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Multi Agent System based Automated Demand Side Management of a Micro-Grid

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ABSTRACT

The objective of this paper is to develop a Multi Agent System (MAS) for automated demand response for a solar micro-grid. We consider a grid connected solar micro-grid, which contains two solar units, each contains a local consumer and a solar PV system and a battery. Initially we measure the load patterns and solar power generated in the solar units. Then we use Multi Agent System (MAS) for automated demand response and advanced distributed energy management of solar micro-grid with smart grid frame work. We develop a simulation model 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 autonomously to stabilize and optimize the solar micro-grid. Furthermore, MAS, due to decentralised approach, reduces the timings and increases the operational efficiency. Thus MAS in solar micro-grid energy management leads to economic and environmental optimization. Simulated operation of solar generators and loads are studied by for automated energy management and demand side management. Outcome of the simulation studies demonstrates the effectiveness of proposed MAS in automated energy management of micro-grid.

Keywords: Micro-grid; Energy management; Demand Side Management; Automation; Multi Agent System; JADE.

1. INTRODUCTION

Electric industry landscape is changing due to proliferation of renewable resources and active demand. We are moving rapidly towards a more decentralized, more sustainable, and smarter power system. The smart grid paradigm represents a transition towards an intelligent, digitally enhanced, two way power delivery grids. Smart Grid uses Information and Communications Technologies (ICT) to improve the reliability, availability, and efficiency of the electric system [1]. Solar and wind energy are the only solutions to the growing energy crisis in the world. Micro-grid is an interconnection of low voltage distributed resources with loads. It is the building block of smart grid and poised to play a major role in enabling the widespread adoption of renewable energy. 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. Passive 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. Dynamic energy management is a key enabler for the integration of renewable energy on to the electrical grid, making it active [2]. The importance of having more reliable, efficient, smart systems is getting more 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-grid is 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

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problems. In order to reduce communication overhead and improve robustness, there is another stream of research that addresses the energy management problem from 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 of micro-grid with uncertainty of renewable energy resources in the energy system performance and reliability of micro-grid is discussed [7]. A multi-agent system based energy management system (EMS) for implementing a PV-small hydro hybrid micro-grid is discussed in [8]. The main operation of a 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 operation of 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 micro-grid control is discussed [15]. Only in the very recent paper [16], the integration of micro-grid market operations and Distributed Energy Resources (DER) is discussed in detail. Although many micro-grid research activities involving MAS have been reported, they did not consider 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 for the dynamic energy management in Java Agent Development Environment (JADE). Here the 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 are capable of representing the dynamic behaviour of the micro-grid across various possible solar-power and load values with automated demand side management.

The rest of the paper is organized as follows. In section 2, solar micro-grid is explained with the details of solar photo voltaic system and load and power measurement. A detailed discussion on multi agent system approach and multi agent platform is given in section 3. Smart grid frame work is discussed in section 4. Problem formulation is given in section 5. Implementation of dynamic energy management of solar micro-grid in distributed environment is given in section 6. Simulation studies and results are given in section 7. Conclusion is given in section 8.

2. MODELLING OF SOLAR MICROGRID

A micro-grid is a localized grouping of electricity sources in the distribution side which can supply power to communities, universities and other local requirements. It can operate stand alone or connected to main grid. The urban solar micro-grid involves a consumer with a dynamically varying load, transformer providing electricity power from the external grid, a solar generator (solar Photo Voltaic (PV) system) with available power output and a storage facility with a level of battery charge. Architecture of the solar micro-grid is shown in Fig. 1.

The consumer can cover his demand partly by using the electricity produced by the solar generator, store electricity in the battery when the solar source is available and can discharge the storage when needed. The consumer has the possibility to control the storage and the solar power generator. The challenge in solar micro-grid is that the solar power supply is intermittent in nature. The solar power for every hour is measured using NREL (National Renewable Energy Laboratory) web site information. In this paper, we consider 100kW and 200kW solar PV system: one in department and other in hostel of our campus. The load in the department and hostel are calculated every hour and the graphs are drawn as shown in Fig. 2 and Fig. 3.

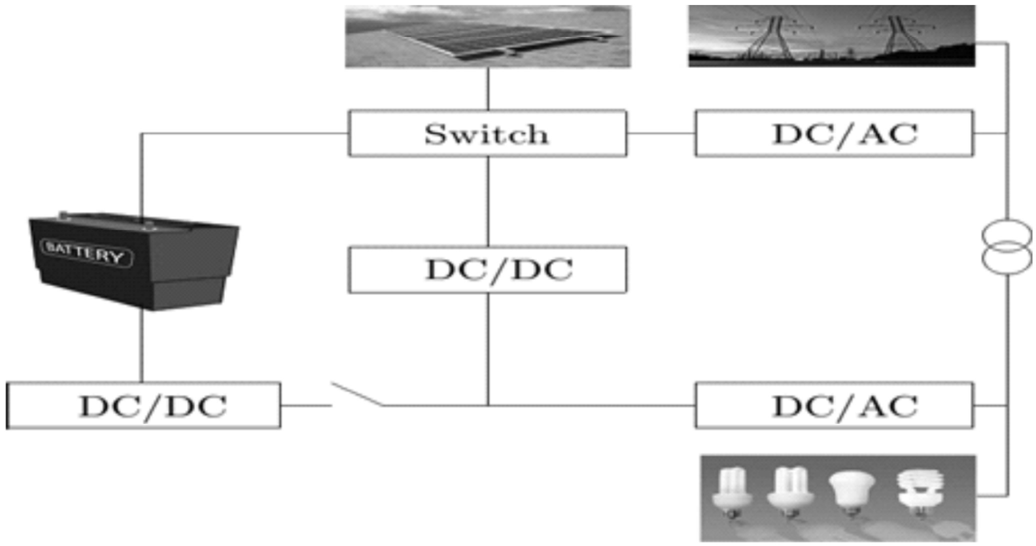

Figure 1: Solar Micro Grid

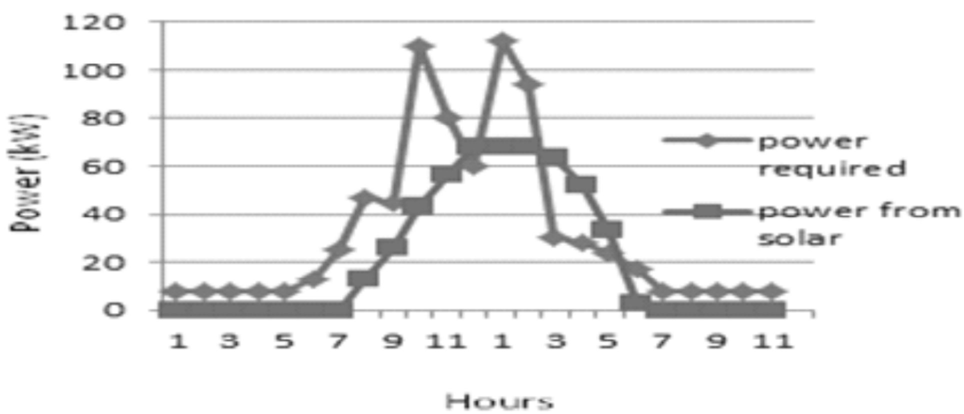

Figure 2: Department Solar Power and Load

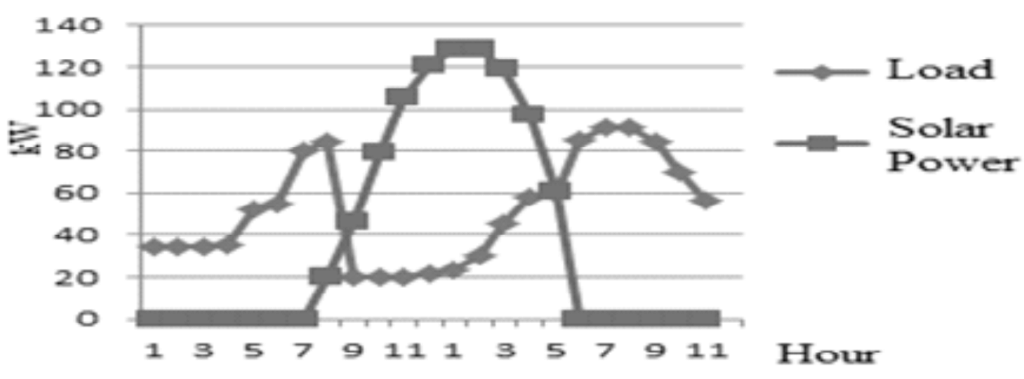

Figure 3: Hostel Solar Power and Load

3. MULTI AGENT SYSTEM

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

(i) The interactions among participating entities are fixed by application developer while coding instructions and so hence they lack run-time adaptive behaviour.

(ii) Applications, those have to operate in environments where maintaining continuous communication, is 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. MAS can locally optimize also contributes to global optimization. The inherent features of MAS are shown in Fig. 4.

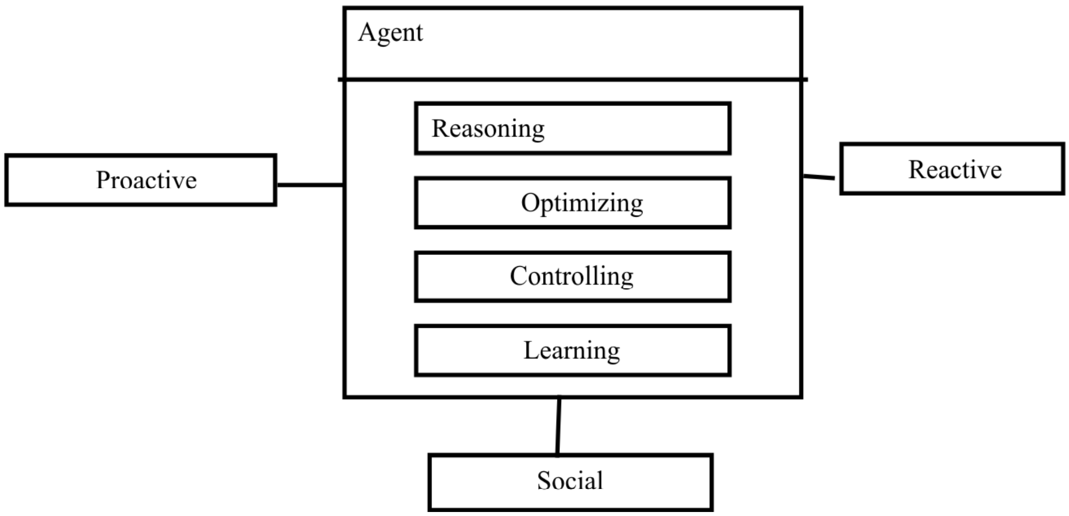

Figure 4: MAS Features

Agents have their own control over their behaviour and internal states in any possible environment. Agents have four behavioural attributes, autonomy, social, proactive and reactive. Autonomy refers to the principle that agents can operate on their own to meet their goals without the need for human guidance. Agents are proactive, i.e., the ability to take the initiative rather than acting simply in response to their environment. Agent can cooperate with other agents for coordinated action. In order to cooperate, agents need to possess social ability, i.e., the ability to interact with other agents with some communication language like Agent Communication Language (ACL). Agents have certain behaviour and tend to satisfy certain objectives using their resources, skills and services. One of the skills could be the ability to produce or store energy and a service could be to sell power in a market. The way that the agent uses its resources, skills and services defines its behaviour and the behaviour of each agent is formed by its goals.

A. Multiagent system in micro-grid

Automating electrical distribution systems by implementing a Supervisory Control And Data Acquisition (SCADA) system is the present, conventional cost-effective solutions for improving reliability, increasing utilization. SCADA basically refers to a central control system that monitors and control equipment from a remote location. SCADA systems co-ordinate, communicate and control amongst remote sub-stations and control room. Humans have traditionally supervised such problems to reason and resolve issues in SCADA. Also SCADA is complicated due to its centralized approach. In the micro-grid, uncertainty in SCADA systems arises when sensor data or the inferred knowledge cannot be deemed accurate due to intermittent nature of solar power. Applications must deal with inherent noise/error in sensor data or knowledge 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 [18]. 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. MAS are by nature distributed and concurrent, they are independent entities engaged in the system, with decentralized approach, they have their own perception of the environment, goal and agenda and they try to achieve the best for themselves while behaving strategically.The energy management system in micro-grid is tightly associated with the communications between stakeholders and entities (agents) to exchange information. Actions can be taken in less few milliseconds, many times faster than SCADA and so operational efficiency is increased considerably. MAS give effective solution to uncertainty, incompleteness and inconsistent or conflicting data from renewable resources. Intelligent multi-agent systems perform this role autonomously. Plug and play adaptability for renewable energy has to be seamless in micro-grid. So MAS can include or remove energy resources on the fly based on the particular scenario requirements. The development of smart grid and related technologies combine advances in distributed systems, artificial intelligence, control, and information and communications technologies. Smart grids exhibit high level of autonomy, self-healing and reliability, and to provide features such as reconfiguration, protection, restoration, and interaction with other users through demand response [19]. In MAS, set of economic and control mechanisms are used for dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter. MAS have begun to emerge as an integrated solution approach to distributed computing, communication, and data integration needs for deregulated power systems.

(B) Advantage of Multi Agent systems.

MAS are based on agent-based computing and agent-oriented programming. An agent-based approach is flexible, robust, and can adapt to the environment, when the system components of the system are not known in advance, dynamic, and are heterogeneous. Agent-based computing offers the ability to decentralize computing solutions by incorporating autonomy and intelligence into cooperative, distributed applications. It deals with Distributed Data Access and Processing. Software agents are distributed across networks with different levels of intelligence, designed to perform a specific role, with associated knowledge and skills, distributed and heterogeneous information is efficiently assimilated locally and utilized in a coordinated fashion in distributed environment, resulting in reduced information processing time and network bandwidth in comparison to that of centralized system. It has the property of interoperability. The industry has software applications, developed in many different computer languages, intended for use on many different platforms. It can be operated across the platforms and languages. The ability of different agents to coordinate behaviour through cooperation, negotiation and mediation, helps in distributed decision support system. Thus autonomous distributed agents align local objectives with global objectives [20].

(C) Multi Agent Platform

Agent platform is a software environment, where software agents run. In this paper, JADE (Java Agent Development Environment) frame work [21] that conforms to FIPA (Foundation of Intelligent and Physical Agent) standard for intelligent agents [22], is used.In JADE, 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) that is responsible for delivering messages between agents and provides services for message transportation in the agent system as shown in Fig. 5.

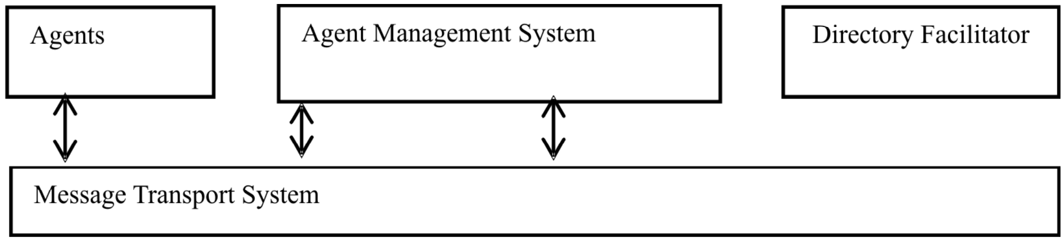

Figure 5: Architecture of Multi Agent System

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 behaviour and tends to satisfy certain objectives using its resources, skills and services. The agent supports high level communication, so that the agents not only exchange simple values, but also knowledge, commands, beliefs or procedures that have to be followed. Agent Communication Language (ACL) is used for communication between agents. In ACL, this message has the following part (1) Message Type, (2) Receiver. (3) Language. The agents should use the same language in order to parse the messages correctly. (4) Ontology. The agents share the same ontology in order to understand the content of the message. (5) Content. The information the agent wants to convey to other agent. Along with the processing time, the communication time of ACL messages plays a significant role in performance of MAS.

4. SMARTGRID FRAMEWORK OF MICROGRID

Smart grid is an automated electric power system that monitors and controls grid activities, ensuring the two-way flow of electricity and information between power plants and consumers and all points in between. In its most basic form, implementation of a smarter grid is adding intelligence to all areas of the electric power system to optimize our use of electricity. Smart grid is used to reduce electricity bills by shifting loads from peak hours to non-peak hours, reducing out-of-pocket costs resulting from loss of power, giving opportunity to interact with the electricity markets through home area network and smart meters.

(A) Advance Metering Infrastructure

Advance Metering Infrastructure (AMI) facilitates monitoring and measurement of consumer information through smart meters installed at customer premises. AMI refers to systems that measure, collect, analyse, transmit and manage the energy use using advanced information and communication technologies. It is like meters with Subscriber Identity Module (SIM) card which send and receive data from the utility. Remote terminal unit, phasor measurement unit, intelligent electronic devices, smart meters, fault pause indicators are used for sensing and measurement.

(B) Phasor Measurement Unit

Using Phasor Measurement Unit (PMU) the control centres can analyse the data at the micro level as the data reaches here with the timestamp. Data can be analysed at the rate of 25 samples per second. So with the increased visibility and using data analytics methods the possible faults are identified beforehand and prevented. Thus the possible brown outs and block outs are avoided saving billions of dollars.

(C) Self-healing

Self-healing is about identifying and isolating the malfunctioning part of the network and dynamically reconfiguring the network for normal operation in an autonomous way in a short span of time. Thus the losses due to faults are considerably reduced in smart grid.

(D) Dynamic pricing

Dynamic pricing is about variation of the price based on demand and supply. When the renewable energy is inducted with the grid, the consumer becomes a prosumer. He can generate power through solar or other form of resources and supply to the grid. Through net-metering, he can measure how much energy supplied to grid and accordingly paid. So when many prosumer generate and supply to grid, the grid price is varied based on total power available and the load demand at that point of time. In a way it influences consumer behaviour.

(E) Demand side management

In case of Demand side management, the utility in a sense "owns the switch" of consumer's equipment and sheds loads only when the stability or reliability of the electrical distribution system is threatened, whereas demand response places the "on-off switch" in the hands of the consumer. Demand response refer to mechanisms used to encourage consumers to voluntarily trim electricity usage at specific times of the day (such as peak hours) during high electricity prices (Time of Use tariffs), or during emergencies (such as preventing a blackout). Depending on the generation capacity, demand response is also used to shift demand (load) from peak to off-peak at times of high production and low demand.

(E) Demand response (DR)

It is becoming a growing part of the resource base that electric system operators rely on to maintain reliability on the grid. Market liberalization, economic pressures, and environmental regulations are all moving toward a path of fewer traditional central power plants and more distributed energy resources (DER) to address future energy needs. Advanced technologies can help speed this transition and make it more reliable along the way. Automated demand response (ADR) describes a system that automates the DR dispatch process, from the grid operator to the end-use customer—all without any manual intervention

(F) Smart micro-grid

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5. PROBLEM FORMULATION

In the solar micro-grid every hour the solar power, load and the battery level, non-critical loads and dynamic pricing are monitored continuously and based on the randomness of load and intermittent of solar power the agent considers all possible logical options and chooses the best possible action to increase the operational efficiency for optimal energy management of advanced, dynamic, solar micro-grid leading to economic and environmental optimization and efficient autonomous demand side management.

6. IMPLEMENTATION

(A) Flow Chart and Algorithm

We consider a grid connected solar micro-grid system which contains a local consumer, a solar PV system and a battery. The first solar unit is in the department with capacity of 100kW and the other solar unit is in the hostel with capacity of 200 kW. Solar energy in hourly basis and the load is calculated as given in section 3. The load pattern along with the generated solar energy of the department and the hostel are shown in the Fig.2 and Fig.3. 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). Considering all the possible options available for the solar micro-grid, flow chart is drawn as shown in Fig.6. Every hour the solar power, load and the battery level, non-critical loads, dynamic pricing of grid are monitored continuously and based on hourly data, the agent takes best possible action for optimal energy management of solar micro-grid in distributed environment. The proposed system has the following agents: Solar power generator agent, load agent, grid agent, diesel agent and control agent. Each PV system has all these agents. Multi agent programming is done in JADE in Eclipse environment. The overall procedure is the following:

(i) Initially the Department Load Agent (DLA) communicates the power demand through an ACL message with the available solar power in Department Solar Agent (DSA) in the department at that specific hour.

(ii) If required power is fully available in DSA then takes required power and the cycle gets completed.

(ii) If surplus power is available in DSA, then it checks Department Battery (DB) to charge and if excess energy is still available, it checks the battery of hostel agent (HB) to charge and anything further excess available is given back to the grid.

(iv) If partially available then it will look into the availability of solar power in the hostel solar agent (HSA). If required power is not available in HSA then it looks into the battery of the department (DB). The full requirements is taken from the battery till it gets drained and then it checks with the hostel battery (HB) and gets power till it gets drained.

(v) Even after taking power from solar unit and battery, if power is still required, then it checks for Non-Critical Load shedding at that particular hour and follow demand side management strategies. Load response strategies include both load shedding as well as load shifting. Load shedding involves curtailing equipment that is not mission critical and load shifting is the rescheduling of energy-intensive operations to a different time period. Non critical loads can have many priorities based on the requirement. Even after this, if load requires power, itchecks with the unit pricing of the grid at that hour and the diesel power unit price and chooses the least priced one.

(vi) 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.

(vii) Similar steps are followed for the agent 2 (hostel). 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 communication between the agents is done through ACL. The complete interactions are shown in the sniffer diagrams. The console output gives the transaction report of a particular scenario.

(B) Agent formulation

The agent diagram is shown in the figure agent diagram**.** The proposed multi-agent system comprises many intelligentagents representing various components in a micro-grid. Eachagent has a localized knowledge base, containing rules andbehaviours, which governs its decision making process. The following agents are formed to simulate multi-agent system in JADE environment.

Generator Agent: Generation Agent (GA) receives power request from Load agent. It allows solar generators owners to set selling price for trading. Every hour the planning is done for the micro-grid operations for supplying and buying power. The initialization for all agents begins with registering itself with the Directory Facilitator (DF) by providing it with a set of service descriptions like to setName and setType. For GA, setName and setType are chosen to be solar power source and power selling respectively. Users can key in the amount of power they want to buy from the GA..

Load Agent: Load Agent (L1) allows customer to specify the amount of power to purchase and communicate to the Generator Agent (S1). The Load Agent is taken as a buyer agent because it searches the DF yellow pages for generation agents offering power supply services. LA first registers itself with DF by providing load and power buyer as input parameters to setName and setType respectively. Whenever LA receives an order from control agent to buy power from the GA, it executes a request, which calls for proposals from all GAs and submit a final confirmation to the GA which offered the best price.

Grid Agent: Grid Agent registers with DF by giving Grid Agent and grid status as inputs to setNameand setType respectively. Grid Agent collects real time grid pricing and informs other agents about connection status of grid. Grid price varies every hour leads to dynamic pricing concept of smart-grid. The main set of behaviour for GrA is receiving request from CA. This behaviour will wait for messages from CA to determine whether the micro-grid needs to buy power or sell net surplus power to the grid during grid connected mode. Then it gives the power or accepts the power according to control agent instructions.

Diesel Agent: Diesel Agent registers with diesel agent and status as inputs to setName and setType respectively. It gives the price of per unit power. It receives request from the from the CA and sell power to Load Agent when diesel per unit price is less than the grid per unit price.

Control Agent: Control Agents (CA) is responsible for monitoring, controlling and negotiating power levels and performing power exchange between the solar micro-grid and main grid. Initially CA registers as control and micro-grid control management as inputs to setName and set Type respectively The Control Agent (CA) displays the total micro-grid power generation and loading as well as computing the net micro-grid power every hour. Then the agent will determine whether to buy or sell power to the grid based on the value of net power. If the grid power unit price is greater than Diesel Generator (DG) unit price then it prefers to buy from DG

(C) Interaction of agents

DF is the basis for the development of plug-and- play capabilities. It can dynamically include the resources as and when they are necessary. All the agents, by the time they are created, automatically announce to the DF the services that they could provide to the system. Here, the load agents participate in the system as buyers of energy, while the GA agent sells energy. The GA starts the transaction by sending a request to the DF. The DF agent provides the list of agents that can buy energy. Then, the GA sends a request to all the members of the list. Finally, the load agent accepts or refuses the offer based on conditions. Also the load agent can look into much GAs, registered in the DF and choose the required one based on the conditions.

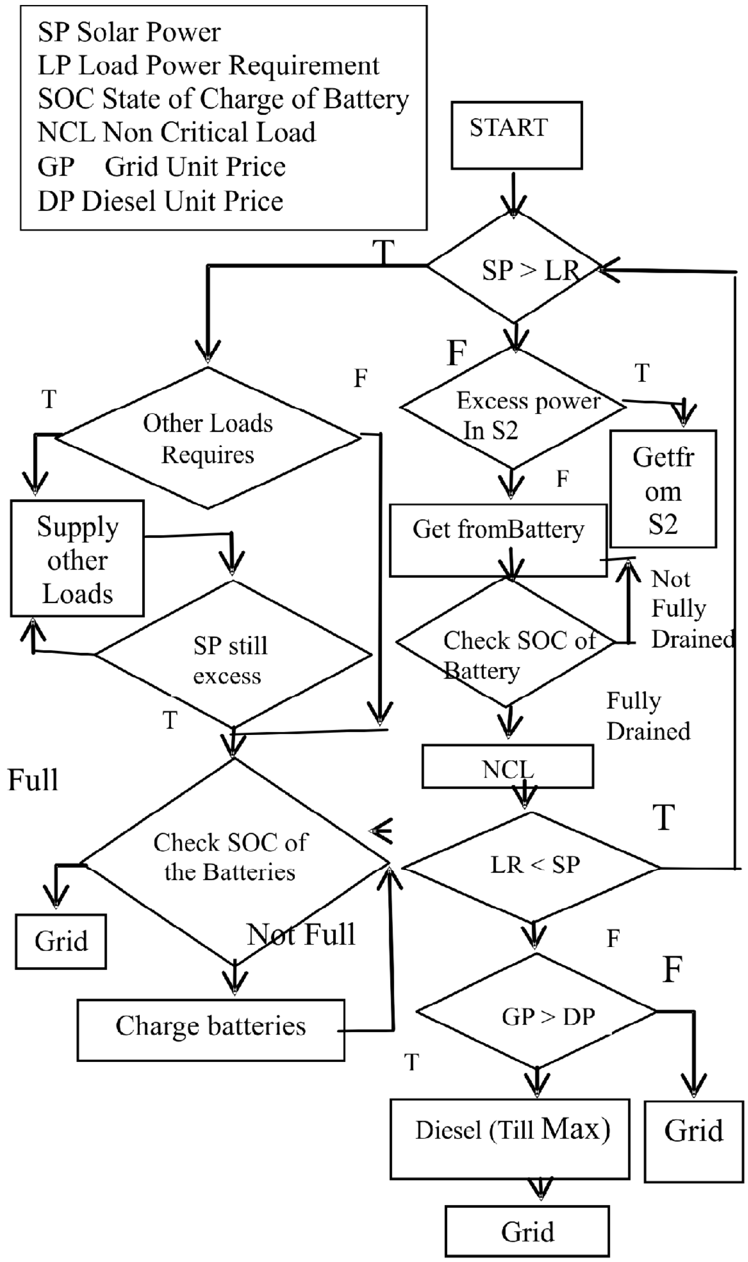

Figure 6: Flow chart for energy management of micro-grid

7. SIMULATION RESULTS

One round of operation of solar micro-grid was simulated considering all the possible scenarios and the console output and the sniffer agent tracking all message exchanges between the agents are observed. Each arrow in the sniffer diagram represents a message sent. Users can check where and whom the message originated from by tracing the number of incoming and outgoing arrows for that particular agent. All the operations are considers 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. The load and solar data are fed in to SQL server database and the agents in JADE receive data from them. The front end is done with processing software. Various scenarios are considered and sniffer diagrams and the console output representing the interaction of the agents and transaction details are studied. All the possible demand side management strategies are tested and the following case study is made.The sniffer diagram shows the communication between the agents. The sequence of operations is as follows

(i) College Load requires 100kW and college solar power is only 10kW. So it requires 90kW. It checks with the Hostel solar agent. In the hostel the solar power is 50kW and load is 30kW. So the surplus 20kW is given to the College load agent through control agent. Now the college load needs 70kW

(ii) Then College Load look into the College battery and gets the available 10kW and then gets the available 20kW from hostel battery. The further requirements are managed by shedding non-critical of load 10kW and getting the remaining 30kW from grid as the grid unit price at that hourly interval, which is Indian Rupees 9/kWh, to the diesel unit price of Indian Rupees 10/kWh.. 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. The smart grid feature dynamic pricing is incorporated. 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. The smart grid feature dynamic pricing is incorporated and hence various possible scenarios, like when the load is less than solar power or solar is greater than load, battery is low or high, grid per unit price is high or low, when there is no solar power, etc. are considered and the agent chooses the best possible actions for demand side management and thereby for economic and environmental optimization of solar micro-grid. Fig.7. shows console output of a case study and Fig. 8 shows the sniffer diagram. The ACL communication from college load is asking 20kW from the hostel solar agent is shown in Fig. 9.

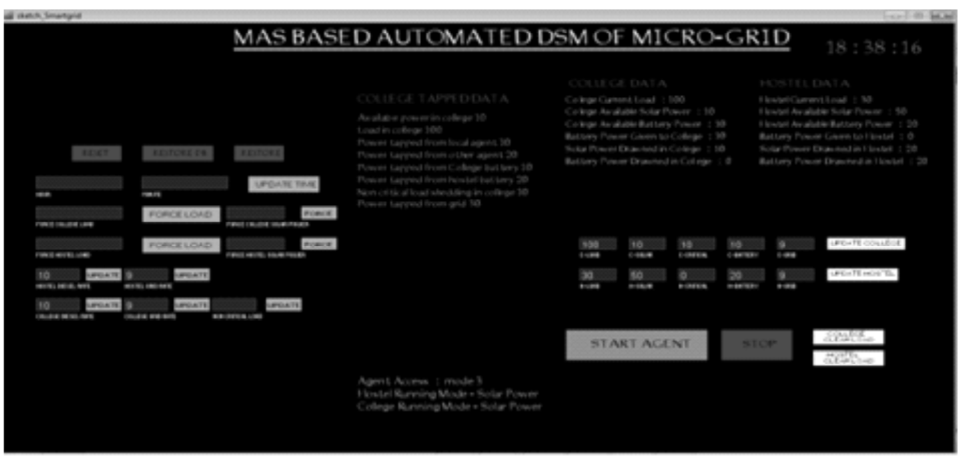

Figure 7: Console Out put

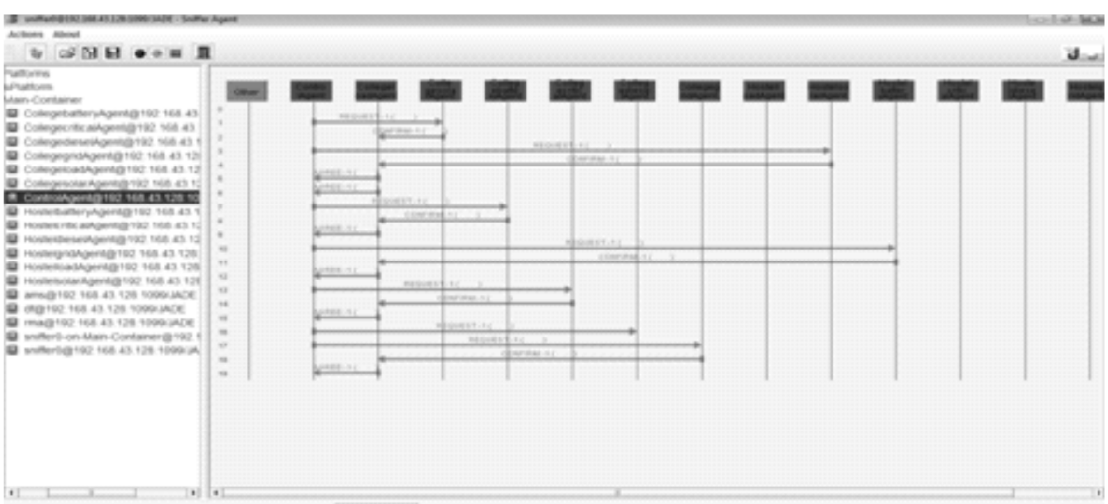

Figure 8. Sniffer Diagram in JADE

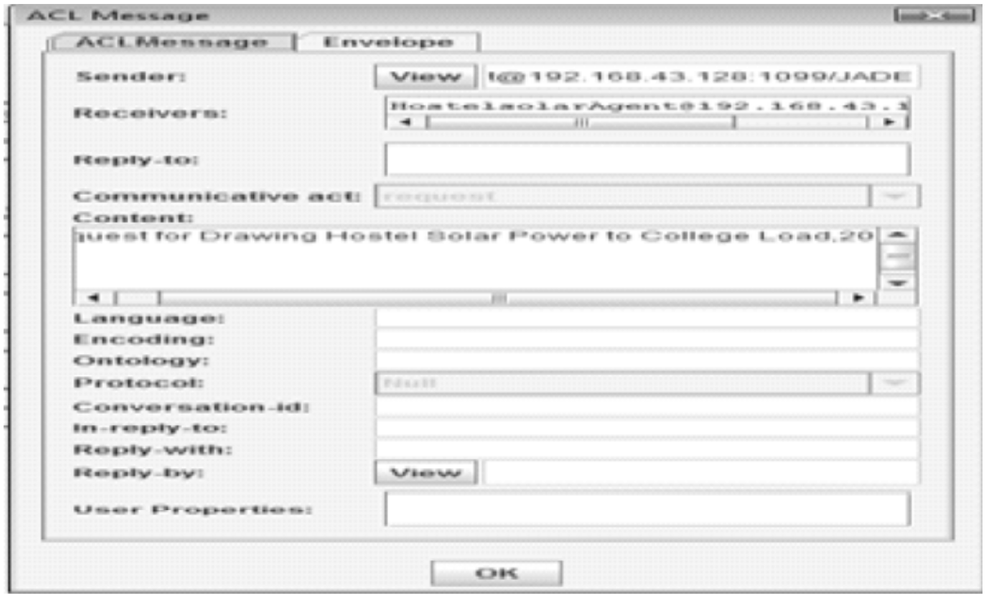

Figure 9: ACL message

8. CONCLUSION

The automation of demand side management of solar micro-grid, which consists of two solar generators, is done with a Multi-Agent 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 distributed energy management of advanced, dynamic 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 gives the intelligent consumer the ability to explore all possible logical sequence of options and understand the stochastic environment and select the best DSM actions for optimal energy management to increase operational efficiency in a distributed environment. Future work will focus on extension to multiple agents integrating diverse renewable generators (solar and wind) with several intelligent consumers with conflicting requirements.

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