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Autonomous Energy Management of a Micro-Grid using Multi Agent System

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Abstract

Multi Agent System (MAS) is a distributed system with loosely coupled agents; work together to solve problems that are beyond their individual capabilities.The objective of this paper is to implement MAS in Java Agent Development Environment (JADE) for distributed, autonomous energy management of a solar micro-grid. A grid connected solar micro-grid, which contains two solar Photo Voltaic (PV) systems, each contains a local consumer, a solar PV system and a battery, is considered. Load usage patterns and solar power generated in the two solar units are measured. Each constituents of the micro-grid is taken as an agent and these agents take decision autonomously as well as collectively for optimal energy management. The proposed approach autonomously manages the dynamics due to intermittent nature of solar power, randomness of load, dynamic pricing of grid and choose the best possible action to stabilize and optimize the solar micro-grid. MAS has the flexibility for plug and play and so solar power and load is added or removed seamlessly without affecting the micro-grid operations. Furthermore, MAS increases the operational efficiency, leading to economic and environmental optimization of solar micro-grid. All the smart grid features are implemented in the micro-grid, which is not attempted so far. The simulation outcomes demonstrate the effectiveness of proposed MAS in distributed, autonomous energy management of micro-grid, solving the constraints of using solar power. All agent actions for stabilizing the grid can be accomplished in less than ten milliseconds, taking automation of micro-grid to the next higher level.

Keywords: Energy Management, JADE, Multi Agent System, Optimization, Solar Micro-Grid

1. Introduction

The countries across the world are more concerned about the environment and started investing more on renewable resources like solar and wind. We are moving towards a more decentralized, more sustainable and smarter power system. The computational intelligence methods like neural networks, fuzzy logics and evolutionary algorithms are used for energy management of micro-grid are discussed[1]. Most of the existing research on micro-grid uses centralized approach. In the recent timesdistributed approach is used in energy management problem due to reduce communication overhead and improved robustness. One such approach is Multi Agent System based modelling of micro-grid in which agent autonomously takes decision and also coordinates with other agent for collaborative action. The distributed nature and dynamic decision making capabilities in solving complex problems motivates the use of MultiAgent System for the operation of micro-grid[2]. Agent based modelling is used in micro-grid with uncertainty of renewable energy resources, for maintaining stability and reliability[3]. MultiAgent System is implemented in Energy Management System (EMS) in a PV-small hydro hybrid micro-grid[4]. The main operations of a Multi Agent System for micro-grid control are discussed[5]. Eddy and Gooi discussed about optimization of micro-grid using MAS[6]. The design and implementation of Multi Agent

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System in micro-grid energy management is discussed in detail in the paper[7]. Multi-agent based distributed energy management for intelligent micro-grid is discussed in[8]. Multi agent based micro-grid control is discussed in[9]. The complete review of micro-grids in MultiAgent System perspectives are discussed in[10]. Only in the very recent paper[11],MAS is implemented in JADE for autonomous power restoration is discussed in detail. Although many micro-grid research activities involving MAS have been reported, their approach is not comprehensive, including all the options available for optimal energy management of a micro-grid. So we propose a Multi Agent System based advanced distributed energy optimization of solar micro-grid by comprehensively analysing and simulating all the possible options and choose the best option for the dynamic energy management. In the proposed approach, agent autonomously choose the best option every hour, considering the intermittent nature of solar power, randomness of load, dynamic pricing of grid and variation of critical loads, to stabilize and optimize the solar micro-grid. Simulation results in this paper represent the dynamic behaviour of the micro-grid across various possible solar-power and load values. The paper is organized as follows. Section 2 deals about solar power and load measurement. A detailed discussion on Multi Agent System approach and implementation of autonomous energy management in solar micro-grid is given in Section 3. Simulation and results are given in Section 4. Conclusion is given in Section 5.

2. Solar Power and Load Measurement

A micro-grid is a low capacity of electricity sources in the distribution side which can supply power to local requirements like colleges, universities and rural communities. We consider two solar units in our campus premises one in the department with 150kW capacity and other in hostel with 200Kw, each one has a solar power generator, load and battery. Solar power on hourly basis is taken from National Renewable Energy Laboratory (NREL). The usage of load is calculated per hour for the department and hostel. The power and load graph for every hour is drawn for the department and hostel as shown in Figure 1 and Figure 2.

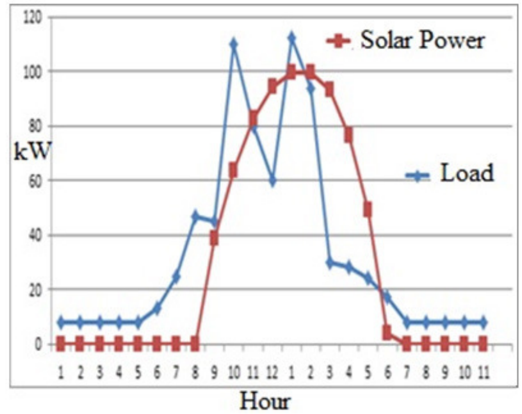

Figure 1. Department solar power and load.

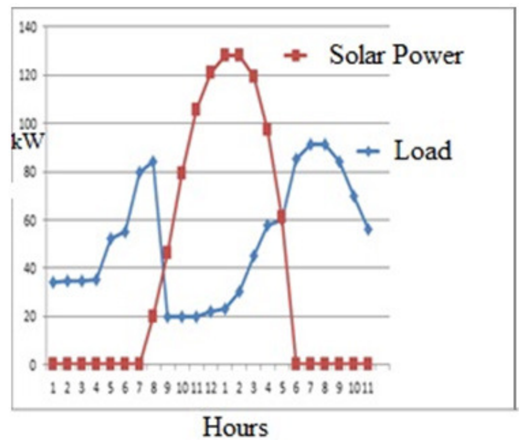

Figure 2. Hostel solar power and load.

3. Multi Agent System Approach for Autonomous Energy Management of Micro-grid

3.1 Multi Agent System

Distributed system with many on-going interactions and continuous communications are almost infeasible. These considerations have motivated the development of approaches to distributed system based on agents, which provide ways for adaptation and on-going interaction. A Multi Agent System (MAS) is a distributed system consisting of multiple software agents, which form a loosely coupled agents, work together to solve problems that are beyond their individual capabilities. MAS are sub-field of Distributed Artificial Intelligence (DAI). Multi-

Agents paves a way to systems that are decentralized rather than centralized, emergent rather than planned and concurrent rather than sequential, with many advantages. MAS have inherent benefits such as flexibility, scalability, autonomy and reduction in problem complexity[12]. In MAS, several autonomous and intelligent entities called agents are working in collaboration to achieve the overall goal of a system through strategic action. An agent receives information about a state of its environment, takes actions which may alter that state and expresses preferences among the various possible states. Agents have four behavioural attributes, autonomy, social, proactive and reactive. Autonomy means the agents can operate on their own to meet their goals without the need for human guidance. Agents are proactive, they have the ability to take the initiative rather than acting simply in response to their environment. Agents possess social ability so that they can cooperate with other agents for coordinated action. They interact with other agents with some communication language like Agent Communication Language (ACL). Reasoning, optimizing, controlling and learning are the inherent characteristics of an agent[13].

Electrical distribution automation by Supervisory Control and Data Acquisition (SCADA) system is the conventional solution for improving reliability, increasing the utilization of power grid. SCADA refers to a central control system that monitors and control equipment from a remote location. SCADA systems co-ordinate, communicate and control remote sub-stations from the control room. Humans have supervised, reasoned and resolved the issues in SCADA. Also SCADA is complicated due to its centralized approach. In the micro-grid, uncertainty in SCADA systems arises due to intermittent nature of renewable Distributed Energy Resources (DER) like solar and wind. SCADA must deal with inherent noise in sensor data as well as uncertainty, incompleteness and inconsistent or conflicting data from multiple, heterogeneous renewable energy resources in micro-grid. A multi-agent Energy Management System (EMS) can cope with heterogeneity and give better, faster solution than SCADA[14]. MAS can deal with disadvantages of SCADA and increase the operational efficiency of micro-grid due to its inherent characteristics and functionalities, taking the automation of micro-grid to the next level.

3.2 Multi Agent Platform –JADE

In this paper, Java Agent Development Environment (JADE) frame work[15] that conforms to Foundation of Intelligent and Physical Agent (FIPA) standard for intelligent agents[16] is used to run the software agents of MAS. JADE is also used as runtime environment in which agents execute, thereby the underlying complexity of the operating system or network is hidden from agents. Agents be on one computeror can span multiple computers, yet the code for communicating messages is the same. The JADE runtime execution is done within a Java Virtual Machine (JVM). Agent lives in a container and a platform contains many containers. A platform encompasses main container and all the containers within an agent system. JADE providesa distributed platform for users to focus more on developing agents for control and monitoring of power balance during micro-grid operation. When a platform is created, the main container is the initialized first. Agent Management System (AMS) and Directory Facilitator (DF) agents are created once the main container is initialized as shown in Figure 3. Agent Management Service (AMS) is like white pages, it manages the agent platform, by maintaining directory of Agent Identifiers (AIDs) and agent states. Only one AMS will exist in a single platform in the main container. Once registered, AMS gives valid Agent ID to registered agents. Directory Facilitator (DF) gives the default yellow page services in the platform. DF allows the agents to discover the services of other agents in the network. The Message Transport Service (MTS) is responsible for communicating messages between agents and provides services for message transfer among the agent system. Every agent must register in AMS and then it discovers the nature of other agents in the DF and chooses to communicate them through MTS. An agent has certain type of behaviour and tends to satisfy its objectives using its resources, skills and services. The agent supports high level communication language, Agent Communication Language (ACL), where the agents not only simply exchanging values, but knowledge, commands and semantics are also exchanged to make it more semantic. The communication between the agents takes place asynchronously for distributed, coordinated action.

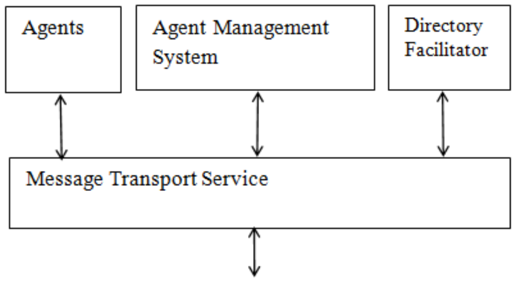

Figure 3. Architecture of Multi Agent System.

3.3 Problem Formulation

The dynamic variation in the solar micro-grid system due to integration of renewable energy to the grid is to be autonomously managed. In the grid connected solar micro-grid, the intermittent nature of solar power, randomness of load and the battery State of Charge (SOC), non-critical loads, critical loads and dynamic pricing are monitored continuously every hour. All possible logical options are considered andthe best possible action is chosen for optimal energy management of advanced, dynamic, solar micro-grid leading to economic and environmental optimization.

3.4 Implementation

3.4.1 Flow Chart

Two grid connected solar units are considered, each contains a local consumer, a solar PV system and a battery. One in the department with capacity of 150kW and the other solar unit is in the hostel with capacity of 200 kW. The proposed system has solar power generator agent, load agent, battery agent, grid agent, diesel agent and control agent. Each PV system has all these agents. Multi agent the programming is done for all the agents in JADE platform using Eclipse environment. The flow chart is given in Figure 4 and the overall procedure is the following:

- Initially the Department Load (DL) looks at its local solar power source (SDP). If surplus energy is available in S1, then it checks the local battery (B1) to charge and if excess energy is available it checks the battery of hostel agent (B2) and charges it. The remaining excess available is given back to the grid.
- If partially available then it will look into the availability of solar power in the hostel solar unit (SHP). If required power is not available in SHP then it looks into the battery of the department (B1). If fully available it takes from it and if partially available then it checks with the hostel battery (B2). If required power is available, it is taken.
- Even after taking from solar unit and battery, if power is still required, then it checks for Non-Critical Load (NCL) shedding at that particular hour. Non Critical Loads (NCL) can have many priorities and layers based the requirement. Even after shedding NCL, if load requires power, it checks with the unit pricing of the grid (GP)and the diesel (DP) at that particular hour and chooses the least priced one.
- Every hour based on the load requirement and availability of solar power the agent takes the best possible decision for economic operations in a distributed environment.
- Similar steps are followed for the Hostel Load agent [HL]. All the communication is done through ACL. Thus every hour the solar micro-grid energy management is done dynamically for distributed optimization of solar micro-grid by using Multi Agent System in JADE platform.

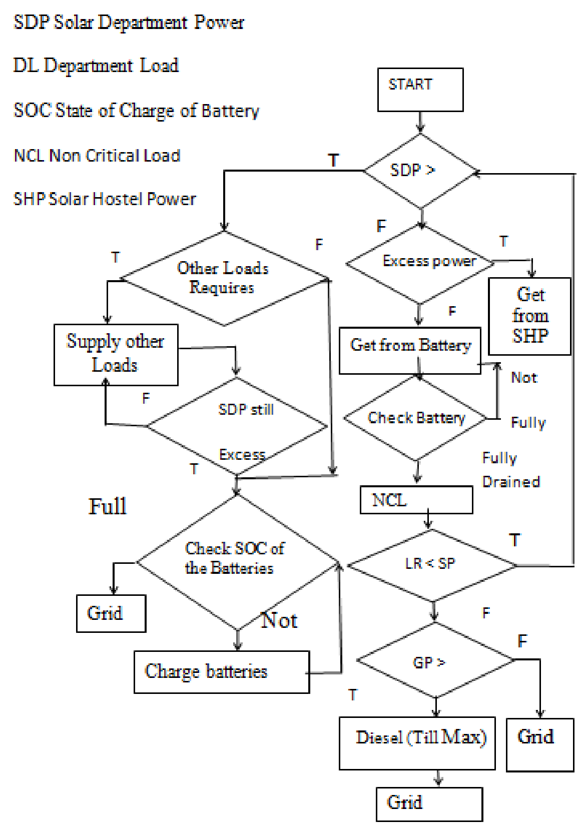

Figure 4. Flow chart for energy management of solar micro-grid.

Programming is done for every agent in JADE and communication between the agents is done through ACL. Directory Facilitator (DF) is used for plug-and-play capabilities. It can dynamically include the resources

```
OUTPUT-------------------------------------2
                HOSTEL
Power                           : 40kW
Load                            : 80kW
Power Tapped from local Agent   : 40kW
Power Tapped from other Agent   : 0kW
Power Tapped by Battery         : 0kW
Battery Charge                  : 0.0%
Power Remaining                 : 0kW
Power Needed                    : 40kW
Power sent to Grid              : 0KW
Non Critical Load Shed          : 10kW
Power Needed after Load shedding : 30kW

Preferred non-renewable power Source : Diesel Generator(DG)  Price/kWh = Rs.5
Power Tapped from DG                 : 30kW    Grid Price/kWh = Rs.6
Total Power Tapped from DG           : 30kW

--------------------------------------------
             DEPARTMENT
Power                           : 50kW
Load                            : 90kW
Power Tapped from local Agent   : 50kW
Power Tapped from other Agent   : 0kW
Power Tapped by Battery         : 0kW
Battery Charge                  : 0.0%
Power Remaining                 : 0kW
Power Needed                    : 40kW
Power sent to Grid              : 0KW
Non Critical Load Shed          : 12kW
Power Needed after Load shedding : 28kW

Preferred non-renewable power Source  : Diesel Generator(DG)  Price/kWh = Rs.5
Power Tapped from Diesel Generator    : 28kW    Grid Price = Rs.6
Total Power Tapped from DG            : 28kW
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Figure 5. Console output of energy management of solar micro-grid.

and loads as and when they are necessary to manage the variation of solar power. All the agents inform to the DF the services that they could provide to the system. Here, the load agents register as buyers of energy as a service, while the Grid Agent (GA)registers in DF as sellers of energy. The GA sends request to the DF to know the requirement. The DF agent provides the list of load agents that require energy. Then, the GA sends a request to all the load agents in the DF list. The load agent accepts or refuses the offer after considering all other offers. Also the load agent can look into other Gas, registered in the DF and choose the required one based on the comparisons.

3.4.2 Simulations and Results

All the operations are considered as shown in the flow chart and for these scenarios, the Java programming is done in JADE environment and executed in Eclipse Integrated Development Environment (IDE). Various scenarios are considered and sniffer diagrams and the console output representing the interaction of the agents and transaction details are studied. The sequences of operations are as follows. Hostel load taps 40 kW from hostel solar power as hostel power is 40 kW which is less than the required power of hostel load, which is 80kW. Hostel load further needs 40kW and so it look into the hostel and department batteries where no power is available and so it sheds the non-critical load of 10kW and the remaining power required, 30kW is taken from the Diesel Generator (DG) as its per unit price is less than the grid unit price. College load taps 50kW of power from college solar power and it still requires 40kW of power. It looks to its battery and hostel battery, where there is no power. Then it sheds the non-critical load of 12kW. Further required 28 kW is taken from Diesel Generator after comparing the grid unit price at that hourly interval, which is Indian Rupees 6/kWh, to the diesel unit price of Indian Rupees 5/kWh. The console outputs and sniffer diagram of the solar micro-grid are shown in Figure 5 and Figure 6. Every hour the power is traded with the grid or diesel generator, due to the intermittent nature of the solar power. After negotiations among the agents, the final result of how much power is being traded with the grid or Diesel Generator based on the per unit price at that time is reported by Control Agent (CA).The smart grid feature dynamic pricing is incorporated and hence various possible

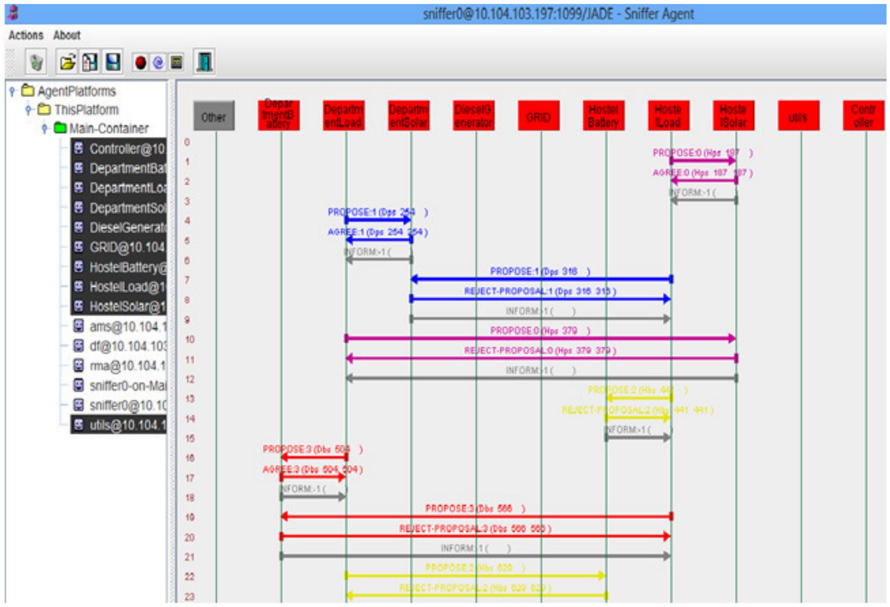

Figure 6. JADE sniffer diagram of energy management of solar micro-grid.

scenarios, like when the load is less than solar power or solar is greater than load, battery is low or high, grid perunit price is high or low, when there is no solar power, etc. are considered and the agent chooses the best possible actions for economic and environmental optimization of solar micro-grid. Actions of agent take in less than 10 milliseconds to improve the operational efficiency. Thus Multi Agent System is implemented in JADE platform for autonomous, optimal energy management and demand side management of the solar micro-grid.Multi Agent System can also be applied to smart grid, which is building block of micro-grid, for decentralised operation to replace the present SCADA system.

4. Conclusion

The autonomous energy management of solar micro-grid, which consists of two solar generators, are done with a MultiAgent System approach. A MAS model was developed for the solar micro-grid by using JADE and all the options available for the agents in the micro-grid are comprehensively analysed for optimal, autonomous energy management of advanced, dynamic solar micro-grid to achieve the lower cost of power generation under intermittent nature of solar PV system and varying load conditions. The proposed framework gives the consumer the ability to explore all possible options and select the best action for improving operational efficiency and thus for optimal energy management of the solar micro-grid in a distributed environment. Future work will focus on extension to heterogeneous agents like solar and wind etc., with many intelligent consumers taking autonomous decision for local optimization as well as collaborating with each other for taking strategic decision for global optimization with conflicting requirements.

5. References

1. Colson CM, Nehrir MH, Pourmousavi S. Towards real-time micro-grid power management using computational intelligence methods. Proceedings of IEEE-Power Energy Society General Meeting; Minneapolis, MN. 2010 Jul 25-29. p. 1–8.
2. Mocci S, Natale N, PiloF, Ruggeri S. Demand side integration in LV smart grids with Multi Agent control system. Electric Power System Research. 2015 Aug; 125:23–33.
3. KuznetsovaE, Li YF, Ruiz C, ZioE. An integrated framework of agent-based modeling and robust optimization for micro-grid energy management. Applied Energy.2014 Sep; 125(2):70–88.
4. Zhao B, Xue M, Zhang X, Wang C, Zhao J. A MAS based energy management system for a stand-alone micro-grid at high altitude. Applied Energy. 2015 Apr; 143: 251–61.
5. Dimeas A, Hatziargyriou ND. Operation of a Multi Agent System for micro-grid control. IEEE Transactions on Power Systems. 2005 Aug; 20(3):1447–55.
6. Eddy FYS, Gooi, HB. Multi Agent System for optimization of micro-grids. Proceedings of 8th International Conference on Power Electronics – ECCE Asia. Institute of

Electrical and Electronics Engineers (IEEE); Jeju. 2011. p. 2374–81.

7. Pipattanasomporn M, Feroze H, Rahman S. Securing critical loads in a PV-based micro-grid with a Multi Agent System. Renewable Energy. 2012 Mar; 39(1):166–74.
8. LogenthiranT, Srinivasan D, Khambadkone AM, Aung HN. Multi Agent System for real-time operation of a micro-grid in real-time digital simulator. IEEE Transaction on Smart Grid. 2012 Jun; 3(2):925–33.
9. Nunna HSVS, DoollaS. Multi agent-based distributed-energy-resource management for intelligent micro-grids. IEEE Transactions on Industrial Electronics. 2013 Apr; 60(4):1678–87.
10. Gomez-Sanz JJ, Garcia–Rodriguez S, Cuartero-Soler N, Hernandez-Callejo L. Reviewing micro-grids from a MultiAgent Systems perspective. Energies. 2014; 7(5):3355–82.
11. AnishaK, Rathina Kumar M. JADEimplementation of power restoration in automated distributed system. Indian Journal of Science and Technology. 2015 Aug; 8(19):556–71.
12. Fard AA,Rafe V. A formal architecture style of designing of MultiAgent System. Indian Journal of Science and Technology. 2014 May; 7(5):662–71.
13. Lagorse J, Paire D, Miraoui A. A MultiAgent System for energy management of distributed power sources. Renewable Energy. 2010 Jan; 35(1):174–82.
14. Calderwood S, Liu W, Hong J, Loughlin M.An architecture of Multi Agent System for SCADA-dealing with uncertainty, plan and actions.Proceedings of ICINCOPP. 2013 Jul; 1:300–6.
15. Java Agent Development Environment development toolkit.2015. Available from: http:// www.jade.tlab.com
16. The Foundations for Intelligent Physical Agents. 2015. Available from: http://www.fipa.org