, thus, a rapid control may be needed for solving the problem that may be caused by the disturbances. At some buses, the voltage may decrease below the allowable limits. We discuss here their capability to create a coherent structure that can guarantee an efficient way to manage and control multiple distributed energy resources (DERs) [10].

A. Agents Types

In our approach, two types of agents are used such as bus agent (BAG) and Stored energy Compensation agent (CAG).

A.1 Bus Agent (BAG):

Bus agent is exist in each bus and respect to the following rules:

Rule 1: When BAG detects a decrease in the voltage level under the limit, a message “power demand” is sent to all neighbor agents.

Rule 2: When BAG receives a message “reject to power demand” from the first, it sends the same message to the second agent.

Rule 3: When it receives a message “generation limit” and the voltage does not attain the permitted level, BAG sends another message to the renewable energy generation of the second priority.

Rule 4: When the voltage enters within the allowable limits, BAG sends a message “stop” to the agents.

A.2 Stored energy Compensation agent (CAG)

The agent CAG plays an important role in the system; it determines the stored power energy and the transmission power line thermal capacity. It acts according to the simple rules for solving the local optimization problem of compensation.

Rule 1: When CAG receives a message “power demand”, it will verify two constraints such as the stored power energy (limit) and thermal capacity of the power line. If the two constraints are verified, it will send a positive message to BAG.

Rule 2: if one of the two constraints is not satisfied, it sends a rejection message to BAG.

Rule 3: if CAG receives more than one message "power demand", all messages are classified in a vector with priority order starting by the low power amount.

Rule 4: When CAG receives a message "stop", it confirms the stop.

B. Message Types

The main objective of the messages is to maintain the agents informed by the neighbor agents' conditions. Messages can be classified according to interaction and communication of agents. They are classified into two types for making easy the distribution, control and coordination by agents.

B1. Information Messages

These types of messages are designed for giving information exchange among agents during the normal condition. They are message state request and message state reply.

B2. Contingency Messages

When the voltage is outside the limits, this type of information may be exchanged among the agents in order to recover the situation. These messages are: "power demand", "reject to power demand", "Stored power limit", "stop", and "confirmation".

C. Voltage Regulation by Multi-Agents System

The objective of this study is to decentralize energy management using Multi-agents. Each BAG collects information about the grid from neighbor agents, and hence it determines during contingency the nearest energy storage has the smallest electrical amount. For example, if agent is located at bus (i, j) that is represented by:

$$AGij \; for \quad i = 1,......m \quad and \quad j = 1,....n \tag{1}$$

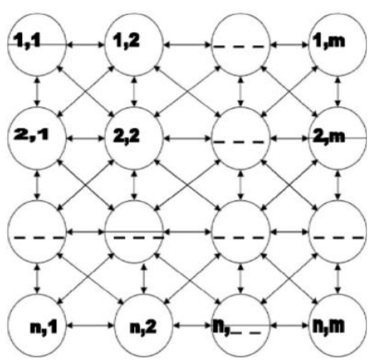

Figure 2: Multi-agents compensation Proposition.

Each agent has a maximum 8 neighbors which are defined as follows:

$$AGij = \{AGi'j', AGij', AGi''j', AGi'j, AGi''j'', AGi''j, AGij'', AGi'j''\} \tag{2}$$

where, $\begin{cases} i' = i-1 \\ i'' = i+1 \end{cases}$ *and*, $\begin{cases} j' = j-1 \\ j'' = j+1 \end{cases}$

TABLE 1: Agent Arrangement.

	j'	j	j"
i'	AG(i'j')	AG(i'j)	AG(i'j")
i	AG(i'j)	AG(ij)	AG(i'j")
i"	AG(i"j')	AG(i"j)	AG(i"j")

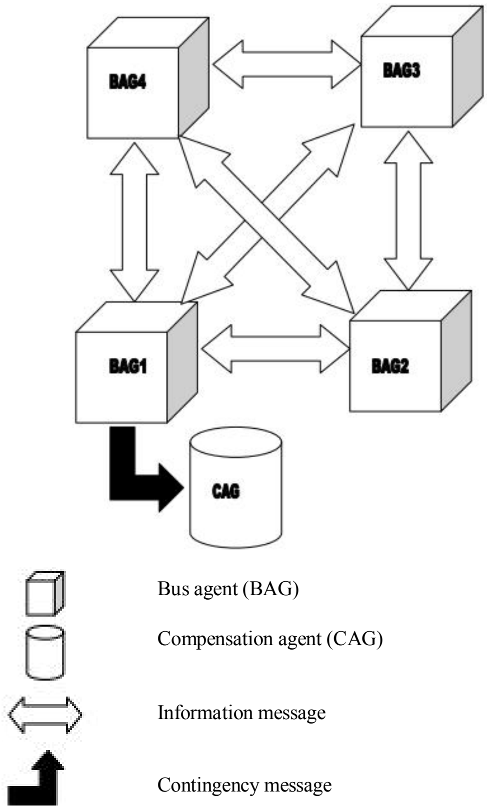

Figure 3: Different types of agents and messages.

Each bus can have a maximum of information about its Envirement exchange among agents. Data base of agent consists of the system information that can be classified into two categories of structure arrays. One concerns the branches and other structure arrays of buses as shown in Figs. 4 and 5 respectively.

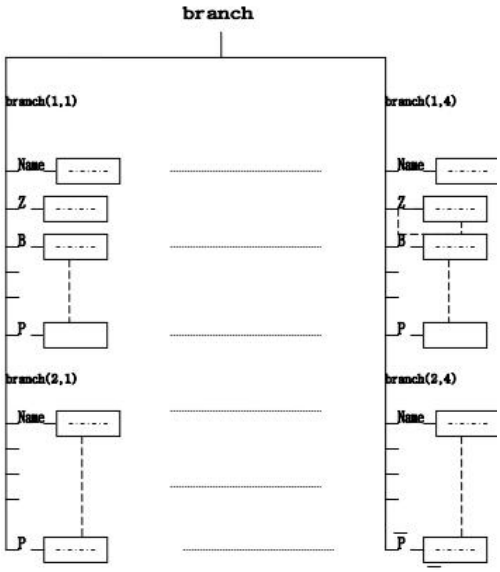

Figure 4: Branch data structure arrays

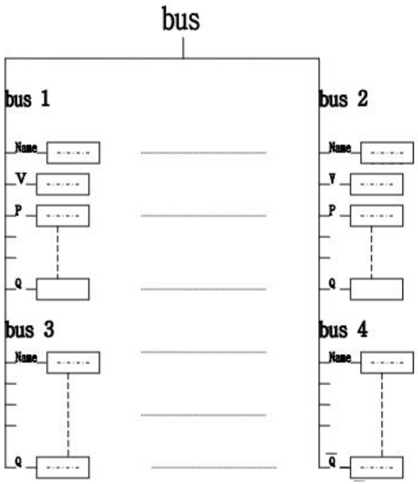

Figure 5: Bus data structure.

VI. Simulation Results and Discussion

A standard IEEE 9 bus shown in Fig.6 has been implemented for testing our approach concerning multi-agents by applying the previous mentioned rules using Matlab. Bus 1 is taken as reference and the others are PQ buses. Static VAR compensator (SVC) may be installed to inject reactive power at buses 4 and 7. Thus, bus 7 is considered as customer-owned solar PV. Simulink model of the test bench that has been developed in our laboratory for testing our approach is shown in Fig.7.

The load at bus 9 has been increased from 125 MW to 425 MW, all voltage levels of buses remain within allowable limits, except bus 9 voltage level is reduced to 0.79 pu (see Fig. 8). Agent of bus 9 detects that the voltage of its bus has been reduced below the allowable limit. Then, it communicates with near neighbors which have power source. In this case, bus 4 may reply. CAG 4 verifies the two constraints which are thermal capacity of power transmission line and the stored electrical energy of the compensator. If the two conditions have been satisfied, a positive reply may be sent to BAG 9. The obtained result is illustrated in Fig.9.

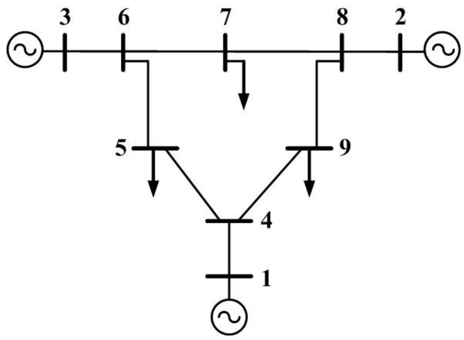

Figure 6: IEEE 9 bus power grid.

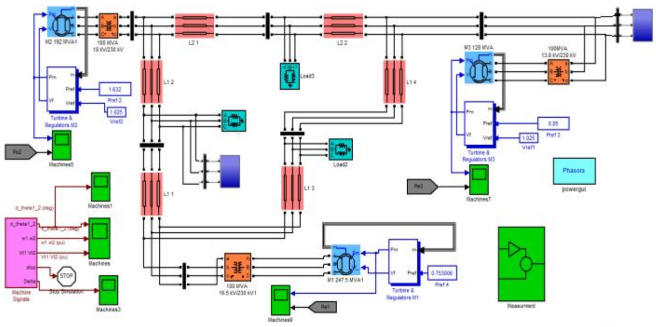

Figure 7: IEEE 9 bus power grid Simulink model with two SVCs.

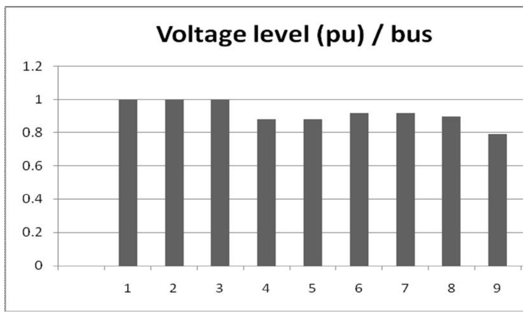

Figure 8: Buses voltage levels during the contingency (bus 9 changes from 125 MW to 425 MW).

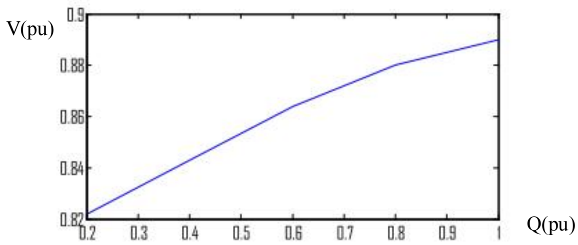

Figure 9: Bus 9 voltage as function of reactive power injected at bus4.

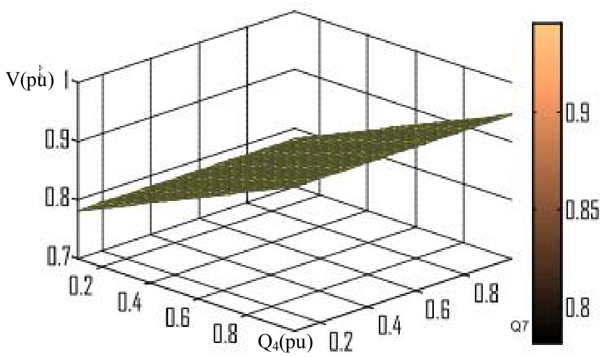

Figure 10: Bus 9 voltage levels as function of reactive power injected at bus 4 and bus 7.

When bus 4 attains its maximum of power energy that can be injected to the power grid, its agent will send a message "Stop" to BAG 9. If the voltage level does not return back within the limits, BAG 9 determines the next compensation agent (CAG) that is in the second order which can contribute to increase its voltage level. CAG 7 may receive a message and which in turn verifies the two constraints. It can be noted that the last satisfies the conditions and inject the required energy for returning back the voltage level within the limits as shown in Fig.10.

VII. Conclusions

In this research work, two types of agents CAG and BAG have been used to regulate the voltage levels by injecting more reactive power at some buses using the static VAR Compensators. The interaction between the two types of agents is based on communication and exchange of information about the parameters and the state of the power grid. The voltage regulation can be controlled by bus agents and assured by generation agent starting by the low power generation order. Data base of each agent may contribute more in the coordination and the successful solution without conflict that may lead to time delay during the critical contingency. The simulation has been used to verify the proposed approach.

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