Defining Multi Agent System for a Reliable Micro-Grid

H.M.N. Dinushi, M.H.M.S. Kariapper, G.D. Porawagamage,
P.K.H. Rathnayaka, U.P. Srimal, K.T.M.U. Hemapala
Department of Electrical Engineering
University of Moratuwa
Moratuwa, Sri Lanka
gayashandasun@gmail.com, kasun234@gmail.com, upsrimal@gmail.com,

***Abstract*—Electrical power supply to serve critical facilities are of high importance in today's world. Instead of building a large electric power system, an intelligent Micro Grid (MG) can be considered as a promising power supply alternative for those critical facilities. This study presents the development and controlling of a laboratory scale MG which consists of several Distributed Energy Resources (DERs) such as Solar PV, Diesel Generator, Micro Hydro model, Battery Bank with a bidirectional inverter and critical and non-critical loads. Controlling of the MG is done by using distributed autonomous control strategies and Multi Agent System Architectures. It can operate in a grid connected mode as well as autonomous mode when it is isolated. The whole system was simulated using MATLAB and the simulation results and practical results were compared when MG is operated in different scenarios. The effectiveness of this controlling method is discussed in this paper.**

Keywords—Micro Grid, Multi Agent System, Distributed Autinomous Control

I. INTRODUCTION

Micro Grids are newly developed type of a power system that comprises of small modular electricity generation sources and small loads[1]. The increasing demand for electricity and the environmental pollution which has occurred due to the conventional power plants, will force electricity regulators to implement micro grid concept which comparatively involves more renewable energy sources [2]. In a large power system, some distributed energy sources and related loads can be identified as a micro grid. When a fault occurs in the system, the micro grid can operate in self-sustained mode with the best economical options by an intelligent control system. This is helpful to increase the reliability of the whole power system[3]. But developing such advance controlling mechanism had been a challenge due to the intermittent nature of the energy sources involved in the MG.

MGs can be used to meet backup power, remote power, increase the reliability of the system, cooling and heating needs of the customers [4]. In the Micro Grid almost all the micro sources and loads can be controlled as a single system to keep the frequency and voltage at an acceptable level in the islanded mode. There is a single point of connection to the main grid called, point of common coupling (PCC) to operate in the grid connected mode.

Main focus of this paper is to analyze the operation of a MG in an intentionally islanded situation such as a fault occurring in the main Grid. Another critical reason for the islanded microgrid operation is to realize sustainable human development. According to the World Bank's 2010 development report, 1.6 billion people in developing countries do not have the access to electricity[5]. MGs operating in islanded mode can be a worthy solution for this problem.

A laboratory scale Micro grid test-bed is constructed with a well – defined, reliable control system using distributed autonomous control strategies and Multi Agent System Architectures. The MG is simulated using MATLAB. In this paper, behavior of micro grid at different scenarios are explained, comparing practical and simulation results to examine the effectiveness of the controlling mechanism.

II. MICRO GRID CONTROL

The Micro Grid, which consists of DGs such as solar power, micro hydro, wind power, storage system, critical and non-critical loads. As mentioned earlier, micro grid operates in grid connected mode and islanded mode as well. Thus, it may lead to some operational problems. Therefore, use of Multi-Agent System (MAS) architecture as depicted in Fig. 1 for controlling the Micro Grid, solves number of specific operational problems. According to the architecture main element is the Agent. DG Agent, Load Agent, Database Agent, User Agent and PCC Agent are there in the Micro Grid. Flexible and smooth operation can be obtained by this architecture [6].

One of the characteristics of an agent is, that it can adapt to changing environments. Also agents are provided with a certain level of autonomy, which allows them to take some decisions without any influence from central agent/controller etc.

Use of Multi Agent System allows

- A robust and reliable operation. For an instance if one of the controllers fails, other agents adopt for the system requirement.

978-1-4799-1740-2/15/$31.00 ©2015 IEEE

- Any energy resource to be embedded to the system with no complexities.
- The whole system to operate at optimal levels as each agent tends to maintain the allocated area at optimal level.
- Optimally controlled market operation by considering buying and selling energy
- The sources to operate at their optimum operating point by considering generating cost.

Each energy node acts as an agent. DG Agent, Load Agent and PCC Agent measure the power, voltage and frequency of their own bus and transmit to the Database Agent and Control Agent. The database agent keeps a record on given data.

Critical and non-critical loads can be defined manually to the load agent and decides which loads to be shed in order to maintain system voltage and frequency itself. DG Agents are allocated for each power source. PCC agent checks whether the main grid power is available or not. If it's not available, islanding is done immediately. The control agent analyses the obtained information from agents and direct them according to priorities. User agent displays all the data and enables the user to control manually.

Frequency and voltage are controlled according to the decisions made by control agent. The controlling process is as follows.

A. Grid Connected Mode

Voltage and frequency are controlled by the utility grid.

B. Islanded Mode

Scenario1- frequency and voltage are controlled using the bidirectional inverter by discharging the battery.
Scenario2- in case the bidirectional inverter fails, frequency and voltage is controlled using a diesel generator.
Scenario3- in case both inverter and diesel generator fail, micro hydro is used to control the frequency and voltage.

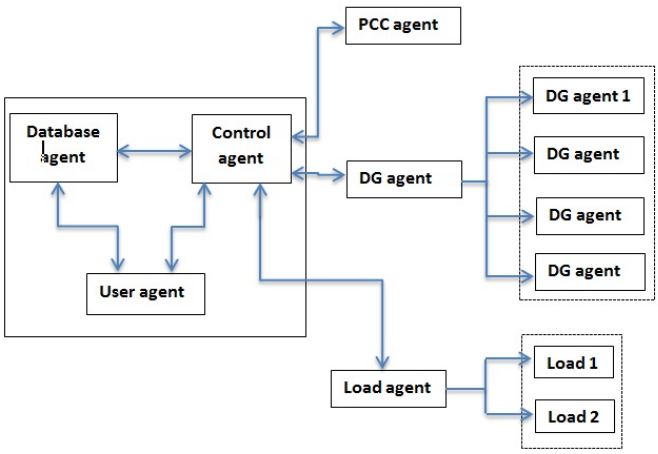

Fig. 1. MAS Architecture

III. HARDWARE IMPLEMENTATION

A. System Description

Micro-Grid test bed is developed in accordance with MAS architecture and autonomous control. It is a single phase AC system, with 230V, 50Hz; comprising solar PV (80W), micro hydro model (120W), battery bank (270Ah), either a grid or a diesel generator (5kW) and two motor loads (0.37kW each) and lighting loads (60x12W) (categorized as critical and non-critical) which is shown in Fig. 2. All the DERs are connected to the AC grid via flexible power electronic interface [7] except for the DG and MG. Also, there is a Micro Grid Central Controller (MGCC) which is responsible for the optimization of the MG operation.

1) Micro Hydro

Micro hydro model is implemented using two induction motors coupled together where one acts as the prime mover and the other acts as the generator. It has a dummy load and an induction generator controller (IGC). If the generation is higher than the demand, the excess power is dissipated through dummy loads. Controlling of the dummy load is done by IGC. The binary weighted mechanism is used to supply a constant power to the system[8].

2) Solar PV

Solar PV generates a DC voltage (21.6V) and it is connected to the Micro Grid by using a DC – AC inverter.

3) Diesel Generator

A 5kW, 50Hz, 230V, Single phase, diesel generator is available in our micro grid. It is capable of keeping the voltage and frequency within the acceptable level. It is used as the frequency and voltage controller when there is a failure with the bidirectional inverter.

4) Battery Bank

A Battery bank with a bidirectional inverter is used to stabilize the operation of MG when there is a fluctuation in the energy demand

5) Loads

Loads are divided into 2 parts as critical and non-critical for the load shedding purpose.

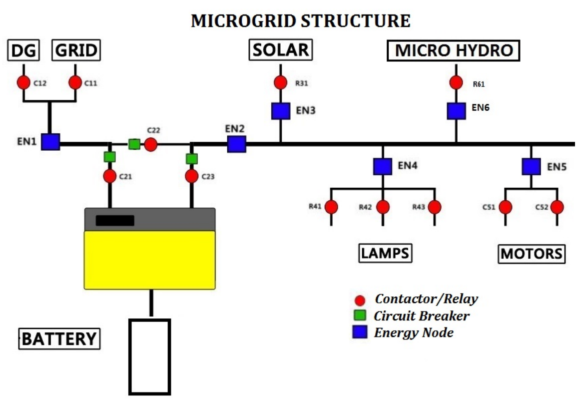

Fig. 2. Micro Grid Structure

B. Communication Between Agents

Energy node (act as an agent) monitors system parameters at each section and it is a major component when it comes to controlling the micro grid. An overview of energy node is shown in Fig. 3. It comprised with 3 main sections

- Energy calculation (ADE 7753)
- Data conversion (PIC 18F452)
- Wireless communication (XBee)

ADE 7753 IC is used for energy calculation. Current and voltage signals of the relevant circuit are taken and the desired parameters are calculated (Vrms, Irms, and Active Power). PIC 18F452 is used for data conversion and X-bee is the wireless RF module for communication.

ADE 7753 is only compatible with SPI Communication Protocol whereas X-bee module is only compatible with the UART communication protocol. Hence we have to connect PIC microprocessor as an intermediate processor, which does the data conversion.

LCD display is used for observing the system parameters in the circuit and relay circuitry for controlling the micro sources. Loads in the MG are connected as the auxiliary parts in the energy node [9].

The main tasks of the user interface agent is to display the data obtained from the database agent. The user can access the micro grid through the user interface and also control the system manually [10]. The Fig. 5 shows an example of a display which demonstrates the variation of frequency over time, according to switching of loads and sources. The overall implemented system is shown in Fig. 4.

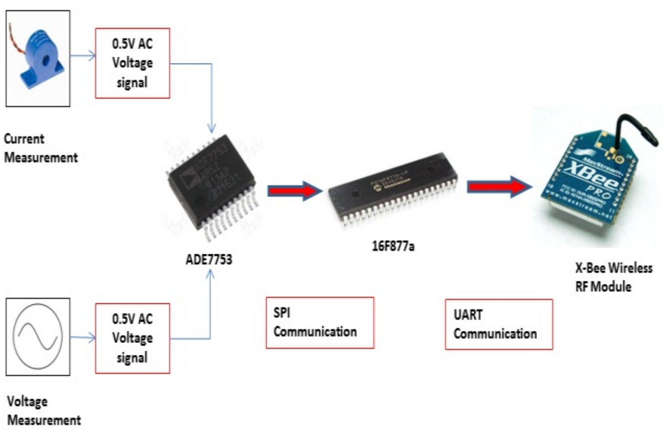

Fig. 3. Overview of Energy Node

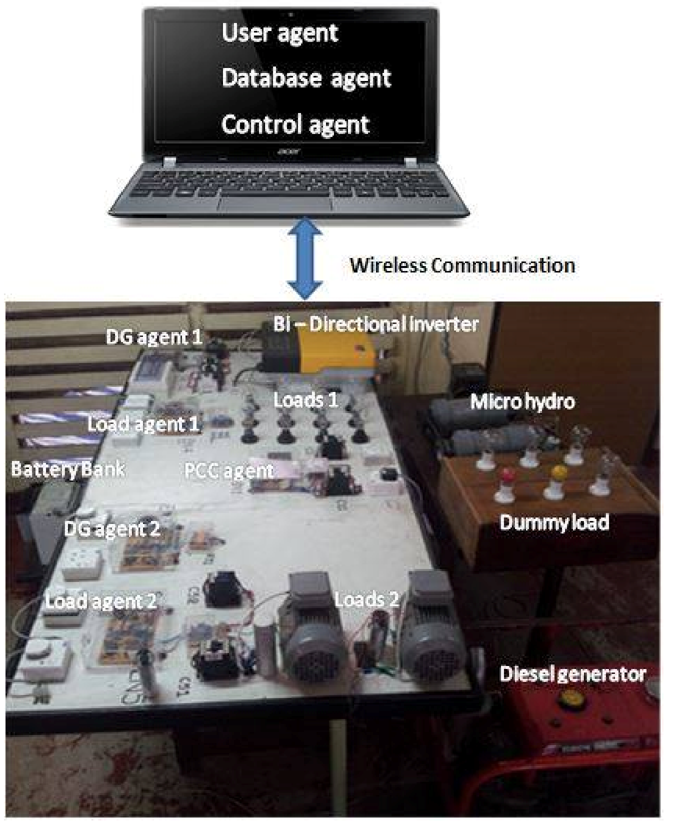

Fig. 4. Implemented Micro Grid

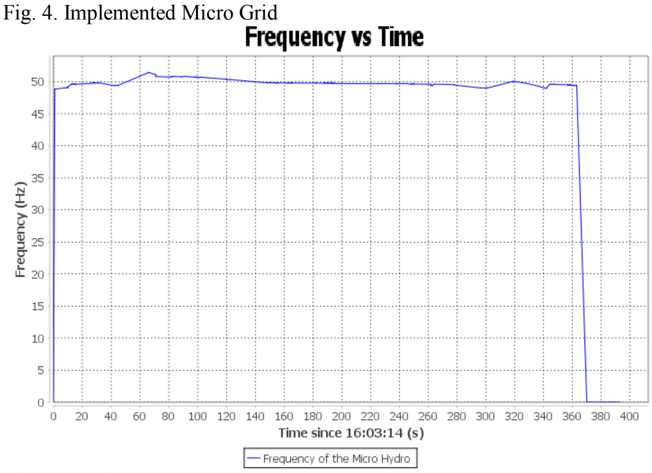

Fig. 5. Database Agent

IV. SIMULATION

The micro Grid system was simulated using MATLAB 2013a. Simscape, Sim power system, Simelectronics libraries were used [11]. Simulation was carried out by modelling each component in the grid such as micro hydro, solar, diesel generator, bidirectional inverter and battery bank separately and integrated them to get the whole system which is shown in Fig. 6 [12]. The system was simulated for four different scenarios and results were obtained for each case to verify the capability of multi agent system architecture to provide intelligent control to the system.

Case A: Islanding process when a fault occurs in the utility grid

The intentional upstream fault is introduced on the utility main grid at 0.05 s. This fault is identified by the MAS (PCC agent) and the system is switched to the islanded mode of operation from the grid connected mode. The main utility supply is disconnected by the PCC agent within a short period of time after detecting the faulty condition. It is demonstrated in Fig. 9(a), (b).

The micro grid voltage variation is illustrated in Fig 8(a), 8(b). The graphs illustrate how the system voltage is stabilized within the standard voltage limit after the faulty condition. When the grid is absent, controlling of frequency and voltage is handed over to the bidirectional inverter which is connected to the battery bank. Simulation and practical results show that the micro grid system is protected at a faulty condition of a utility grid. Practical results give a slight difference compared to the simulation result due to delay in the contactor breaker.

The capability of the MAS is proved by this smooth and continuous transition.

Case B: Serving critical loads

When there is an outage or a faulty condition, loads are supplied mainly by the DGs of the micro grid through the inverter.

If the generation from renewable sources is larger than the demand all loads are supplied through the renewable sources and the battery is charged from the excess power.

If it is less, the demand is satisfied by the battery bank and by renewable energy sources. In case the power from the battery bank and DGs are not enough, only critical loads are supplied using a load shedding method. The Fig. 10 illustrates a re-routing of load scenario.

In this case of Fig10 (a), (b), available power from DGs of the system is limited. Therefore a load shedding method is needed in order to supply power for the critical loads which should be given the highest priority. If the available power is increased, power is re-routed to non-critical loads which are given a lower priority. The MAS facilitates this option to the micro grid by communicating with agents and developing priorities by revising the system. This allows the system to maintain at an optimal level by supplying loads as possible by re-routing. The micro grid is capable of completing this detecting priority task within 0.02s.

Case C: Frequency and voltage controlling using micro hydro

The micro grid system is consisted with a strong frequency controlling mechanism. The sequence of frequency controlling is explained in Fig.7 [13].

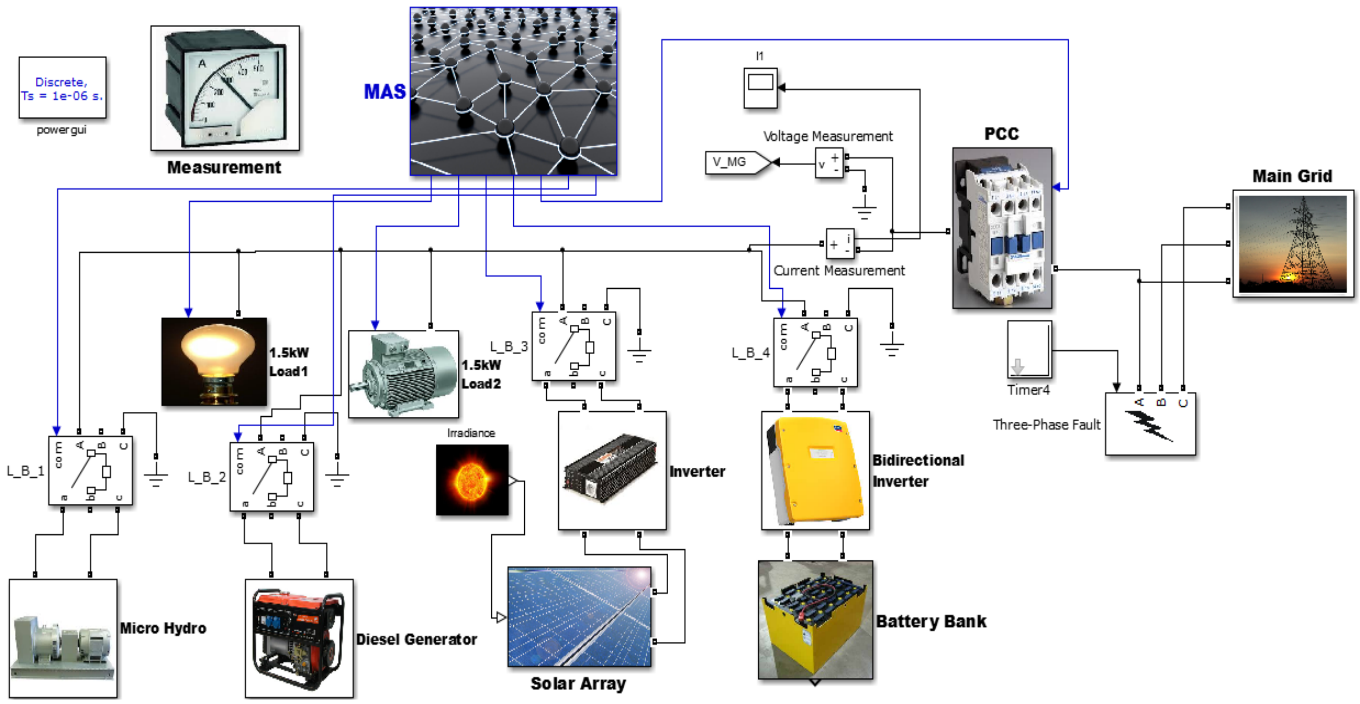

Fig. 6. Simulation of the MG

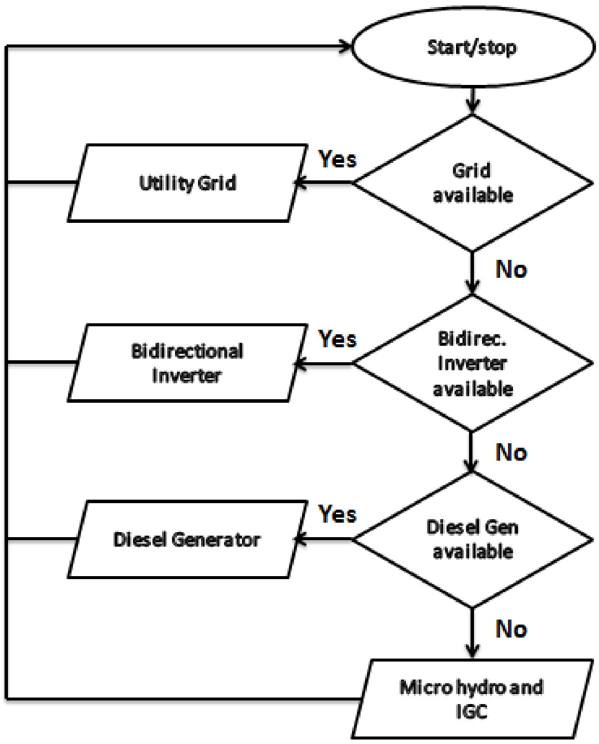

Fig. 7. Frequency controlling Sequence

In this case, simulation and practical results of controlling frequency using micro hydro and induction generator controller (IGC) is illustrated.

Micro hydro system is modeled using an induction motor and an induction generator. As mentioned above induction motor acts as the prime mover. The micro hydro system can provide limited power. Therefore, only selected loads (critical loads) can be served. Induction generator has no internal mechanism to control its' output. To control the frequency, IGC uses dummy loads in order to dissipate excess power after supplying critical loads.

As Fig. 11 (a), (b) illustrate, the micro hydro supplies power only for critical loads. At t=0.7s 65W load is added to the system and results in a drop of system voltage as in the figure. Frequency drop is occurring due to the increment of load power. This drop in frequency causes a further drop in voltage, due to reduction excitation. Then IGC reduces its allocated dummy load power and re-build the system voltage to the required level within a 0.15s. The figure demonstrates how the IGC builds the system voltage up.

Likewise IGC verifies the system voltage to be stable when there is a change in critical loads. The DG agent which is allocated for micro hydro, makes this operation work smoothly. As it is capable of taking decisions in order to maintain the system at the required level, operations can be done within a short period. The MAS helps to maintain a reliable system.

Case A-Islanding process voltages

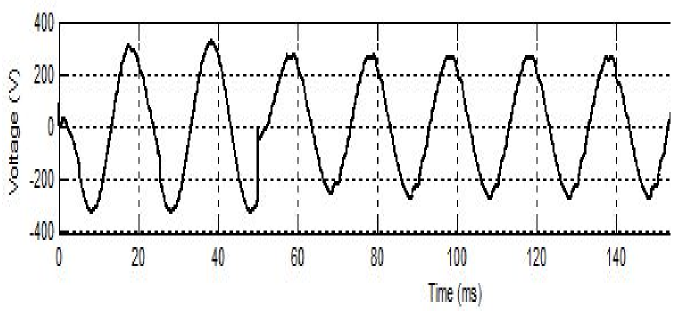

Fig. 8(a). Simulation results for micro grid voltage

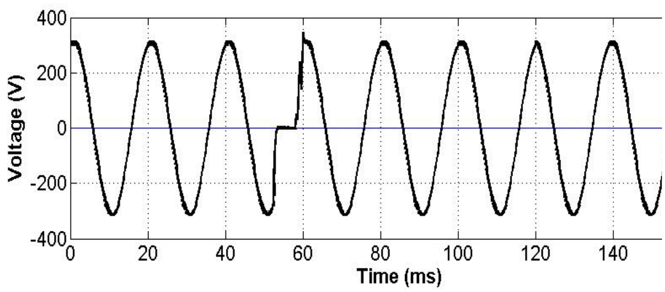

Fig. 8(b). Practical results for micro grid voltage

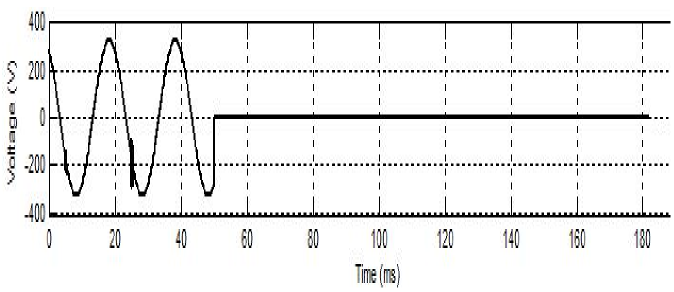

Fig. 9(a). Simulation results for utility grid voltage

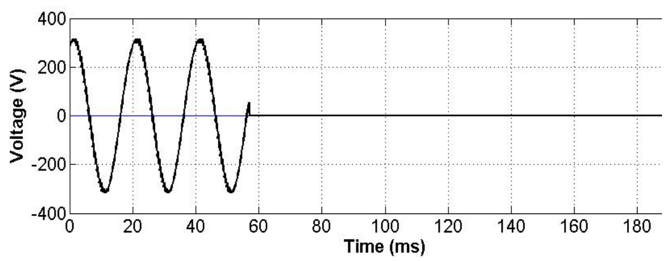

Fig. 9(b). Practical results for utility grid voltage

Case B- Serving critical load

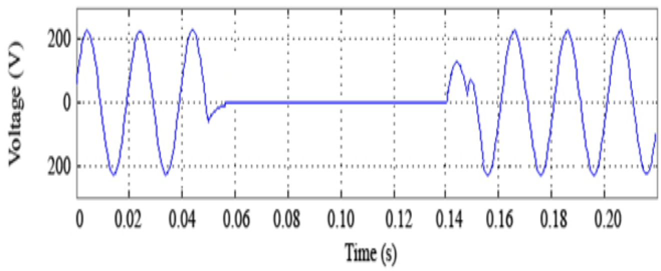

Fig. 10(a). Simulation results for re-routing loads

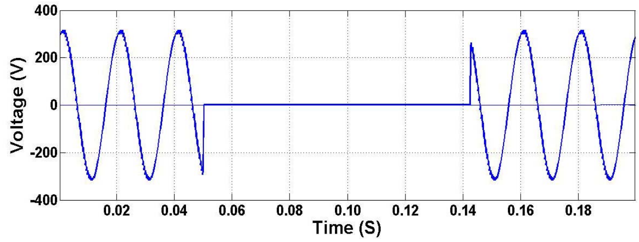

Fig . 10(b). Practical results for re-routing loads

Case C- Frequency and voltage controlling using micro hydro

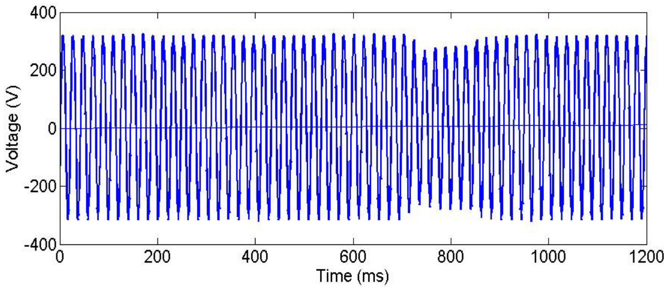

Fig. 11(a). Simulation results for micro grid voltage

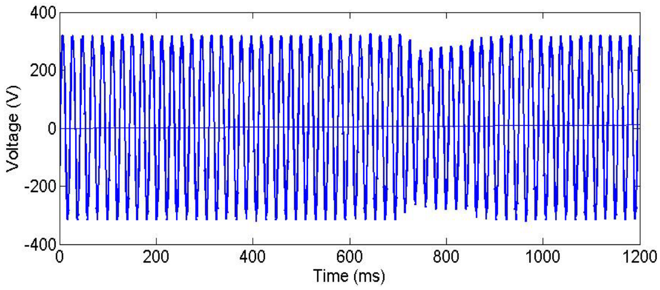

Fig . 11(b). Practical results for micro grid voltage

V. CONCLUSION

This study presents the development and controlling of a laboratory scale Multi Agent System based micro grid, which is comprised of several Distributed Energy Resources (DERs) such as Solar PV, Diesel Generator, Micro Hydro model, Battery bank with a bidirectional inverter and critical and non-critical loads. Each DER is connected to the micro grid system through an energy node. The whole system is controlled in autonomous mode based on Multi Agent System. The implemented load shedding mechanism avoids fast and long frequency deviation of the sytem and enhances the performance of the system. The seamless transition of islanding process, reliable and robust frequency and voltage controlling, optimal load shedding mechanism and maximum use of renewable energy were achieved through this architecture. The simulation results and practical results were tallied proving the accuracy of implemented test bed of micro grid. This micro grid test bed can be used for studying purposes of micro grid control further.

VI. REFERENCES

[1] J. Stevens and B. Schenkman. (2012). DC Energy Storage in the CERTS Microgrid[Online]. Available: http://certs.lbl.gov/pdf/microgrid-dc-storage.pdf.

[2] D. Georgakis, S. Papathanassiou and N. Hatziargyriou, "Operation of a prototype Microgrid system based on micro-sources," *Power Electronics Specialists Conference*, 2004, pp. 2521-2526.

[3] T.L. Vandoorn, B.Renders, L. Degroote, B.Meersman, L.Vandevelde, “Active Load Control in Islanded Microgrids Based on the Grid Voltage,”, IEEE Trans. Smart Grid, vol. 2. March, 2011.

[4] The World Bank. Washington, DC, World development report 2010, Development and climate change 2010, [Online]. Available: [Online]. Available: http://go.worldbank.org/ZXULQ9SCC0

[5] R.H. Lasseter, P. Piagi, “Microgrid: A Conceptual Solution,”PESC’04 Aachen, Germany, June 2004.

[6] H. Feroze, "Multi-agent systems in microgrids: Design and implementation," M.S. thesis, Dept. Elect. Eng., Virginia Polytechnic Institute and State Univ., United States, 2009.

[7] R.H. Lasseter and P. Piagi: “Control and Design of Microgrid Components”, Dept. Elect. and Comput. Eng., Univ. Wisconsin-Madison., January 2006.

[8] N. Smith (1994). Motors as Generators for micro hydro power [Online]. Available:http://www.pssurvival.com/ps/Motors/Induction_Motor_Gen/Motors_As_Generators_N_Smith_UK_1994.pdf

[9] A.P.S. Meliopoulos, “Challenges in simulation and design of microgrids,” in *Proc. IEEE Power Eng. Soc.Winter Meeting*, vol. 1, New York, 2002, pp. 309–314

[10] P.J. Binduhewa, B. Mike and R. Alasdair,” Standard Microsource Iinterface For a Microgrid”, CIRED Seminar., Smart Grids for Distribution, Frankfurt., 2008, pp. 23 – 24.

[11] M.K. Kouluri and R.K. Pandey, "Intelligent agent based micro grid control," Intelligent Agent and Multi-Agent Systems (IAMA), 2011 2nd International Conference on, Chennai, 7-9 Sept. 2011, pp.62,66.

[12] M. Elbaz and A. Feliachi, “Real Time Load FrequencyControl for an IsolatedMicrogrid System”, North American Power Symposium (NAPS), 2012, pp. 1-6.

[13] A. Madureira, C. Moreira, and J. A. P. Lopes, "Secondary load-frequency control for microgrids in islanded operation", Proc. Int. Conf. Renewable Energy Power Quality, Portugal, 2005.