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MANAGEMENT OF MICRO GRID WITH MULTI AGENT SYSTEM

MANOJ KUMAR BHARDWAJ[1], SHIMI S.L[2], S. CHATTERJI[3]

[1]Assistant Professor is with Department of Electrical Engineering, Mangalayatan University Aligarh-India (UP).
[2]Assistant Professor is with the Department of Electrical Engineering, NITTTR, Chandigarh-INDIA (Punjab).
[3]Professor is with the Department of Electrical Engineering, NITTTR, Chandigarh-INDIA (Punjab)

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MANOJ KUMAR BHARDWAJ

ABSTRACT

This paper presents an efficient management of micro grid with multi agent system and its application. Instead of building large electric power grids and high capacity transmission lines, an intelligent micro grid (or smart grid) can be considered as a promising power supply alternative. The system under study consists of physical (micro grid) and cyber elements (multi-agent system). The cyber part or the multi-agent system is of primary focus of this work. The micro grid simulation has been implemented in MATLAB/SIMULINK. The set of generation, storage and load systems electrically connected and complemented by a communication system to enable control actions and follow up surveillance is called micro grid. In recent years, multi-agent systems have been proposed to provide intelligent energy control and management systems in micro grids. Multi-agent systems offer their inherent benefits of flexibility, extensibility, autonomy, reduced maintenance and more. The implementation of a control network based on multi-agent systems that is capable of making intelligent decisions on behalf of the user has become an area of intense research. Agents must be able to respond to the information sensed from the external environment quickly enough to manage the micro grid in a timely fashion. The implementation of multi-agent system was completed by identifying Roles (Role Modeling) and Responsibilities (Social and Domain Responsibilities) of agents in the system, and modeling the Knowledge (Facts), rules and ontology for the agents. Finally, both micro grid simulation and multi-agent system are connected together via TCP/IP using external java programming and a third party TCP server in the MATLAB/SIMULINK environment.

Key Words- Multi Agent System (MAS), Energy Management, SCADA System, *TCP,* Power Generation Network, Power Generation Control, Distributed Energy Resources (DER)

NOMENCLATURE

Intelligent Distributed Autonomous Power System (IDAPS), Distributed Generation (DG), Advanced Research Institute (ARI), Foundation of Intelligent Physical Agents (FIPA), Internet Protocol (IP).

INTRODUCTION

A micro grid comes in the category of smart

grid, which is formed by the interconnection of small, modular generation to low voltage distribution systems. Micro grids can be connected to the main power network or be operated autonomously. The local DG units who are selling energy to the network having other tasks also: producing heat for local installations, keeping the voltage locally at particular level or providing a backup system for local critical loads during failure of the main system. These tasks favour the importance of the distributed control and autonomous operation of the micro grid.

Recently there is a progressive transition from a centralized power producing system to a distributed one which includes several small (1- 20 MW) and even smaller (< 0.5 MW) units. It is essential that this distributed power producing system needs a distributed and autonomous control system. Therefore, in this paper, the implementation of a multi agent system (MAS) for the control of a set of small power producing units, which could be the part of a micro grid, have been presented.

The use of MAS technology in controlling a micro grid solves a number of specific operational problems. Like, small distributed generation units having different owners, and several decisions should be taken locally and centralized control is difficult. It is also necessary that micro grids operating in a market requiring actions of the controller of each unit participating in the market must have a certain degree of intelligence.

In spite of building larger power plants and large capacity transmission lines, electricity needs for critical equipment could be met by the concept of micro grid. A micro grid consists of on-site distributed energy resources (DERs) which perform a section of distribution network and a group of loads. Local loads may consist of buildings, offices, homes, and industries. A micro grid supports to improve the competency of the system to allow the local network to be more competent, results in quick recovery from outages and failures.

Intelligent Distributed Autonomous Power System (IDAPS) presented by the Advanced Research Institute (ARI) represents an intelligent micro grid (a smart grid) concept whose aim to improve competency and autonomy of the electric power grid against manmade and natural disasters. In the heart of this concept lies a network consisting of smart/intelligent entities (software agents), capable to learn from their surrounding environment and make decisions on behalf of the user.

Multi agent systems provide various advantages over the SCADA system for the implementation of an intelligent micro grid. First, many multi agent system development toolkits are available as open source software which makes them a superior choice for IDAPS. Second, most toolkits are JAVA based which creates them independent platform. Also, for an approach with an external programming multi agent systems can be connected to any external hardware or software entities to allow a micro grid control. The other benefits of multi agent systems are; to propose inherent benefits of flexibility and extensibility, since DERs, loads and storage units have different owners so they may do their own decision locally. In actual practice, the purpose behind multi agent systems is that a huge and complex task be divided into several smaller tasks assigned to several entities which reduce the need for maintenance and processing of large data.

Micro Grid Management System

A micro grid consisting of the following individual system which manages the entire micro grid unit:

An Agent System

Applications of agent-based systems can be divided into the following two categories:

Single Agent Systems

In a single-agent system, an agent works alone by responding to and interacting with its environment for performing of its targets. In this, agents are explicitly modeled as having their own actions, goals and domain knowledge. So, if there are other agents working in the same environment they do not have impact on the functionality of an agent.

For example, softwares like information retrieval and filtering, mail management engine, news filtering engine, search engine, etc.

Multi Agent Systems

A multi-agent system is a system that consists of several coordinating and computing entities called “agents”. The agents may be software agents, such as computer programs or they may be

people like us. An agent can perform working alone in an environment or it may share, coordinate and communicate with other agents to achieve its predefined/assigned goals. According to [1, 2, 3, 4], a software program can be considered as an agent if it exhibits the following characteristics:

Agents are capable to operate without any supervision of humans and having certain level of control over their actions and internal state, known as autonomy of the agents.

Agents interact and communicate with humans and other agents through some kind of agent communication language, known as social ability.

Agents respond for changes in their environment with time, known as reactivity.

Agents perform actions and take initiatives as per the goals already assigned to them. This characteristic is termed as pro-activeness or goal-oriented or goal-directed behavior.

An agent must contain sufficient data for correspond to its knowledge about the environment and would help in decision making towards its goals, known as data collection.

Agents must contain a list of well defined protocols which define methods of communication with different entities like humans or other agents belonging to the system.

Agents must contain a learning module that would keep updating its data collection according to the performance of its computational component, changing environment and condition of fellow agents.

Multi-agent systems have already been applicable for many applications in communication systems [5], information retrieval systems [6], decision support systems [7], supply chain [8], transportation [9], military systems [10, 11, 12], and many more [13, 14, 15, 16, 17].

Multi Agent System Architecture and Design

It is very important in the context of the IDAPS micro grid, to select an agent platform that must be based on a well-known standard (IEEE) on foundation for intelligent physical agents (FIPA). This will help ensure interoperability among different systems and platforms so that the multi agent system can be universally accepted. As a result, compliance with FIPA should be the number one criteria of an agent platform selected for this task as shown in Fig.1.

IDAPS consists of physical and cyber layers. Physical layer consists of DER devices capable of communicating with the cyber layer entities (the multi agent system). IDAPS allows its registrants from the intricacies and monopolies of the wholesale market for allowing them to buy and sell energy as per their financial and needs. IDAPS operations are divided into normal (grid-connected mode) and outage (island mode) conditions.

Based on the goals of IDAPS a multi-agent system designed for IDAPS should be able to accomplish following seven tasks.

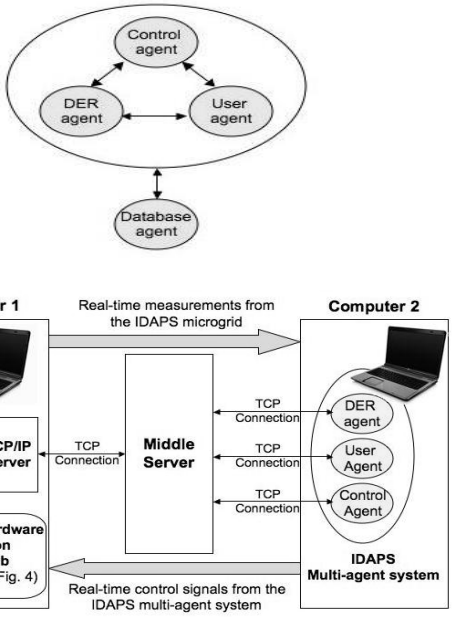

Fig.1 The IDAPS multi-agent architecture, where arrows represent messaging exchange among agents via the Transmission Control Protocol/Internet Protocol (TCP/IP)

Multi-Agent System Functionality

Following is the summarization of the functionality for IDAPS multi agent system with the mentioned seven agents.

1. Control Agent for Control Task
2. User Agent for User Access Task
3. Load Agents for Load Monitor/Control Task
4. Bulletin Board for Bulletin Board Task
5. Aggregation Agent for Message Aggregation Task
6. DER Agent for DER Monitor/Control Task
7. Database Agent for Database

The operation of these seven agents can be divided into grid-connected and island mode conditions:

In the grid-connected mode, the control agent continuously monitors voltage or frequency levels from the main grid and keeps the status of the main circuit breaker in the closed state. In an islanded mode, the control agent continuously monitors voltage levels from the main grid and opens the status of the main circuit breaker.

Following are the user agent's capabilities:

1) Provides user access to IDAPS

2) Monitors voltage, current, active and reactive power consumptions at all critical and non-critical loads

3) Capable of shedding off loads based on user's choice (discussed in a later chapter) when island mode is detected

4) Monitors demand and supply

5) Controls power supply from DERs in order to serve loads

After this modification achieving IDAPS multi-agent system responsibilities would require only four agents, control agent, user agent, DER agent and database agent.

An agent platform is a software environment in which software agents run. It consists of the machines, operating system, agent management system and the agents. The agent platform used for the development of micro grids agents is JADE (Java Agent DEvelopment Framework). JADE is compliant FIPA 2000 (Foundation of Intelligent Physical Agents).

Management functions

The agent based micro grid management system provides the following functionality:

Mainly two strategies have been considered for the control and communication within micro grids: Hierarchical or centralized control and decentralized or distributed control.

Hierarchical control requires a central controller that manages the entire system. The concept is based on the same approach used for SCADA systems in the past. Decentralized or distributed control approach is implemented using the multi agent systems technology. In [18, 19, 20]. Multi agent system implementation controlling a small micro grid (PV generator, converters and inverters, batteries and controllable loads) is presented in [19] and [20]. The work is performed in the micro grid's grid-connected mode. The system is implemented using JADE framework. The objective of this work is to minimize the operational cost of micro grid. The issue of buying and selling of energy in a micro grid market is expressed as symmetrical assignment problem in which persons are matched with objects in order to maximize the benefit. In [21], a multi agent system is proposed that attempts to restore a distribution system network after a fault. It is a hierarchical multi agent system architecture in which lower layer agents sense the absence of energy and inform the higher layer agents, while the higher layer agents try to restore energy by negotiating with their peers. In [22], authors mentioned multi-agent system architecture for micro grid management. The goal of the system is to perform tasks such as measurement data acquisition, DSM (Demand Side Management) functions for load shifting, load curtailment and generation scheduling. The architecture includes several agent entities capable of retrieving generation scheduling patterns from external database. The authors' multi agent system architecture consists of micro grid central controller (MCC, connected to external database for generation scheduling patterns retrieval), micro grid source controller (MSC, connected to DERs) and load controller (LC, connected to loads). MCC, MSC and LC further consist of several agents performing their specific tasks. The multi agent system provides various functionalities among which great emphasis has been given to the secondary regulation system. The secondary regulation system starts operating when a change in load is detected. The change in load causes the batteries to modify their power level and secondary regulation system kicks in. Secondary regulation system then assigns the power requirement difference to generator which fulfills the power requirements. The multi agent system is implemented using JADE.

Specification of Multi Agent System

Control Agent: Control agent will monitor the voltage level from the main grid and status of main circuit breaker. It will be responsible for letting all other agents know of these parameters. It will let other registered agents of the duration and time of outage. The control agent will also have a GUI to display all of these parameters and take input from the users.

User Agent: User agent will provide a GUI, monitor voltage, current, active and reactive power

consumptions at all critical and non-critical loads and control on/off status of loads. Its actions will depend on information from the control agent and the DER agent.

DER Agent: DER Agent will control the operation of DERs. Its actions will also be based on outputs from the control and the user agents. The DER agent and the user agent will always be exchanging messages at regular intervals in order to operate loads at minimal cost.

Database Agent: Database Agent is same as utility agents automatically generated by JADE. As described earlier they keep track of all available agents and their capabilities.

Architecture of Software

There are a number of open source agent development toolkits available including: Aglets software development kit [23], Voyager [24], Zeus [25], JADE [26], Tracy [27, 28], SPRINGS [29], Tryllian [30], FIPAOS [31] and Skeleton Agent [32].

Development of the multi agent system

A multi agent system is developed using an agent building toolkit is achieved by following certain steps. The process starts by specifying abilities of each agent followed by identifying their roles (Role Modeling) and responsibilities (Social and Domain Responsibilities) in the system. It then requires modeling the knowledge (Facts) for the agents that aids in creating the ontology for the system. The final step is creating the agents and code generation. The implementation is completed by implementing external programming.

Integration of the multi agent system and the micro grid simulation

The multi agent system and the micro grid simulation are two different pieces of software existing in two separate environments. In order to exchange messages among them, the two have been connected together using TCP. A third party TCP server is used in the micro grid simulation in MATLAB/SIMULINK. This TCP server only allows single TCP connection at a time. This poses a limitation to our application as it has more than one agent interacting with the micro grid at the same time. To overcome this limitation another TCP server, a middle server, has been implemented that allows multiple TCP connections.

Software Operation

In the Fig.2 a display of the graphical user interface (GUI) of the agents is presented. From this screen the operational cost can be adjusted. Similar forms have been developed for the Loads and the Main Grid.

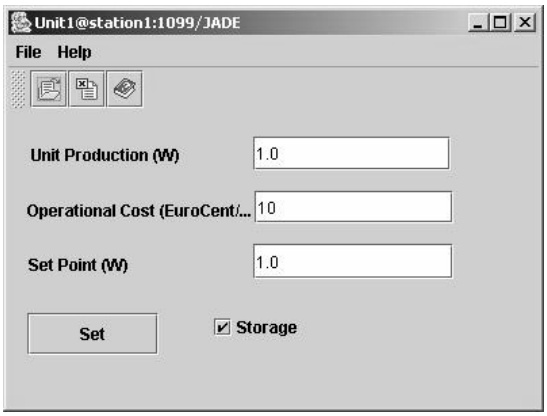

Fig.2 Screenshot of the GUI for the Production Unit

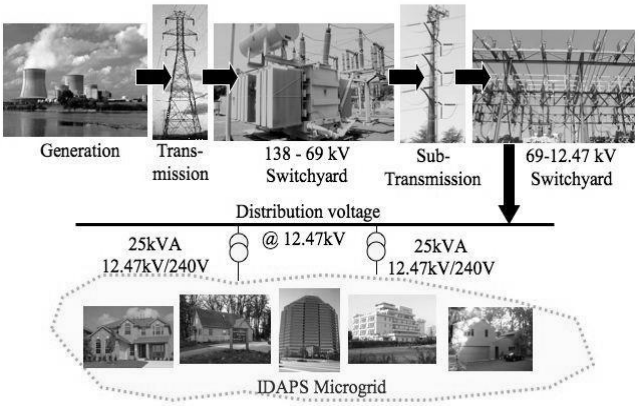

Fig.3 The boundary of an IDAPS micro grid in a Virginia Tech setting

Description of simulation circuit

Fig.3 shows a community micro grid in a Virginia Tech setting and Fig.4 is used for simulating the case studies that consist of one or more DER unit, a grid interface unit (consisting of inverter, filter and PWM), the main circuit breaker, the transformer (12.47 kV: 240V) and the main grid (12.47KV). The multi-agent system adds intelligence to the system. It receives and sends messages from/to the circuit and performs control and management actions.

IV. RESULT

The multi-agent system monitors voltage level from the main grid, controls the status of the main circuit breaker, monitors and controls the power consumption by each load in the community, monitors and controls the power supplied by the DER units and the on/off status of each load by

controlling the electronic circuit breaker associated with it. This multi agent consists of four agents, namely control agent, DER agent, user agent, and database agent.

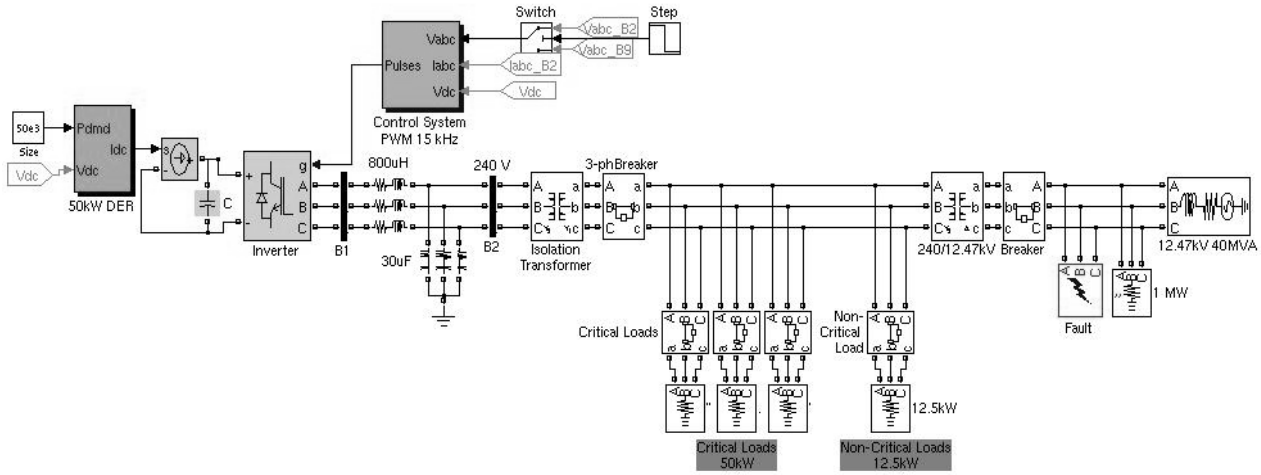

Fig.4 Microgrid hardware simulation in MATLAB, consisting of a 50 kW distributed generator, grid interface, loads and load circuit breakers, a distribution transformer (12.47 kV/240 V), the main circuit breaker and the utility grid at 12.47kV

Control Agent monitors the voltage levels of electricity from the main grid, price signals from the utility and controls the main circuit breaker. In emergency conditions it performs actions to isolate micro grid from main grid by opening the main circuit breaker. It also keeps all the agents in system informed about pricing signals from main grid and whether the system is in grid-connected or islanded mode.

User Agent works on behalf of the homeowner and takes actions based on the options set by the homeowner. It is capable of monitoring and controlling loads, varying power consumption by loads, and participating in bids to buy electricity for the house from the DER units. Each house in the community has an independent user agent.

DER Agent is responsible for storing associated DER information, as well as monitoring and controlling DER power levels and its connect/disconnect status. DER information to be stored may include DER identification number, type (solar cells, micro turbines, fuel cells, etc), power rating (kW), local fuel availability, cost function or price at which users agree to sell, as well as DER availability, i.e. planned maintenance schedule. It also monitors and controls power produced by the DER units and sells electricity to houses in the community. Both DER units in the community are controlled by one DER agent.

Database Agent serves as data access point for all the agents. It also keeps track of locations and names of all the agents in the multi agent system.

The four agents together form the multi-agent system that performs actions to achieve the goal of the system.

V. CONCLUSIONS

A multi-agent system is developed for an IDAPS micro grid with standard development techniques and agent communication protocols. Functionalities of isolating micro grid and securing critical loads are incorporated into the system. The developed system also incorporated an algorithm for supporting non-critical loads using the limited excess capacity from a DER under outage conditions. The system is simulated using a micro grid simulation in MATLAB Simulink.

The multi agent system development process using JADE agent building toolkit requires: specification, application analysis, application design, and application realization. These steps generate agents' codes capable of reacting to external changes in their environment.

Four main agents, namely a control agent, a user agent, a DER agent and a database agent, are

specified to achieve the goals/tasks within an IDAPS micro grid. The agents are then connected to the micro grid simulation in the MATLAB/SIMULINK environment using external programming. The connection is established using TCP/IP connectivity. The system is tested to illustrate the agents' ability.

It is expected that this multi agent system will be useful for many researchers in academia and industry to understand the design, development and practical implementation of an agent based technology in a micro grid environment. Furthermore, the work also contributes to the new design schemes to increase multi agent system's intelligence in the context of micro grids. In particular, these include control algorithms for managing energy demand from various users, and securing critical loads while supporting non-critical loads using remaining capacity.

Additionally, DER units and batteries could be incorporated into the system for better energy management. Especially during the times when the demand is low the available energy could be stored for later use. Incorporating more DERs would then also require inclusion of new DER units' prices and using DERs according to the DER owner's choice. This would require further work on assigning new responsibilities for a DER agent. On the user agent's side, new equations can be developed to generate offer prices that reflect user's desire for using non-critical loads during outages. Below are some suggestions for the parameters, which can be incorporated in the calculation method:

- Base price
- Limitation amount
- Time of the day
- Level of need (High or low) to use the non-critical loads entered by the user
- Duration of outage (if known)

The micro grids management system is developed on top of JADE agent platform; JADE's container architecture allows the deployment of agents in a distributed environment. Under normal circumstances, each micro source, storage or load control system has a devoted local controller agent although the distributed architecture enables any of those agents to be executed on a physically different hardware.

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