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Multi Agent System based Distributed Energy Management of a Micro-Grid

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Abstract: This paper describes the implementation of Multi Agent System (MAS) for advanced distributed energy management of a solar micro-grid. We consider a grid connected solar micro-grid with two solar Photo Voltaic (PV) systems, and each system contains a local consumer, a solar PV system and a battery. First we measure the load patterns and solar power generated in the two solar units. Then we use Multi Agent System for advanced distributed energy management of solar micro-grid with smart grid frame work. The MAS is implemented in Java Agent Development Environment (JADE) for dynamic energy management, which considers the intermittent nature of solar power, randomness of load, dynamic pricing of grid and variation of critical loads and choose the best possible action every hour to stabilize and optimize the solar micro-grid. Furthermore, MAS increases the operational efficiency, due to decentralised approach and reduced timings. Thus MAS in solar micro-grid energy management leads to economic and environmental optimization. Simulated operation of solar generators and loads are studied by performing simulations under all possible agent objectives. The effectiveness of proposed MAS in distributed energy management of micro-grid is demonstrated in the outcome of the simulation studies.

Keywords: Energy management, Automation, Multi Agent System, JADE, Solar Micro grid.

1. INTRODUCTION

The world is becoming more conscious about the global warming. Renewable resources are increasingly found their use as it is environment friendly. Due to complexity of in the existing grid, we are moving rapidly towards a more decentralized, more sustainable, and smarter power system [1]. Solar and wind energy are the only solutions to the growing energy crisis in the world. The intermittent nature of the renewable energy impacts the dynamics and stability of the micro grid. Maintaining a reliable and stable grid will require that these dynamics be balanced in real-time. The existing grid is inadequate to cope with the high penetration of intermittent renewable energy and complex control decisions due to the lack of flexibility and extensibility. Integration of renewable energy on to the electrical grid requires dynamic energy management capabilities because of its intermittency [2]. The importance of having more reliable, efficient, smart systems is getting more awareness and public attention. Emerging technologies help improve efficiency and reduce environmental impacts of energy production and consumption. Micro-grid energy management and various trends in micro-grids are discussed in [3-4]

The computational intelligence methods and classical algorithms for energy management of micro-grid are discussed in [5]. Centralized approach is used in most of the existing research on micro-grid operation problems. In order to reduce communication overhead and improve robustness, the energy management problem is looked into a distributed control perspective. One such approach is Multi Agent System based modelling of micro-grid to provide a common communication interface for all agents representing the autonomous physical elements. Furthermore, the distributed nature and potential for modelling autonomous decision making entities in solving complex problems motivates the use of multi-agent system for the operation of micro-grid [6]. Agent based modelling for the energy system performance and reliability of micro-grid using renewable resources is discussed in [7]. A multi-agent system based energy management

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system (EMS) for implementing a solar and hydro hybrid micro-grid is discussed in [8]. The Multi Agent System for micro-grid control is discussed in [9]. Optimization of micro-grid using MAS is given in detail in [10]. The design and implementation of Multi Agent System in micro-grid energy management is discussed in detail in the paper [11]. Multi-agent system for an integrated micro-grid is discussed in [12]. Multi-agent based distributed energy management for intelligent micro-grid is discussed in [13]. The complete review of micro-grids in multi-agent system perspectives are discussed in [14]. Multi agent based control operations of micro-grid discussed in [15]. Although many micro-grid research activities involving MAS have been reported, all the options available for optimal energy management of a micro-grid were not considered. 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 for the dynamic energy management.

The rest of the paper is organized as follows. In section 2, a detailed discussion on multi agent system approach and multi agent platform is given. In section 3 Problem formulations is given. Implementation of dynamic energy management of solar micro-grid in distributed environment is given in section 4. Simulation studies and results are given in section 5.

2. MULTI AGENT SYSTEM

Autonomous components and coordination are the basic ingredients of any distributed systems. The major limitations of distributed systems that involve many heterogeneous entities are:

i) The interactions among participating entities lack a run-time adaptive behaviour as they are fixed by the application developer while coding instructions.

ii) Applications which have to operate in environments while maintaining continuous communication are expensive.

So, distributed system with many on-going interactions is 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 network’, to work together to solve problems that are beyond their individual capabilities or knowledge of each entity. MAS are the emerging sub-field of Distributed Artificial Intelligence (DAI). Multi-Agents overlay a way to elaborate systems that are decentralized rather than centralized, emergent rather than planned, and concurrent rather than sequential, with many advantages.

2.1. Multi Agent Platforms

Agent platform is a software environment, where software agents are executed. In this paper, JADE (Java Agent Development Environment) frame work [16] that conforms to FIPA (Foundation of Intelligent and Physical Agent) standard for intelligent agents [17], is used. JADE is also used as the runtime environment in which agents execute, thereby masking from the agents the underlying complexity of the operating system or network. The JADE runtime in turn executes within a Java Virtual Machine (JVM). Agents are distributed in many containers and platforms. Agent lives in a container, and a collection of containers make up a platform. A platform encompasses all the containers within an agent system. JADE provides a convenient distributed platform for users to focus on developing agents for control and monitoring of power balance during micro-grid operation. JADE can be described as a distributed platform consisting of main containers and peripheral containers. The main container is always the first container to be initialized. Agent Management System (AMS) and Directory Facilitator (DF) agents are also automatically created in the main container. Other containers have many other agents. Each platform has a main container and other simple containers. JADE is an open system which supports plug and play capabilities and is also scalable without much modification to the control scheme. The directory services and other administration services are hosted on the main container, which is the first container launched in the platform, but are duplicated on the other containers for robustness. JADE platform provides a set of functions and classes to implement agent functionality, such as agent management service, directory facilitator and message passing services.

Agent management service (AMS) is responsible for managing the agent platform, which maintains a directory of Agent Identifiers (AIDs) and agent states. Only one AMS will exist in a single platform. Each agent must register with an AMS in order to get a valid Agent ID. Directory facilitator (DF) provides the default yellow page services in the platform which allows the agents to discover the other agents in the network based on the services they wish to offer or to obtain. The Message Transport Service (MTS) is responsible for delivering messages between agents and provides services for message transportation in the agent system. Every agent must register in AMS. Only then it discovers the nature of other agents in the DF and chooses to communicate with them through MTS. An agent has certain behaviour and tends to satisfy certain objectives using its resources, skills and services. Ability to generate power is a skill and selling power is a service. The agent supports semantic and asynchronous communication language called Agent Communication Language (ACL).

3. PROBLEM FORMULATION

In the solar micro-grid integration to passive grid leads to problem in stability reliability due intermittent nature of solar power and the randomness of loads. Multi Agent System is used to autonomously manage the dynamic nature of solar micro-grid and the best possible action is chosen at every scenario considering all the possible options to increase for effective energy management and to increase operational efficiency, leading to economic and environmental optimization. All the smart grid features like dynamic pricing, demand side management, two way communications are implemented in solar micro-grid.

4. IMPLEMENTATION

Solar micro-grid connected to the power grid which consists of a local consumer, a solar PV system and a battery. There is a 100 kW solar unit in the department and another 200 kW solar unit in the hostel. Observations are made on the load pattern and the solar generation units of the department and hostel.
The following six inputs are considered 1) Photo voltaic Power (kW), 2) Battery Power (kW), 3) Diesel Generator Power (kW), 4) Load Active Power (kW), 5) State of Charge of the Battery (SOC) and 6) Static Switch micro-grid Position (ON for micro-grid connected to the grid or OFF for micro-grid isolated). Fig.1 shows a flowchart which considers all the possible options for the solar micro-grid. The solar power, load and the battery level, non-critical loads, and dynamic pricing of grid are monitored continuously every hour and, based on this data, in such a distributed environment, a best possible action is taken by the agent for optimal energy management of solar micro-grid. The symbols mentioned in the flowchart are L1 = Department Load, L2 = Hostel Load, S1 = Department solar power, S2 = Hostel Solar power, B1 = Department Battery, B2 = Hostel Battery, G= Grid Power, D= Diesel Power, DP=Diesel unit price, GR= Grid unit price. The following are the agents in the proposed system: Solar power generator agent, load agent, grid agent, diesel agent and control agent. All these agents are presented in each PV System. This is implemented using multi agent programming in JADE in an Eclipse environment. The global procedure is as follows.

i) Initially, an ACL message with the power demand of the department load is sent from the agent L1 to department solar power agent S1 at that specific hour. The solar unit in the hostel (S2) is checked if S1 is not sufficient for supplying the load L1.

ii) The department battery (B1) is charged if excess energy is available in S1 and if still excess energy is available it checks the battery of hostel agent (B2) to charge and anymore excess power is given back to the grid.

iii) The cycle gets complete if the required power is fully available in S1.

iv) If power available is only partial, then it looks into the availability of power in the solar unit S2. If required power is not available in S2, then the department battery (B1) is checked. If the load still lacks power, then it checks with the B2. If required power is available, it is taken.

v) Demand side management strategies are followed by shedding the non-critical loads at that hour if power if still required, even after taking from solar unit and battery. Load response strategies include both load shedding as well as load shifting. Load shedding involves curtailing equipment that is not critical and load shifting is the rescheduling of energy-intensive operations to a different time period. Based the requirement, non-critical loads can have many priorities. Even after this, if load requires power, it checks with the unit price of the grid at that hour and the diesel power price and chooses the least priced one.

vi) The agent takes the best possible decision for the most economic operations in a distributed environment based on the load requirement and availability of solar power every hour.

vii) The hostel agent (2) follows a similar procedure. 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. Programming is done for every agent in JADE and the agents communicate among them through ACL. The sniffer diagrams show the complete interactions. The console output gives the transaction report of a particular scenario.

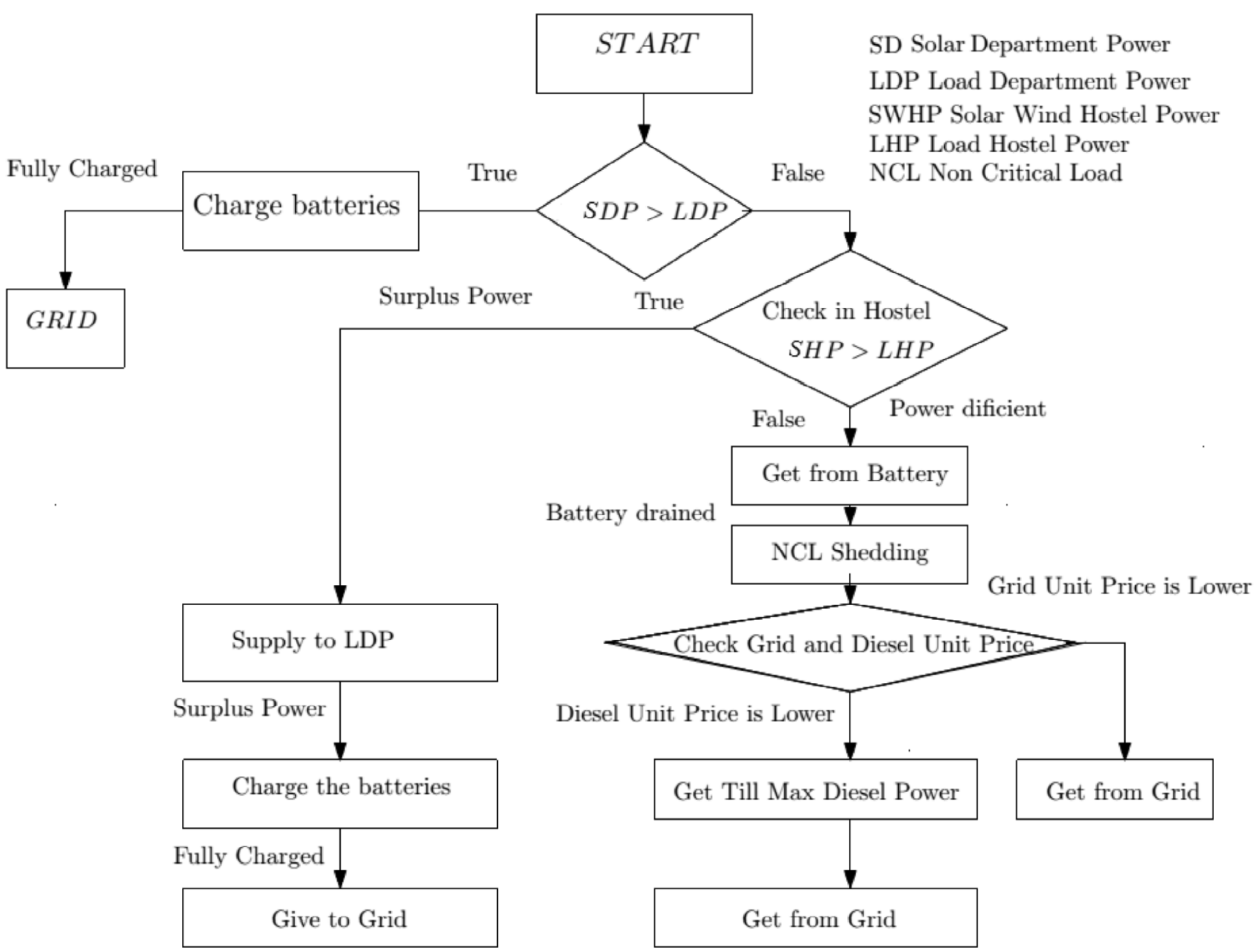

Figure 1: Flow chart for energy management of micro-grid

5. SIMULATION RESULTS

All the above possible cases are considered as in the flowchart and for these scenarios, the Java programming is done in JADE environment and executed in Eclipse Integrated Development Environment.

i) There is a college load power requirement of 100kW and so it taps 10kW power from college solar, which is exactly 10kW.

ii) College load still needs a power of 90kW and so it looks into the hostel solar unit where the solar power is 50kW but the hostel load requirement is 30kW. So the college load takes 20kW from hostel solar. But still, there is a need of 70 kW of power.

iii) Then it sheds the noncritical load of 10kW. Still the college load requires 60kW.

iv) The available 10 kW power from the College Battery is tapped by the college load. So it now requires 50kW power.

v) College load taps a power of 20kW from hostel battery and it still requires 30kW of power.

vi) On an hourly basis, the grid unit price, which is Indian Rupees 10/kWh, is compared to the diesel unit price of Indian Rupees 12/kWh to supply the remaining power of 30kW.

Figure 2, Figure 3 and Figure 4 show the console outputs, ACL message and sniffer diagrams respectively. Every hour the power is traded with the grid or diesel generator, due to the intermittent nature of the solar power. After trading and negotiation are completed, the final result is being reported by CA, which tells users how much power is being traded with the grid or diesel generator based on the per unit price at that time. All possible scenarios are considered for effective energy management and the agent chooses the best possible action considering the economic and environmental optimization of the micro-grid.

6. CONCLUSION

The optimization of distributed energy management of solar micro-grid, which consists of two solar generators, is implemented with a Multi-Agent System approach. JADE platform leverages the advantage of MAS and all the options available for the agents in the micro-grid are comprehensively analysed for

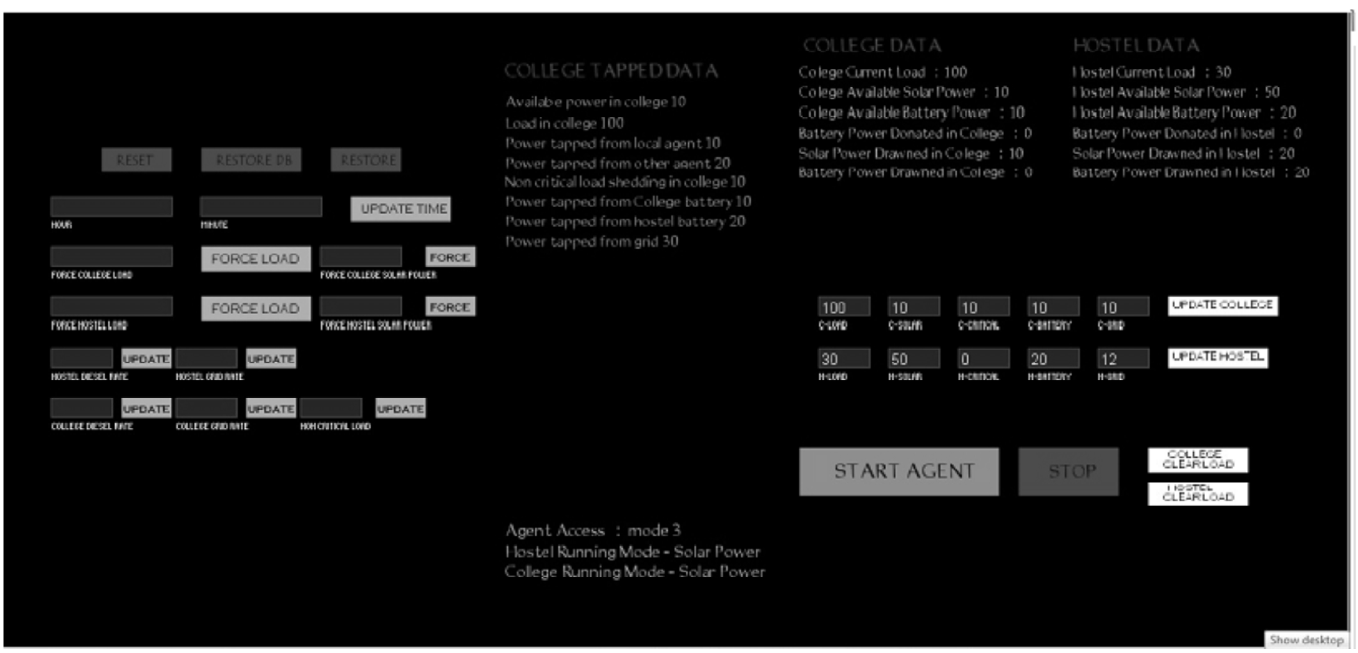

Figure 2. Console Out put

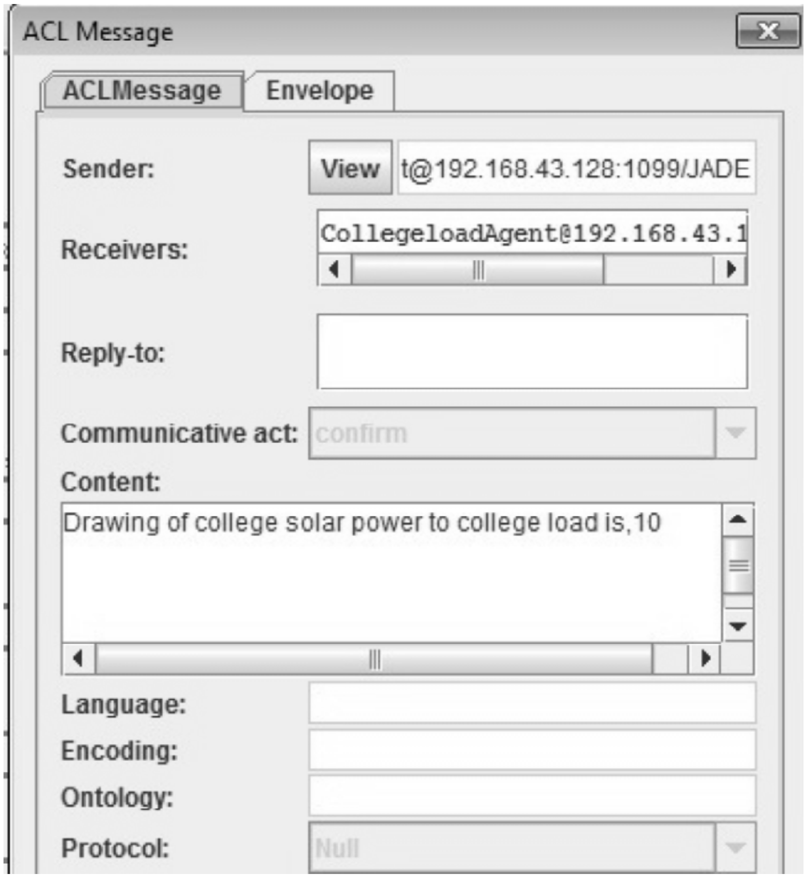

Figure 3: ACL message

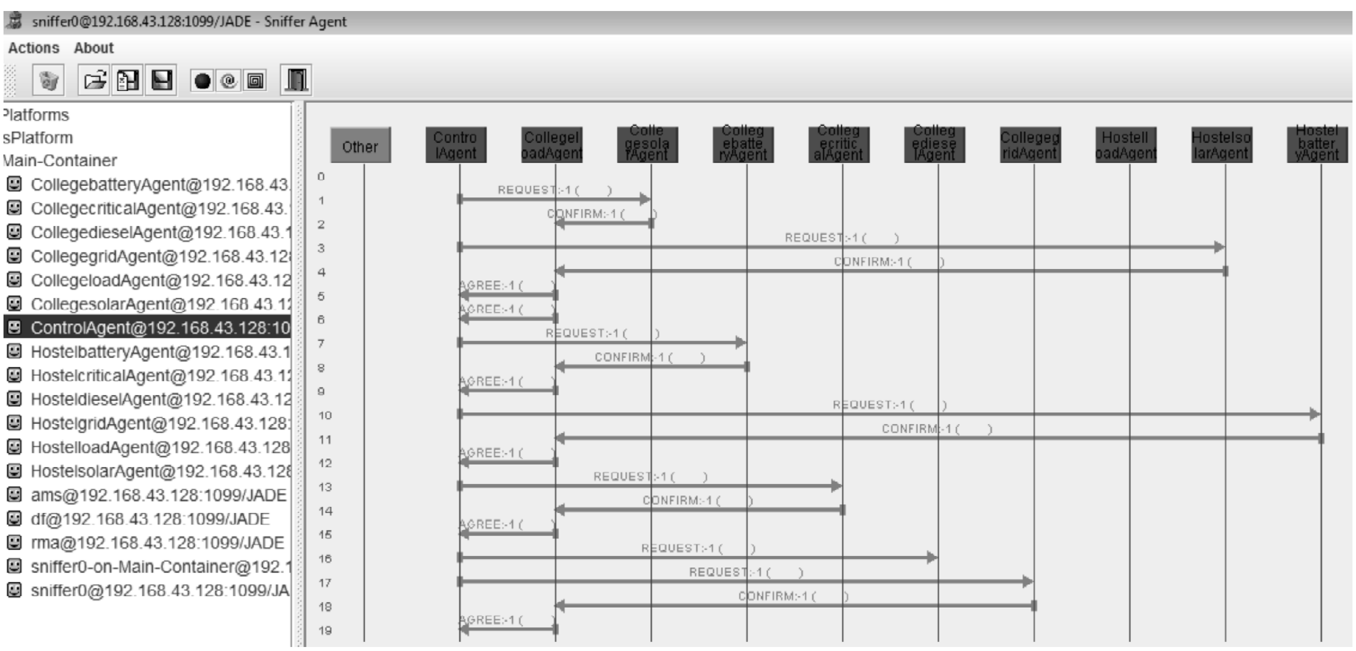

Figure 4: Sniffer Diagram in JADE

optimal distributed energy management of solar micro-grid to achieve the lowest possible cost of power generation under intermittent nature of solar PV system and randomness of load. The proposed framework explores all possible options, understand the stochastic environment and select the optimal energy management actions autonomously to increase operational efficiency in a distributed environment. Future work will focus on extension to multiple agents integrating diverse renewable generators (solar and wind) and co-simulation of MAS with Mat Lab/Simulink for building a model for practical realization of MAS in energy industry.

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