Integrated Energy Management of Micro-Grid using Multi Agent System

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***Abstract*—The objective of this paper is to develop a Multi Agent System (MAS) for the integrated energy management of a solar micro-grid. We consider 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. First we calculate the load patterns and solar power generated in the two solar units. Then we use Multi Agent System based 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 model 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. Further more, MAS increases the operational efficiency and thereby maximizes the power production of solar micro-grid and minimizes the operational cost.Thus MAS in micro-grid leads to economic and environmental optimization. Simulated operation of solar generators and loads are studied by performing simulations under different agent objectives. Outcome of the simulation studies demonstrates the effectiveness of proposed MAS in distributed energy management of micro-grid.**

***Index Terms*—Solar microgrid; Energy Management; Multi Agent System; Java Agent Development Environment(JADE).**

I. Introduction

Electric industry landscape is changing due to proliferation of renewable resources and active demand. Due to indution of Information and Communication Technology(ICT), we are moving towards a more decentralised, more sustainable, and smarter power system,

improving 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 a an interconnection of low voltage distributed resources with loads. It is the building block of smart grid and are poised to play a major role in enabling the widespread adoption of renewable, distributed energy resources in both grid-connected and off-grid environments. Integrating renewable energy in micro-grid is the way forward for economic and environmental optimization, generating clean and green energy, thereby providing solution to the global warming [2]. The randomness in renewable power generation can jeopardize micro-grid stability. Passive networks may be inadequate to cope with the high penetration of Distributed Energy Resoures (DER) and complex control decisions due to the lack of flexibility and extensibility. The dynamics need to be balanced for maintaining a reliable and stable grid [3].

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Emerging technologies help improve efficiency and reduce environmental impacts of energy production and consumption.

The computational intelligence methods and classical algorithms for energy management of microgrids are discussed in [4]. Micro-grid operation problems is addressed with centralized approach in most of the papers. But in the decentralized approach communication overhead is reduced and also and also improves robustness. Multi-agent based modeling of power systems is a promising approach to provide a common communication interface for all agents representing the autonomous physical elements in the power system [5]. Agent based modelling of microgrid with uncertainty of renewable energy resources in the energy system performance and reliability of micro-grid is discussed in [6]. A multi-agent system based energy management system (EMS) for implementing a PV-small hydro hybrid micro-grid is discussed in [7].The main operation of a Multi agent System for micro-grid Control is discussed in [8]. Optimization of micro-grid using MAS is given in detail in [9]. The design and implementation of Multi Agent System in micro-grid energy management is discussed in detail in [10]. Multi-agent system for real-time operation of a micro-grid in real-time digital simulator is discussed in [11]. Multi-agent based distributed energy management for intelligent micro-grid is discussed in [12]. The various trends in micro-grid control is discussed in [13]. The complete review of micro-grids in multi-agent system perspectives are discussed in[14]. All these reference discusses only about energy management of DERs; but only in [15] 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, no proper MAS platform was implemented considering all the options available in a micro-grid for optimization in a dynamic, distributed environment. So we propose a multi agent system based distributed energy optimization of solar micro-grid by comprehensively analyzing all the possible options for the optimization and choosing 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.

A complete optimization process using multi agent system considering all the logical options dynamically in a distributed

environment is not discussed so far. The multi-agent system based integrated energy management is implemented in JADE which is a Foundation for Intelligent Physical Agents (FIPA) compliant open source multi-agent platform. Agents in the multi-agent system interact cooperatively to optimize the operation of the micro-grid.

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. In Section 3, solar power measurement and observation of load are given. A detailed discussion on multi agent system approach and multi agent platform is given 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. Section 7 deals with agent formulation. Simulation studies and results are given in section 8. Discussion and conclusion are given in section 9 and 10 respectively.

II. Measurement of Solar Power and Load in Solar micro-grid

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 consumer can cover his demand partly by using the power from by the renewable generator, store electricity in the battery when the power is available in solar and can discharge the battery when needed. The challenge in using renewable sources

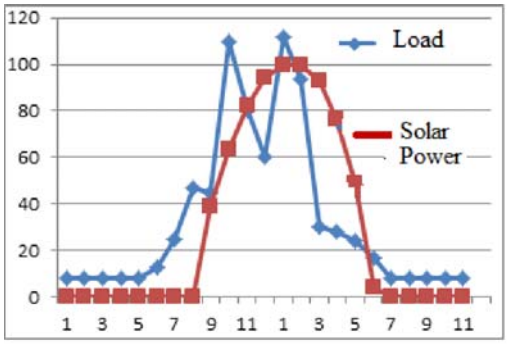

Fig. 1. Solar power and load for department

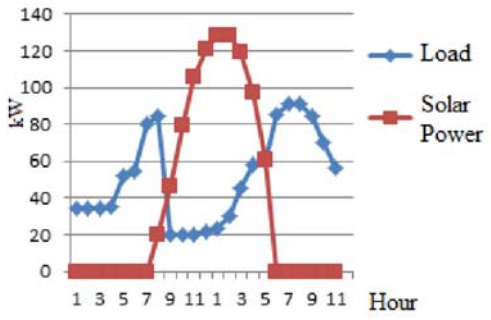

Fig. 2. Solar power and load for hostel

s that the power supply is intermittent in nature so maintaining stability micro-grid is an issue. We consider a solar micro-grid with two solar units, one in department with 150kW and other in hostel with 200kW. Each solar unit consists of solar photo-voltaic system, battery and load. The solar power in hourly basis is calculated from NREL(National Renewable Energy Laboratory).Then the load value in the department and the hostel are calculated for all the electrical appliances used. The solar power and load graph for every hour is drawn for the department and hostel as shown in Fig. 1 and Fig. 2.

III. Multi Agent System Approach

A. Multi Agent System

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

- They lack run-time adaptive behavior as the interactions among participating entities are already fixed by application developer while coding instructions.
- Maintaining continuous communication is expensive. So distributed system with many ongoing interaction is almost infeasible.

These considerations have motivated the development of approaches to distributed system based on agents which provide ways for adaptation and ongoing 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 is a emerging sub-field of Distributed Artificial Intelligence. MAS has inherent benefits such as flexibility, scalability, autonomy and reduction in problem complexity. In MAS, several autonomous and intelligent entities called agents are working in collaboration to achieve the overall goal of a system. 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. Stated simply, agents have their own control over their behavior and internal states in any possible environment. Agents have four behavioral attributes, autonomy, social, proactive and reactive. Reasoning, optimizing, controlling and learning are the inherent characteristics of an agents.

B. Multi Agent System in Micro-grid

Supervisory Control And Data Acquisition (SCADA) system is the conventional method for automation of power systems SCADA basically refers to a central control system that monitor and control equipment from a remote location. SCADA system co-ordinate, communicate and control amongst remote sub-stations and control room.

In the micro-grid, uncertainty in SCADA systems arises when sensor data or inferred knowledge cannot be deemed accurate due to intermittent nature of Distributed Energy Resources. Applications must deal with inherent noise/error

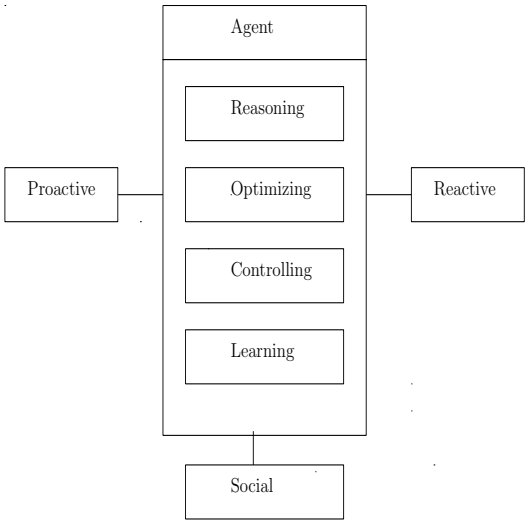

Fig. 3. Functionality of an Agent

in sensor data or knowledge as well as uncertainty, incompleteness and inconsistent or conflicting data from multiple, heterogeneous sources. Humans have traditionally supervised such problems to reason and resolve issues in SCADA. Also SCADA is complicated due to its centralized approach. A multi-agent Energy Management System (EMS) can cope with heterogeneity and give better, faster solution than SCADA. 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. Plug and play adaptability and connection to external grid is seamless in MAS based micro-grid. By nature MAS can be scaled up by adding other agents or by dispersing them in new environment with new resources and capacities. MAS is particularly useful for designing distributed systems requiring autonomy of their entities.

Th 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 [16].

C. Advantage of Multi Agent System

Multi-agent system approach has several advantages over the traditional approaches for management and control of micro-grids. Some of the important advantages of the MAS approach are given below.

1) It is 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.
2) 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.
3) It has the property of interoperability.
4) The ability of different agents to coordinate behavior through cooperation, negotiation and mediation, helps in distributed decision support system. Thus autonomous distributed agents aligns local objectives with global objectives [17].
5) This MAS technology controls a very complicated system with minimum data exchange, minimum computational resources and minimum time with it's decentralized approach.
6) As the information is processed locally and agents exchange their knowledge, the data manipulation is limited. Hence the amount of data exchanged is limited and so the communication expenses are reduced.
7) In case of failure of any controller, the other agents adapt and continue the system functions maintaining the robustness.
8) Plug and play capability for seamless integration of renewable resources and loads are possible.
9) Actions can be taken in few milliseconds, many times faster than SCADA and so operational efficiency is increased considerably.
10) In traditional Supervisory Control And Data Acquisition (SCADA) deployments the human supervisor takes the role of encapsulating and handling inherent uncertainties arising from incompleteness and inconsistencies. Intelligent multi-agent systems perform this role autonomously.

D. Multi Agent Platform

Agent platform is a software environment, where all the software agents run. In this paper, MAS is implemented in JADE (Java Agent Development Environment) framework, which is used as runtime environment for the execution of agents.JADE hides underlying complexity of the operating system and network to the programmer thereby simplifying the programming aspects. The JADE runtime in turn executes within a Java Virtual Machine (JVM). JADE provides a convenient distributed platform for users to focus on developing agents for control and monitoring of power balance during micro-grid operation. When a platform is created, the main container is always the first container to be initialized in JADE. Agent Management System (AMS) and Directory Facilitator (DF) agents are also automatically created once the main container is initialized.

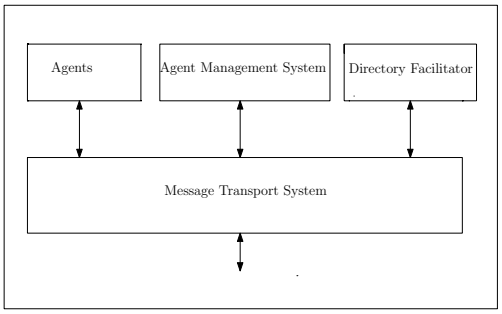

Fig. 4. Architecture of Multi Agent System

JADE platform provides a set of functions and classes to implement agent functionality, such as agent management service, directory facilitator and message passing services as shown in Fig. 4.

- Agent management service (AMS) is like white page and 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) provides services for message transportation in the agent system.

Every agent must register in AMS and then it discovers the nature of other agents in the DF and choose to communicate them through MTS. An agent has a certain behavior and tends to satisfy certain objectives using its resources, skills and services. Agent Communication Language(ACL) is used for communication between agents.The agent support high level communication, so that the agents not only exchange simple values, but also knowledge, commands, beliefs or procedures that have to be followed.

IV. Problem Formulation in Dynamic Energy Management of Solar Micro-grid

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 econamic and environmental optimization.

V. Implementation of Dynamic Energy Management of Solar Micro-grid

We consider a grid connected solar micro-grid system which contains two solar Photo Voltaic (PV) systems each contains a local consumer, a solar PV system and a battery. One in the department with capacity of 100kW and the other in the hostel with capacity of 200 kW. The solar irradiance (G in W/m2) and the temperature (T in o C) influence the solar energy. Solar energy in hourly basis and the load of 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. 1 and Fig. 2. 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. 5. 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 symbols mentioned in the flowchart are L1 = Dept Load, L2 = Hostel Load, S1 = Dept solar power, S2 = Hostel Solar power, B1 = Dept Battery, B2 = Hostel Battery, G= Grid Power, D= Diesel Power, DP=Diesel unit price, GR= Grid unit price.

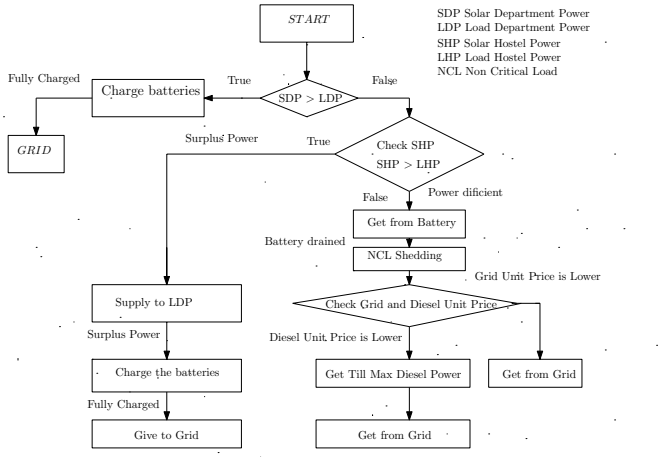

Fig. 5. Flowchart

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 over all procedure is the following.

1) Here first the department load agent (L1) communicates the the power demand through an ACL message with the available solar power in solar agent (S1) in the department at that specific hour. If S1 is not sufficient for covering load L1, it checks with the availability of solar power in the hostel solar unit (S2).

2) If surplus energy is is available in S1, then it checks its

battery (B1) to charge and if excess energy is available it checks the batterry of hostel agent (B2) to charge and anything further excess available is given back to the grid.

3) If required power is fully available in S1 then takes required power and the cycle gets completed.

4) If partially available then it will look into the availability of solar power in the hostel solar unit (S2).If required power is not available in S2 then it look 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 .

5) Even after taking 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 and demand response strategies. Non critical loads can have many priorities based the requirement. Even after this, if load requires power, it check with the pricing of the grid at that hour and the diesel power price and chooses the least priced one.

6) 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.

7) 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.

VI. Agents formulations

The proposed multi-agent system comprises many intelligent agents representing various components in a micro-grid. Each agent has a localized knowledge base, containing rules and behaviors, which governs its decision making process. The following agents are formed to simulate multi-agent system in JADE environment.

A. Generator Agent

Generation Agent (GA) receives power request from Load agent. It allows owners of solar generators to set selling price for trading.The micro-grid operations for supplying and buying power are being planned at every hour. 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 or supply to s GA.

B. Load Agent

Load Agent (L1) allows customer to specify the amount of power to purchase and communicate to the Generator Agent (S1). LA first registers itself with DF by providing load and power buyer as input parameters to setName and setType respectively. LA buy power from the GA based on command received from the control agent. It get proposals from all GAs and chooses the GA which offered the best price. If there are no GA in the DF yellow pages, LA check for batteries and finally ends with Control Agent (CA) buying power from the grid.

C. Grid Agent

Grid Agent registers with DF by giving Grid Agent and grid status as inputs to setName and 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. This agent will wait for messages from CA to determine whether the micro-grid needs to buy power or sell net surplus power to the grid. It gives the power or accept the power according to control agent instructions.

D. Diesel Agent

Diesel Agent register 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 CA and sell power to Load Agent when the diesel price is less than the grid price.

E. 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

F. 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 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. GA gets the list of agents that can buy energy and sends a request to all the members of the list. The

load agents accepts or refuses the offer based on conditions. Also the load agent can look into many GAs, registered in the DF and choose the required one based on the conditions.

VII. 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. 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. Various scenarios are considered and sniffer diagrams and the console output representing the interaction of the agents and transaction details are studied. Fig. 1 shows a snapshot of a case study

A. Sequence of operations

1) Hostel Load taps 55 kW from Hostel solar Power as hostel power is 65 kW which is more than the required power.

2) Department Load needs 70kW but taps 30 kW from Department solar Power as department solar power available is only 30 kW. Still 40 kW is needed.

3) Department Load taps 10 kW from excess solar power available in the Hostel,after supplying to hostel load

4) Department Load taps 5 kW of power from Department Battery which had 5kW of charge.

5) Department Load taps 5 kW of power from Hostel Battery which has 5kW.

6) 10 kW of non-critical load at that hour is shed before tapping from grid or diesel generator.

7) The remaining power of 15 kW is taken from Diesel Generator after comparing the grid unit price at that hourly interval, which is Indian Rupees 9/kWh, to the diesel unit price of Indian Rupees 7/kWh.

The console outputs and sinffer agent diagram are shown in Fig. 6 and Fig. 7. The ACL message communication from department load asking 15kW from the diesel agent is shown in Fig. 8 and the response from the diesel agent giving 15kW is shown in Fig. 9. After negotiation with other agents, the final result is being reported by CA which tells users how much power is being received or given to grid. All agent actions to stabilizing the grid can be accomplished within 10 millisecond.

VIII. Discussion

In this section we provide a qualitative comparison between MAS based advanced distribution energy management of solar micro-grid,which operates in decentralized environment and conventional SCADA system, which operates in centralized environment . MAS has flexibility, scalability and seamless adaptation to dynamic changes.The comparison leads to conclude that the MAS approach is promising for optimal energy management of solar micro-grid. The original contributions are

- In the references the optimization is done considering few cases but in this paper the complete, logical operations are analyzed comprehensively for dynamic optimization using MAS in JADE environment.
- Reliability is improved by maintaining active power balance all the time in the solar micro grid.
- In MAS, due to multi threading concepts, the operations are done in parallel with autonomous decision making capability to increase the operational efficiency. Also the communication between agents are faster due to ACL. Every hour dynamic variations of solar power, non critical load and grid price are accounted to take the best possible decision in the solar micro-grid for economic and environmental optimization. So MAS in micro-grid energy management is more efficient than the conventional methods.
- This paper contributes to the current state of the art of research for distributed generation with micro-grid concept, by proposing a JADE multi-agent tool to control the overall system through modeling and calculation of active power management in a micro grid systems, formed

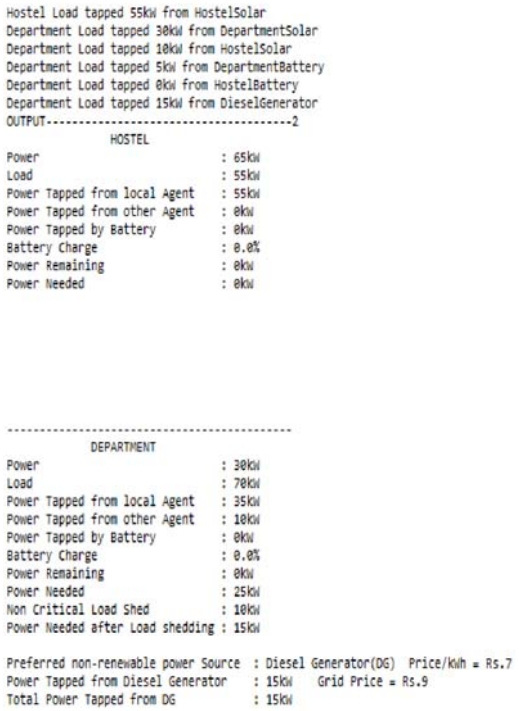

Fig. 6. Console Output

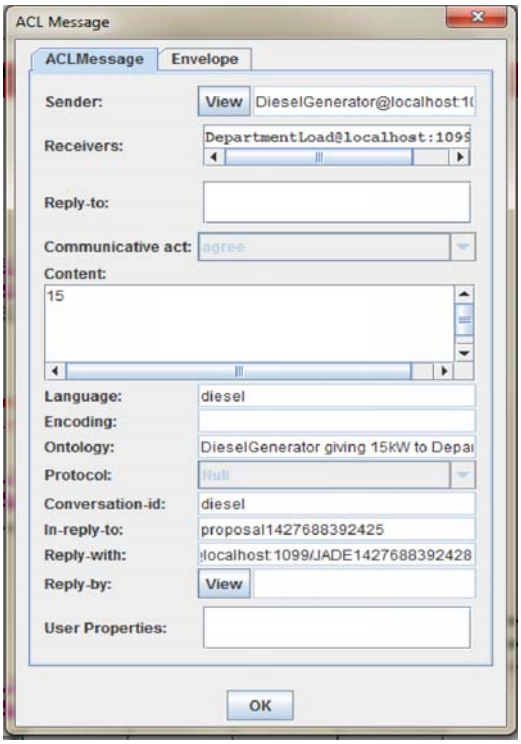

Fig. 7. Sniffer Diagram

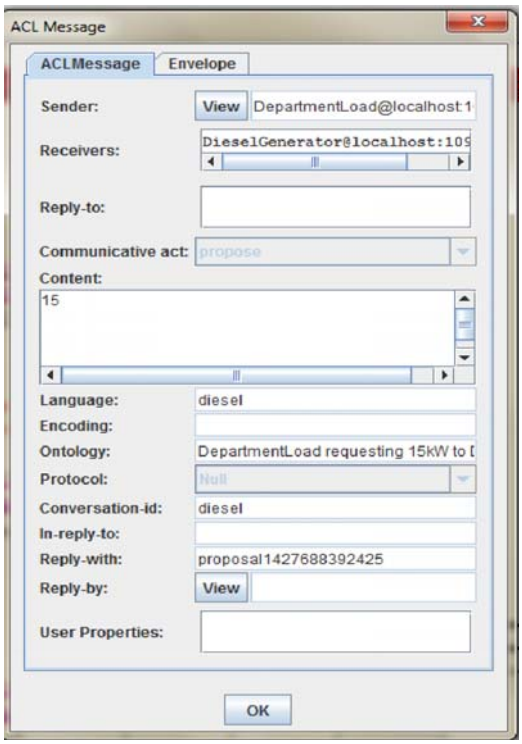

Fig. 8. ACL Message Request

by batteries, photo voltaic and diesel micro sources, in islanded or grid-connected modes.

- Our approach enables customers to dynamically manage the energy in all possible micro-grid operating conditions. Through systems integration, micro-grid stability and reliability are enhanced while the customer benefits from lower costs and more reliable electrical power from renewable energy resources.

IX. Conclusion

The optimization of distributed energy 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 analyzed for optimal distributed energy management of a 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 optimal energy management actions to increase operational efficiency in a distributed environment. Future work will focus on extension to multiple agents integrating solar and wind generators with several intelligent consumers.

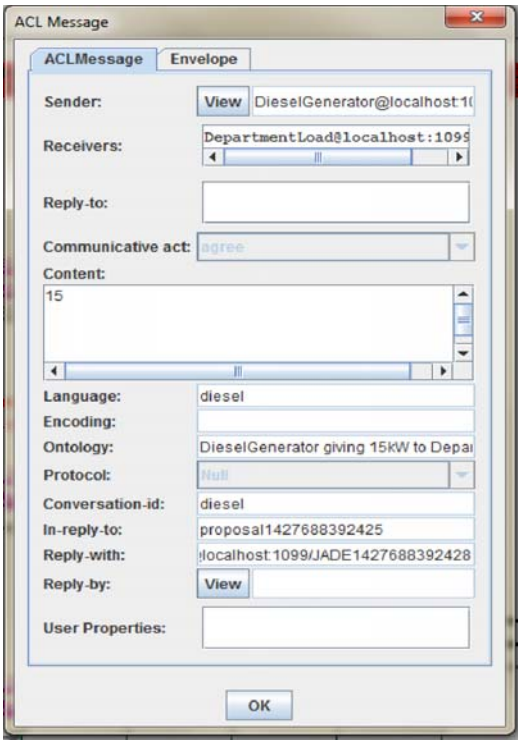

Fig. 9. ACL Message Response

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