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

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Abstract : The objective of this paper is to develop Arduino based Multi Agent System (MAS) for advanced demand side management of a solar micro-grid. High penetration of renewable energy resources needs new coordination and control approaches to meet the stochastic nature of the environment and dynamic loadings. We use Multi Agent System for advanced distributed, autonomous energy management of the micro-grid to dynamically and flexibly adapt to the changes in the environment. We consider a micro-grid which contains two solar Photo Voltaic (PV) system, local consumer, and a battery. We develop a simulation model in Java Agent Development Environment (JADE) for dynamic energy management, which choose the best possible action every hour to stabilize and optimize the solar micro-grid. Furthermore, environment variables are sensed through Arduino microcontroller and given to agents of MAS. The resulting actions are reflected in the LED out puts which can be readily deployed in the actual field.

Keywords : Autonomous Agent, Energy management, Multi Agent System, Micro-grid, JADE, Arduino.

1. INTRODUCTION

Environment consideration is leading proliferation of renewable resources in electrical industry.We are moving towards a more decentralized, more sustainable, and smarter power system. Centralized approach is used in most of the existing research on micro-grid operation problems. In order to reduce communication overhead and improve robustness, distributed approach is used in energy management problem. 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. The design and implementation of Multi Agent System in micro-grid energy management is discussed in detail in the paper [1]. Multi-agent system for operation of an integrated micro-grid is discussed in [2]. Multi-agent based distributed energy management for intelligent micro-grid is discussed in [3]. The complete review of micro-grids in multi-agent system perspectives are discussed in [5]. Multi agent based micro-grid control is discussed [4]. Only in the very recent paper [5], 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, like, grid failure, no solar power in the night, peak load management, demand side management, etc., Also most of the references do MAS simulation in JADE framework. Real time implementation of MAS is not discussed. 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

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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. All the features of smart grid are implemented and the agents operations are verified by Arduino microcontroller for various scenarios.

The rest of the paper is organized as follows. A detailed discussion on multi agent system approach is given in section 2. Micro-grid is explained in section 3. Arduino Micro controller is explained in section 4. Problem formulation is given in section 5. Implementation of autonomous demand side energy management and grid outage management in solar micro-grid is given in section 6. Simulation and results are given in section 7. Conclusion is given in section 8.

2. 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 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 (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. MAS have inherent benefits such as flexibility, scalability, autonomy and reduction in problem complexity [6]. 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. 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 [7]. 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 are reactive to changes in environment. Reasoning, optimizing, controlling and learning are the inherent characteristics of an agent[8].

3. MICRO-GRIDS

Micro-grids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded. Micro-grids can coordinate all the assets and present them to the mega-grid in a manner and at a scale that is consistent with current grid operations, thereby avoiding major new investments that are needed to integrate emerging decentralized resources. Micro-grids have been proposed as a novel distribution network architecture within the Smart-Grids concept, capable to exploit the full benefits from the integration of large numbers of small scale distributed energy resources into low-voltage electricity distribution systems. The present SCADA (Supervisory Control And Data Acquisition) is incapable of managing large numbers of renewable energy resources due to its intermittent nature [9]. Multi Agent Systems are used to manage the dynamic nature of the renewable resources..

4. ARDUINO SERIAL COMMUNICATION USING RXTX LIBRARY

This is the most suitable method for accessing the Arduino from the Java code. A library called RxTx is used which facilitates serial communication with the Arduino UNO. Messages are sent to and received

from the Arduino serially. However, since the communication is serial, only one agent can access the Microcontroller at a time. In our case, the control agent is responsible for this communication. The Arduino board can, however, limit the number of values sensed from the environment due to the lack of many analog pins. Potentiometers connected to analog pins of the Arduino board are used to input the sensed values of the environment like Load Required and Solar Power Available,etc., Potentiometers connected to analog pins of the Arduino board are used to input the sensed values. The Arduino IDE itself is written in Java, and it can communicate to the serial port via the RxTx Java library. The required command for turning on the LED is parsed from the message of the communication from Eclipse.

The potentiometer values can be obtained from the Arduino board through this serial communication. The results of strategic operations of agents can be reflected in the microcontroller which is given to the physical device for actuation. This information is again passed to the Arduino board through serial communication and given to its digital pins to which LEDs are connected. These LEDs indicate the action taken by the agents and the status of the LEDs trigger the action of the actuators. An Arduino program is written and uploaded for the above mentioned purpose. The Loads will get power from a source based on priorities for The first priority the lowest cost among all other sources and the second is the nature of source. In this case renewable sources are preferred.The above two conditions not only gives the consumer an advantage over hectic grid prices but also helps in the improving the environment leading to economic and environmental optimization.

During Every instance, the Eclipse program will fetch the potentiometer details which in real time correspond to the Load Required, Solar Power that can be Generated, etc.,. The Eclipse Communicates with the Arduino at a standard baud rate of 9600 symbols/sec. At the end of every instance, ECLIPSE will send information to ARDUINO in an asynchronous communication language that contains the pattern of LED's that has to glow for that instant. This will be parsed by the Arduino to issue the high command to corresponding digital output pins. These LED's in real time correspond to the command signal issued by ECLIPSE MAS System to the Actuators that allows the power flow between various sources and loads. All these actions take place parallel in Eclipse with the help of MAS concept for faster actions. During a grid failure, the entire micro-grid will operate under islanding mode. The MAS System senses such faults and initializes non critical load shedding. Loads such as Air Conditioner, Refrigerator and Washing Machine are considered as non-critical loads.

5. PROBLEM FORMULATION

The challenges due to penetration of renewable energy resources like solar and wind have to be dynamically managed in order to maintain stability, reliability and fault tolerance. In the solar micro-grid demand side management and grid outage is implemented autonomously by using multi agent system and the agents operations are practically verified using Arduino microcontroller.

6. IMPLEMENTATION OF DEMAND SIDE MANAGEMENT AND GRID OUTAGE MANAGEMENT

The environment variables *i.e*. Load Demand, Solar 1 Generation, Solar 2 Generation, State of Charge of the Battery, Information on grid availability and the NC Load are sensed through the potentiometer and are given to the microcontroller. Using these values, the program calculates the optimal power distribution. This is reflected in microcontroller which is given to the physical device for actuation (LEDs).In the flow chart, initially the load gets power from solar1 and then if required it gets from solar 2. Then the remaining excess solar power is used to charge the battery and finally the excess power is given to the grid. If there is shortage of power for load then the load receives power from both the solar and then from the battery. If grid is available the remaining required power is received from the grid. During the grid outage the micro-grid gets isolated and it balances the power requirement by appropriate load shedding.

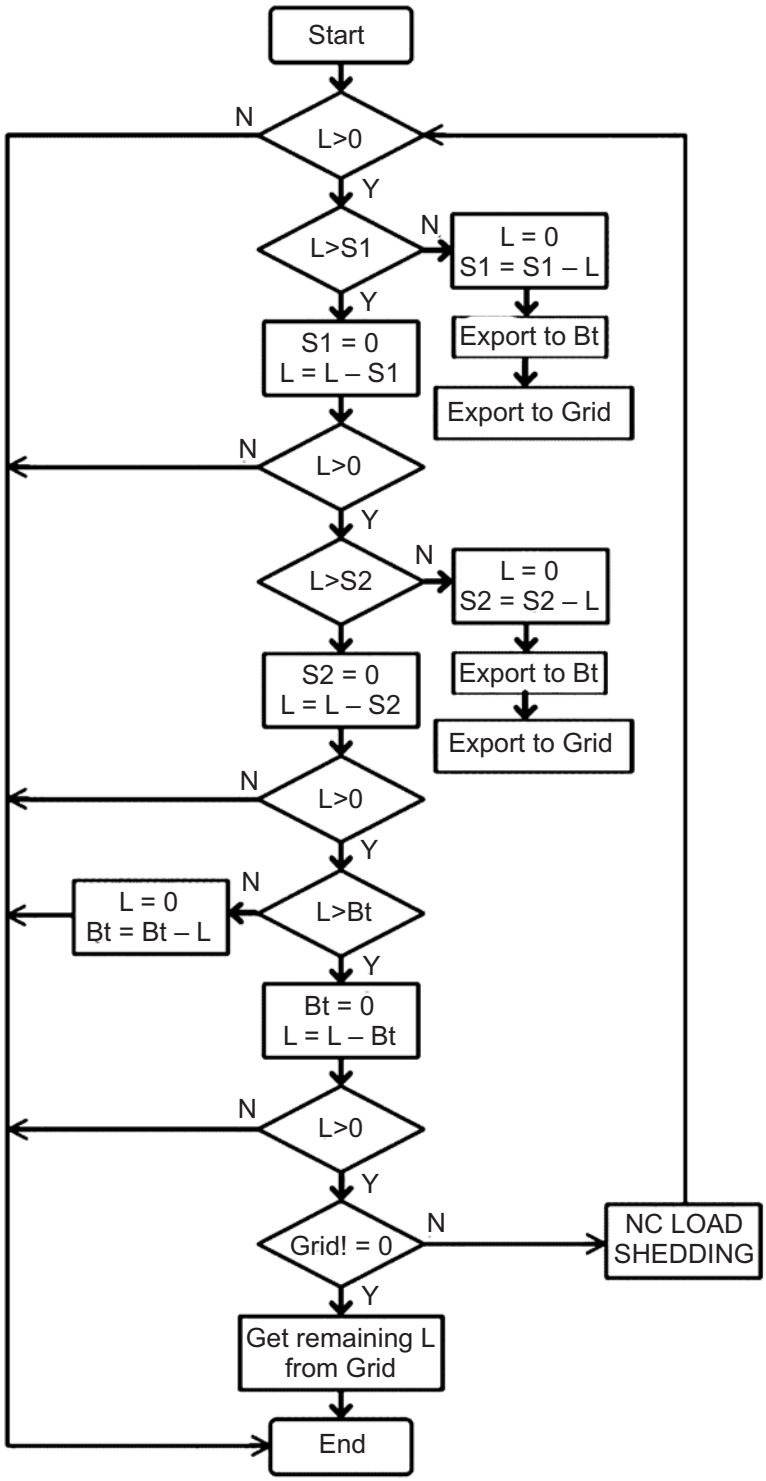

Figure 1: Flowchart

7. SIMULATIONS AND RESULTS

All the operations are considers as shown in the flow chart and for these scenarios, the java programming is done in JADE [10] 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. The Arduino board is connected to the bread board where all the potentiometer and LEDs. This Arduino board is connected with computer serial port through ethernet card. Arduino software is run to upload the program into the board. The potentiometers are fixed with the

environment variables of solar values, load values, battery values, grid value and Non Critical Load (NCL) value. Four LEDs are fixed on the bread board representing two solar units, a battery unit, and grid.The JADE agents are made to run in the Eclipse environment. The agents receive environment variables from the pot through Arduino microcontroller and take strategic decisions by communicating and coordinating with other agents. The resulting actions in the form of command signals are given to the various micro-grid components represented in the form of LEDs through Arduino. In this case, all the LEDS glow as all the agents are are involved in the process. The potentiometers can be varied for various environment values and the LED actions are verified with environmental dynamics

Table 1
Ttest Case 1 – Sensed Values

Input Pins	*Agents*	*Equivalent Power*
A0	Load (kW)	100
A1	Solar 1 (kW) 50	50
A2	Solar 2 (kW) 30	30
A3	Battery (kW) 10	10
A4	Grid	Zero (Outage)
A5	NC (%)	10

Process :

- Though the load needs 100 kW, due to the Grid outage and non-availability of enough power sources, the NCL are shed to manage the deficiency.
- 90 kW is the demand now. This is satisfied by Solar 1, Solar 2 and the Battery.
- As Solar 1, Solar 2 and Battery give power to the Load after shedding, LEDs at pins 8, 9 and 10 glow.
- The further required 10Kw is managed by shedding Non Critical Load.

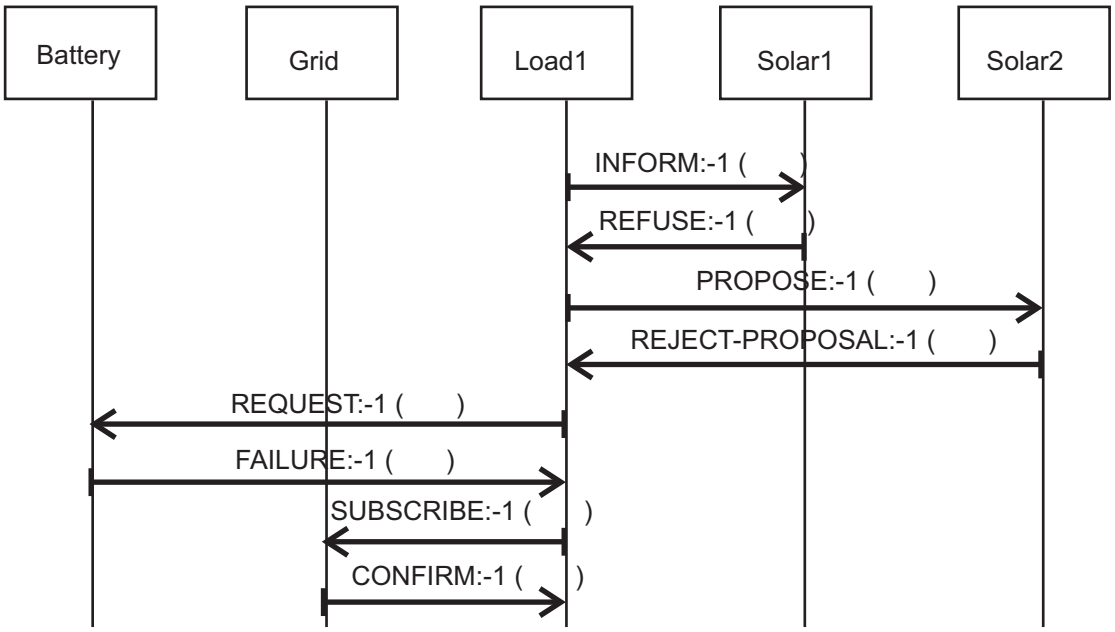

Figure 2: TEST CASE 1- Sniffer

Console Output : The console output the and JADE sniffer and Arduino output snapshot are shown in Fig.4., Fig 5 and Fig 6.

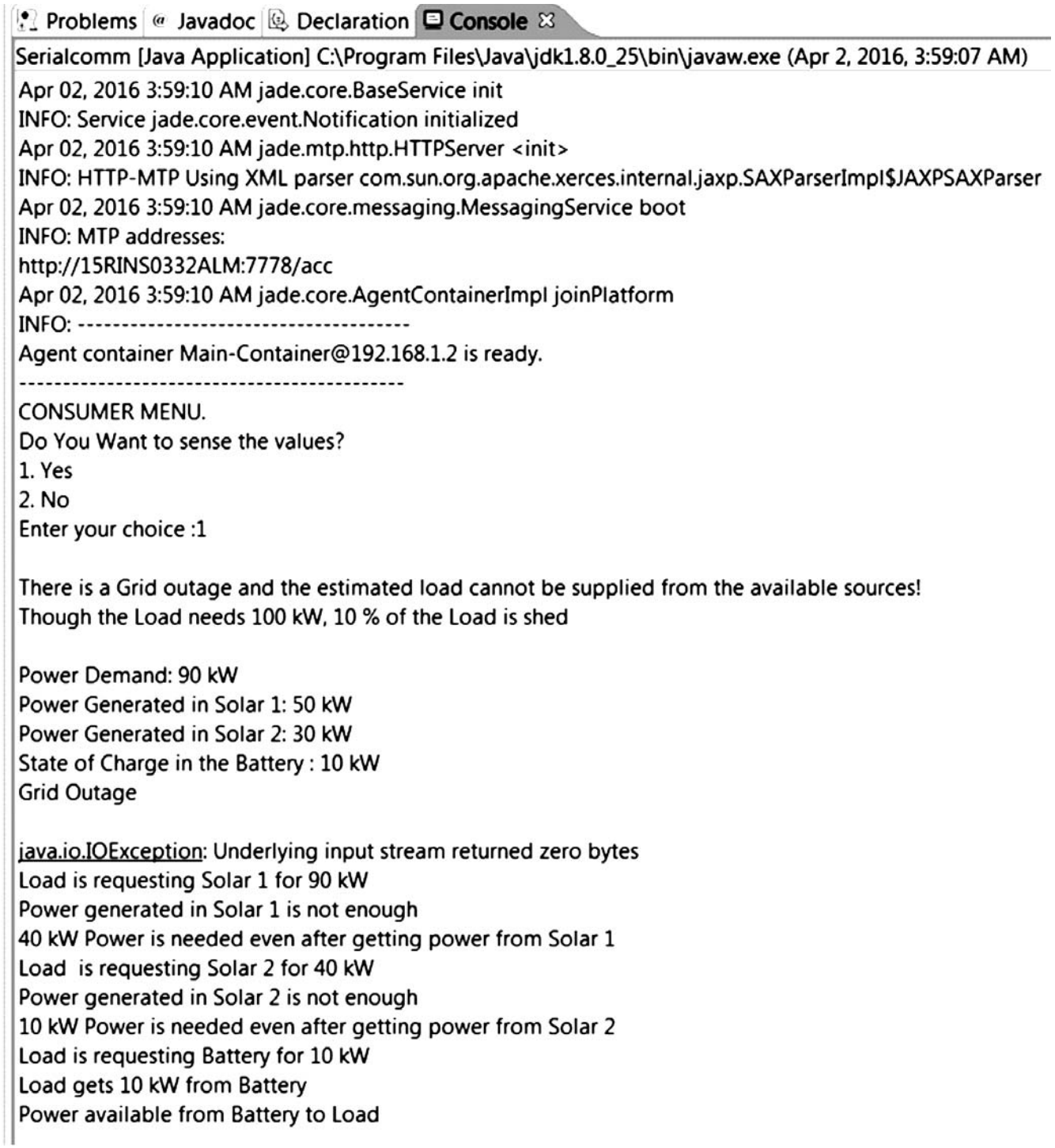

Figure 3: Test Case-1 console output

Hardware Output :

Table 2
Test Case-1 hardware output

Output Pins	*Pin 8*	*Pin 9*	*Pin 10*	*Pin 11*
Agents	Solar 1	Solar 2	Battery	Grid
On/Off	On	On	On	Off

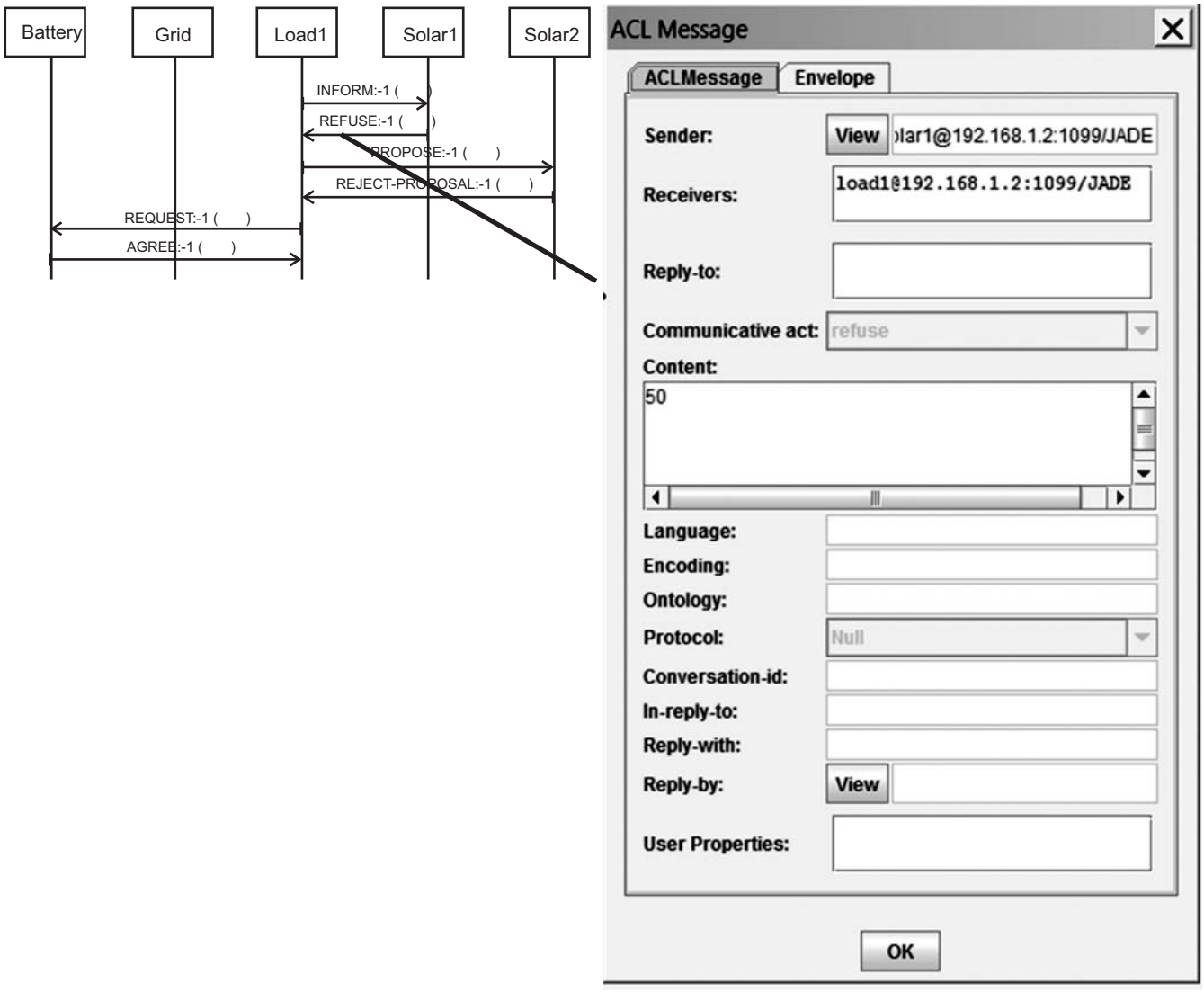

Figure 4: Sniffer Solar 1 giving power to the Load

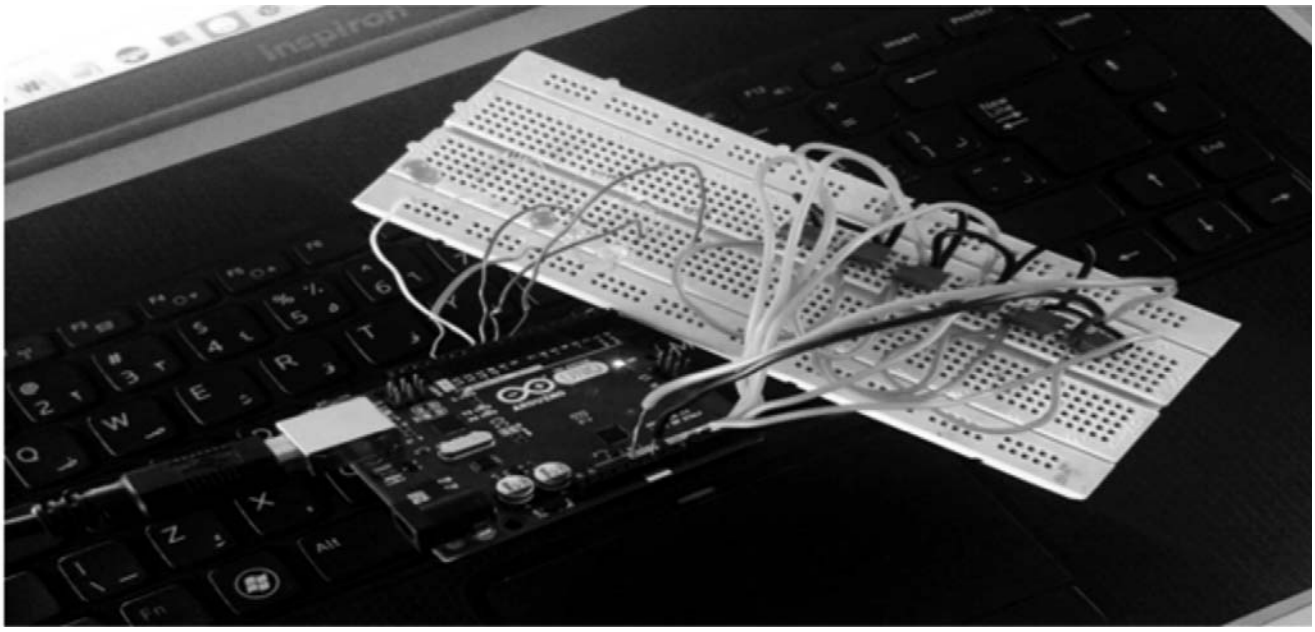

Figure 5: Arduino with hardware

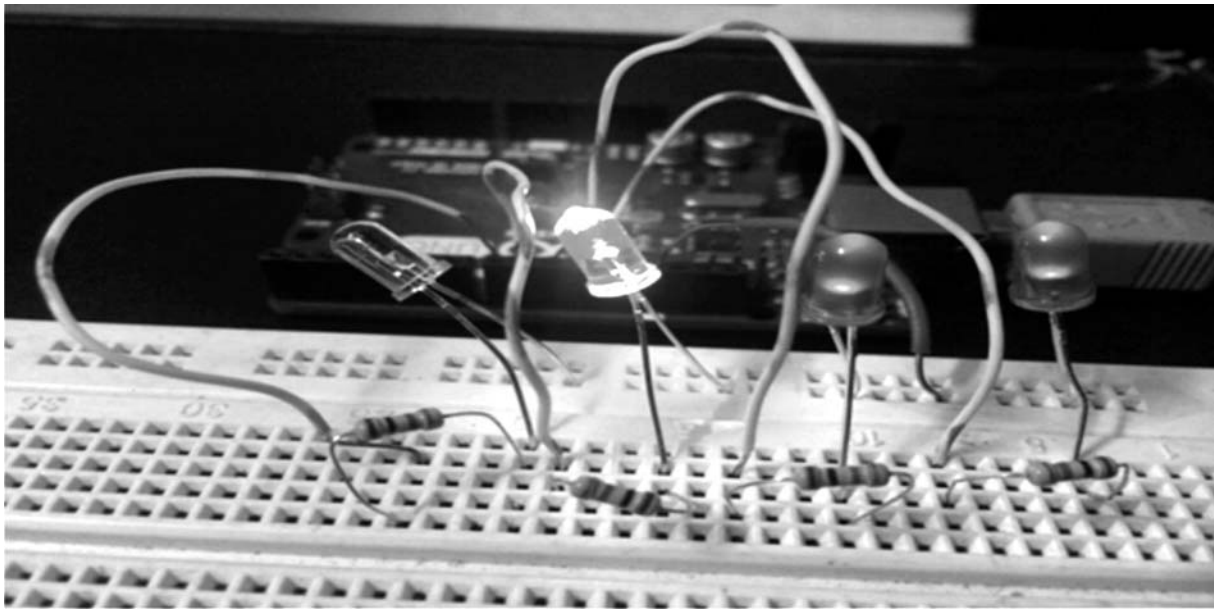

Figure 6: Hardware Output

8. CONCLUSION

The demand side management and grid outage management is implemented in a solar micro-grid 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 energy management of a solar micro-grid.The operations of agents are practically verified by Arduino microcontroller. Future work will focus on applying to IOT into our system to make it smarter.

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