Designing A Multi-Agent Mechanism For Energy Management In A Photovoltaic System

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ABSTRACT: Several studies have been conducted on the energy management, but procedures performed on management have been less by the artificial intelligence algorithms. In the present study, we try to solve the management problem of an active load in a hybrid system consisting a grid, a photovoltaic, a battery and a super capacitor by using multi-agent systems. In this study, one of artificial intelligence algorithm, known as subsumption architecture, will be used for the management of agents, in which each energy source is considered as an agent and according to the priority of these agents, they fall into corresponding levels. In this system, each agent has the capability of making decision and can inform other agents through by a communication cable. Results of the simulation show that the proposed algorithm can well supply energy for loads and control voltage and also, this procedure reduces the need for fossil fuel energy sources.

Keywords: Photovoltaic power plant, Energy management, Artificial intelligence, Multi-agent system, Subsumption architecture.

INTRODUCTION

Nowadays, the temperature rise of the earth due to greenhouse gas emissions and reducing fossil energy sources due to their immethodical use, have necessitated rapid development of renewable energy sources such as solar, wind, etc. Although, these energy systems are good but they are not everlasting, so there is a need to some devices for energy storage such that when produced energy is more than consumed energy, this excess energy to be stored in some facilities such as batteries or super-condensator (SC) to be used in the required time. Using these sources of energy, along with fossil or nuclear fuel power plants, could reduce the cost of energy production and help cleanliness of the environment.

One of the biggest problems in using these sources is their management. The system should be able to manage these sources in a way that energy demanding from fossil fuel power plants come to its lowest level. In contrary, the most part of energy demands of consumers to be provided through renewable energy sources. On the one hand, such a system should be smart to adopt correct decisions in the network and react appropriately to voltage drops and power outages; on the other hand it should help integration of distributed energy systems in the network (Cohen, 2008; Sycara, 1998). Multi-agent systems (MASs) are systems that have such features and are suitable for managing such networks. These systems are used in AI and particularly in intelligent robot behaviors. An agent in multi-agent systems is an object that can be perceived in the environment and act to the environment through its reactors. By multi-agent systems, a large complex management system can be considered as a set of small simple management systems. More precisely, these agents can solve a major management problem by their interaction and cooperation. The advantages of using such systems are (Zhenhua, 2007):

- Acceleration in responding and system efficiency improvement with respect to asynchronous and parallel computing.
- Stability and high reliability.
- Scalability and flexibility (ability to add new agents into the system)
- Low cost.
- Re-development and reusability.

In this paper, we try to manage energy of an active load (an active load is a load which is converted to an energy consumer in a period of time, and in another time period, to an energy generator) that is provided by a
photovoltaic cell connected to the grid in such a manner that demands the least energy from the grid. For this, we will use a multi-agent system in which agents are distributed on the basis of a decision and remain interaction with each other with the aid of subsumption algorithm. These agents want to have a distributed control over sources. So that firstly, they can provide energy requirements of the load, and secondly consume the minimum energy of the grid.

**Related Works**

Energy management in an electrical network can be considered in three sectors; production, distribution and consumption. In case of production, it has been considered the management between energy producing sources and energy saving devices and most studies have been conducted on large-scale system especially on the reactive power compensation system (Leon et al., 2001; Dong et al., 2005; Dixon et al., 2005). And other studies have been performed on the consistency between producing agents and loads (Zhenhua, 2007; Lum et al., 2005; Dimeas et al., 2005). In distribution sector, most of studies have been conducted on the organization of distribution network by smart switches which can reconfigure network and agents (Gomez et al., 2006; Pant et al., 2007; Baxevanos et al., 2007; Huang et al., 2007). In these studies, the agents try to adapt the network with errors and to improve network performance by choosing the shortest path between the source and the load. In consumption level multi-agent systems have also been used. Although the management of consumption is a problem characteristic to the production sector, here multi-agent systems could help users through negotiation and exclude loads of lower priority at peak consumption out of network and therefore, reduce energy costs (Zhou et al. 2005). InAbras et al., (2010) for a house built-up from sources and equipment controlled by software agents, an energy management system has been designed, in which the management system dynamically establishes a strategy of production and consumption in order to fulfill user’s satisfaction level from its service and every agent constantly controls the present satisfaction level. When this level climbs down to a threshold, fulfills user’s satisfaction level with cooperating and consulting with other agent. In case of energy production management by a fuel cell, it has been used of three energy producing sources, i.e. photovoltaic generator, wind generator and fuel cell and attempt has been made to supply most of required energy for the load through solar cells and wind turbine and when they could not supply load, energy loss would be compensated through fuel cells. This is accomplished using valves and switches applied in fuel cells in hydrogen and oxygen tanks (El-Shater et al., 2006). In the case of energy distribution for energy management for a load connected to a photovoltaic cell, the main grid and energy-saving sources, it has been used of multi-agent systems (Lagorse et al., 2010). The energy required for battery is supplied by photovoltaic generator and energy of super conductor is provided by an active load. In this system, a token was used to manage agents; when an agent has the token, the agent controls bus voltage and supplies the load’s required energy and other agent just controls the current. Agents are in interaction and cooperation with each other and can report their situation to other agents and be informed about other agents’ situation. The system that we are going to manage is one similar to this system but in the proposed system, photovoltaic cell is also connected directly to the bus and can be connected to bus when it’s needed and can provide consumer’s required energy. Also, managerially, we have applied an artificial intelligence algorithm in which the number of transmitted messages among agents have been reduced (down to only 2 messages) while in mentioned managerial procedure, in order to transmit messages among agents, at least three messages must be transmitted among agents and this would cause to reduce system velocity. Also in the proposed managerial procedure, if one of agents went to fault for any reason (for example, a communication cable among agents was disconnected), other agents would be able to supply the load’s required energy and prevent blackout caused by this fault, while in the managerial procedure proposed by Lagorse, if a fault occurs in an agent with the token, the whole system will fail.

**System Presentation**

**Electrical Network Architecture**

As shown in Figure (1), a system which we aimed at its energy management is a network with an active load. This system contains two energy resources:
- Photovoltaic generator of 190 V.
- Grid of 230 V (Phase to Phase).

Additionally, the system includes two storage devices:
40 AH battery bank under a voltage of 190 V.
A super-condensator (SC) pack of 14F under a nominal voltage of 80 V.

All elements with nominal voltage of 100V are connected to the load through a DC bus. The grid is connected to the bus via a current rectifier and Buck convertor from 230V to 100V while PV and battery are connected to the bus through a buck convertor from 190V to 100V. The load connected to the gird is an active load which could become energy generator in a period of time hence a set of capacitors (SC) would be used in the network in which the energy to be stored there. It’s clear that the SC should connect to the bus through two convertors where in a case that SC gives energy to the load then one of convertors is boosting (80V to 100V) and when the energy is stored in SC the other convertor is buck (100V to 80V).

There is a switch to disconnect the connection between the battery and PV after charging the battery so that when the battery charge dropped to a specified value and the PV was capable of producing energy then the connection is made between them allowing the battery to be charged and after full battery charging the connection between them is to be disconnected in order to prevent deterioration of the battery and to extend its lifetime.

**Control Architecture**

Each convertor connected to the bus must control the current in order to manage consumption power of the load. This is accomplished by a classic PI controller installed in the convertor. Every source has two options for controlling: it is either in controlled-current mode and controls load current or in controlled-voltage mode and controls the bus voltage. It is evident that in this system, one of agents can control voltage. The controlled-current mode is used when SC agent take voltage control. It is for this reason that SC agent loses its energy over the time and consequently the input voltage of the convertor between SC and load reduces and this will cause to decrease in output voltage of convertor. Therefore, the SC agent shares a current with other agents whenever it controls voltage. In this case, all agents in the controlled-current mode supply the shared current. In this way, the bus voltage would be constant. In this study, currents to be shared applied to agents, are not necessarily optimal. Optimized values can be calculated by optimization algorithms. However, we are not going to discuss it here.

Figure (2) shows proposed controlled structure for this system. Selection of control mode is done by a switch-like symbol which has been showed in the figure. Whenever this switch is connected to Vref, the relevant agent controls voltage and whenever the switch is connected to Iref, the agent controls current. When an agent is not able to control the voltage, the other one is replaced.
**Management System Algorithm**

In this work, we try to use subsumption architecture in order to render managerial affairs in our proposed system. This architecture is one of reactive architectures in which a number of fundamental behaviors are defined for system in such a way that these behaviors are based on the priority assigned for each behavior. In this architecture, the lower levels are of high priority and can prevent system decision based on higher levels. This type of architecture was firstly designed by Brooks to motion control of a mobile robot (Brooks, 1986). In order to control robot's behaviors he categorized some behaviors of the robot in the environment in 8 levels and prioritizes them from 0 to 7. Later, this type of architecture was used in robotics for controlling robots. Toal and et al. and Rosenblatt and et al. defined a complicated behavior of a robot in terms of a collection of simple decisions in different layers (Danielet al., 1996; Kenneth Rosenblatt et al., 1989). They could improve robot performance by creating a negotiation mechanism among layers and hence helped the robot to achieve its goals. The leveling used in this study is schematically showed in Figure (3).

Considering that the load available in system is an active load and when it is converted to a generator, its energy is saved in a super-conductor. Thus, it is necessary that energy is supplied by superconductor when the load is converted to a consumer. This agent is of higher priority than the others. This is why the superconductor agent is placed on the zero-level of subsumption architecture. If this agent is not able to control voltage, then this is the photovoltaic agent that is of higher priority than others so that its generated energy is used by the load and its energy dissipation is prevented. This is why this agent is placed at level 1. The photovoltaic agent can give energy to load only when sunlight falls onto the surface of photovoltaic panels. If sunlight cannot reach on the surface, the photovoltaic cell cannot control voltage. Therefore, if the SC agent can control voltage, it supplies energy required by the load, otherwise, agents at higher levels from the photovoltaic agent, controls bus voltage. Considering that this study aims reducing consumption of energies produced by fossil fuels, therefore, in this architecture, the battery agent is placed on a lower level than the grid agent and this is the battery agent that controls voltage. And this is why the battery agent is put at level 2 in subsumption architecture. The battery agent can provide energy to the network when it has charge. If the battery is discharged, agents at lower levels than battery will controls voltage if they are able to supply energy needed. Otherwise the energy of grid agent is always available; therefore, the grid controls voltage as long as one of SC, PV and battery agents does not have the needed energy to control voltage.

**Communicative Among Agents**

In the proposed procedure for energy management of the consumer, a distributed control and decision has been used. This kind of management increases systems reliability. If in such a system, one of agents errors anyway, other agents can supply energy to the load with excluding that agent. In this system, agents have contact with each other through a communication cable. Informed each other of their capabilities through sending signals and the agents decisions according to the architecture mentioned in earlier section. Figure (4) shows schematically the way agents are communicated with the energy management system.

![Figure 3. System layering with Subsumption Architecture](image)
RESULTS AND ANALYSIS

After the simulation of the proposed model in section 3, system reaction in the time period of 20s has been simulated. In this simulation, we assume that at first the battery is full charged, SC has 75% charged and PV is able to produce power. Thus, based on the order of subsumption architecture, first, SC agent takes the bus voltage control and supplies the whole load’s power at $t = 1.7s$. At this time, the SC agent has 62.5% charged and drops voltage at two ends of SC, therefore, this agent shares 4A of load's current between PV and battery agents in such a way that the bus voltage would not decrease. Both PV and battery agents supply 2A of the load’s current. This state follows until $t = 4.4s$, that at this time SC has 49% charged and this agent can bus voltage control and it shares 15A of the load’s current with no PV agent. Since the PV agent is able to generate energy, it can supply this load’s power. This state remains constant until $t = 7s$ when the SC agent has 45% charged and at this time, SC loses voltage control due to its failure to supply load’s power. Figure (5) shows the current plot and Figure (6) represents discharge plot of the SC agent.

After that this agent loses voltage control, according to the subsumption architecture, the PV agent is informed about it. Since the PV agent is able to generate energy, it takes the voltage control and supplies the whole load’s current. Figures (7) and (8) show current and voltage plots at two ends of PV agent.
The PV agent controls voltage until $t = 9s$ and provides the whole load's current. At this time, because of absence of sunlight, this agent cannot supply the load's power and it decides to deliver the bus voltage control to another agent. Therefore, this issue is informed to the battery agent that is at the higher level than PV. Because the battery agent has 87% charged now, therefore, it takes the bus voltage control. The battery agent follows this state until either its charge drops to the threshold value (7%) or SC and PV agents with higher priorities gain the ability to supply load's energy and control voltage. The battery agent takes the bus voltage control till $t = 11.6s$ when its charge is in the threshold value and it loses voltage control. The battery agent informs its inability in voltage control to the grid agent.

The grid agent controls voltage because of its ability to supply load's power for a long time. Grid agent takes voltage control until SC, PV and battery agents can supply the load's power. Figure (9) shows the current plot and Figure (10) represents the charge status of the battery agent.

Grid agent gains the voltage control till $t = 13s$ and supplies the load's current. At this time, the PV agent gains the ability to supply energy due to irradiation of sunlight and controls over voltage. At $t = 14s$ the load turns into a generator (Figure (11)). The SC agent notices this case and saves load's produced energy through an 80 to 100 converter. Considering that the PV agent is not able to supply the load's required energy and battery, once the load turns to a generator, and PV is able to generate energy, the battery can be charged by PV. Therefore, at the time that SC is being charged, the battery is charged by PV, too. Figure (12) shows a current plot that grid agent gives to the load.
The battery is fully charged at \( t = 15 \text{s} \) and the switch between the battery and PV will be cut (the battery agent controls the switches on and off states). The load is at energy-generating mode till \( t = 15.36 \text{s} \). In this time, it turns into a consumer because in this time the charge of SC agent has 91.5% charged.

According to subsumption architecture, this agent takes the voltage control. The SC agent supplies the whole load's power for remaining simulation times. Figure (13) represents the bus voltage for the time period of 0-20s. As can be seen, voltage at two ends of the load remains at 100v at this span.
CONCLUSION

In this study, renewable energy sources were introduced as alternatives to fossil in order to reducing environmental contaminations and also present managerial problems in these systems. Results showed that using artificial intelligence algorithms is very efficient to this end. In this study, energy sources were considered as agents and these agents had contact with each other according to an artificial intelligence algorithm, called subsumption architecture. They could excellently supply the load’s power through negotiating with each other. In the method, when an agent faced to problem, other agents were able to decide and to manage load’s energy without that agent. In this system, so long as there were energy in the resources, agents can supply the load’s power by the subsumption architecture. Only the load wasn’t received energy when any resources didn’t have required energy of the load. Results of simulation showed that the adapted management procedure for this system cause bus voltage to remain constant and also, it gives rise to lower the use of fossil fuel energy sources and consequently, decreases environmental contaminations.

REFERENCES