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Development of a mas based distributed intelligent control and fault control strategy for microgrid

Mikroşebeke için mas tabanlı dağıtılmış akıllı kontrol ve hata kontrol stratejisinin geliştirilmesi

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Development of a MAS Based Distributed Intelligent Control and Fault Control Strategy for Microgrid

Highlights

- *JADE platformunda mikroşebeke sistemi için çoklu-etmen sistemin tasarımı ve geliştirilmesi Design and development of multi-agent system for Microgrid system on JADE- platform*
- *Mikro Şebeke için arıza kontrol stratejisinin geliştirilmesi Development of fault control strategy for Microgrid system*
- *Çoklu-etmen sistemi kullanarak mikroşebeke sisteminin güç akışı kontrolü Power flow control of Microgrid system using multi-agent system*

Graphical Abstract

Multi-agent system based distributed control and detecting fault in the microgrid system is presented in this paper.

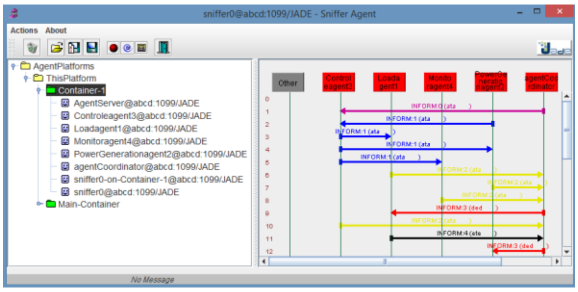

Figure. 17. Cooperation among agents

Aim

Makalenin amacı, mikroşebekenin çoklu-etmen sistem tabanlı akıllı kontrolünü geliştirmek ve tasarlamaktır. /The purpose of the paper is development and design MAS-based intelligent control of Microgrid system.

Design & Methodology

Mikro şebeke sisteminin modellenmesi, simülasyonu ve kontrolü MATLAB/Simulink ve JADE platformunda uygulanmış. MACSimJX arayüzü, MATLAB/Simulation ve MAS'ın birbirine bağlanması için kullanılmış. Modeling and simulation of microgrid system are implemented on MATLAB/Simulink and JADE-platform. MACSimJX interface is utilized for interconnection of MATLAB/Simulation and MAS.

Originality

Arızalar sırasında Mikroşebekenin güç akışının simülasyonu ve kontrolü, şebekeye bağlı moddan otonom moduna sorunsuz geçiş sağlamak için MATLAB/Simulink, MACSimJX ve JADE platformları kullanılarak geliştirilmiştir. / Simulation and control of power flow of Microgrid during faults are developed using MATLAB/Simulink, MACSimJX and JADE platforms to provide seamlessly transition from grid-connected to an island mode.

Bulgular (Findings)

MAS-based intelligent control of Microgrid system provides intelligent control of power flow during faults and smoothly transfer from grid-connected to islanded operation mode. / Çoklu-etmen tabanlı mikroşebeke sisteminin akıllı kontrolü, arızalar olduğunda güç akışının akıllı kontrolünü ve şebekeye bağlı moddan ada işletim moduna sorunsuz bir şekilde aktarılmasını sağlamak.

Conclusion

This study suggested fault control strategy for Microgrid utilizing distributed multi-agent system. MAS-based intelligent control of Microgrid system provides intelligent control of power flow if there are faults and smoothly transfer from grid-connected to islanded operation mode.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Mikroşebeke İçin Mas Tabanlı Dağıtılmış Akıllı Kontrol ve Hata Kontrol Stratejisinin Geliştirilmesi

Araştırma Makalesi / Research Article

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ÖZ

Çoklu-Etmen-Sistem (MAS) teknolojisi, proaktivite, esneklik, reaktivite ve sosyallik gibi birçok çekici özelliğe sahiptir. Bir mikroşebeke platformu içinde verimli ve etkili yönetim ve otomasyon süreçlerini uygulamak için teknoloji platformu olarak kapsamlı bir şekilde kurulmuştur. Bu makale, MAS platformuna sahip MATLAB-Simulink yazılımı kullanılarak mikroşebeke sisteminin tasarımını ve geliştirilmesini sunmaktadır. MAS yazılımını uygulamak için JAVA Etmen Geliştirme Çerçevesi (JADE) kullanılır. MAS, enerji kaynağı etmeni, yük etmeni ve kontrol etmeni dağıtımından oluşan üç etmenden meydana gelir. Dağıtılmış etmen, mikroşebekedeki farklı enerji kaynaklarının güç seviyesini izlemek ve kontrol etmek için kullanılır. Yük etmeni, tüketicinin güç tüketim seviyesini izlemek için kullanılır. Enerji kaynağından yüke giden güç akışını kontrol etmek ve aynı zamanda sistemin anormalliğine dayanarak güç ağını yeniden yapılandırmak için ise kontrol etmeni kullanılır. Geliştirilen sistemin etkinliğini test etmek için, mikroşebeke sisteminin farklı çalışma koşulları için simülasyon çalışmaları yapılmıştır. Test sonucuna göre, geliştirilen sistemin her açıdan daha iyi performans gösterdiği görülmektedir.

Anahtar Kelimeler: Dağıtılmış Enerji Kaynağı (DER), dağıtılmış kontrol, hata kontrolü, MACSimJX ve JADE, Çoklu-Etmen Sistemi (MAS).

Development of a Mas Based Distributed Intelligent Control and Fault Control Strategy for Microgrid

ABSTRACT

The technology of Multi-Agent-System (MAS) has a lot of attractive qualities such as proactivity, flexibility, reactivity and sociality. It is extensively established as the technology platform for implementing efficient and effective processes of management and automation within a microgrid platform. This paper presents the design and development of the microgrid system using MATLAB-Simulink software with multi-agent system platform. The JAVA agent development framework (JADE) is used for implementing MAS software. MAS consist of the three agents are distributed energy source agent, load agent and control agent. The distributed agent used to monitor and control the power level of the different energy sources in the microgrid. The load agent used to monitor the power consumption level of the consumer. The control agent used to control the power flow from energy source to load and also used for restructuring the power network based on abnormality of the system. To test the effectiveness of the developed system, simulation studies are carried out for different operating conditions of the microgrid system. From the test result, the developed system outperform in all aspect.

Keywords: Distributed Energy Resource (DER), distributed control, fault control, MACSimJX and JADE, Multi-Agent System (MAS).

1. INTRODUCTION

It is expected that the interest in microgrid will show a significant growth as distribution networks have been penetrated by the distributed power resources [1, 2].

A significant concern is how to incorporate the various distributed energy resources into the existent distribution networks by a proper coordination of their generators or the operation of their storage units and through curbing their possible adverse effects on both, network operation and control [3]. Distributed power resources are very fickle and hard to predict with sureness, therefore there is a fluctuation of power with passage of time. Because of the variety in generation and loads, the microgrids show excessive nonlinearities, unstable dynamics as well as uncertainties which necessitate advanced potent and intelligent control strategies to resolve it [4, 5].

Conventional supervisory control and data acquisition (SCADA) has a principal controller that collects entire system information for decision making. SCADA is incompetent for coping with the extensive infiltration of intermittent sustainable sources of power as well as intricate control decisions as a result of lacking the flexibility and extensibility [6].

Current energy systems shifted towards more decentralization in generation, changeable market activities as well as more complicated distribution techniques, so it became hard to use central control to manage the network [7]. The technics of multi-agent system (MAS) grants a resolution for developing power

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distributed control in the electrical networks through safe and credible network operations under variation operational statuses. Multi-agent systems provide their ingrained advantages of resilience, extensibility, independency and more and also overcome the problem of the conventional supervisory control. MAS is composed of abundant numbers of agents which function in dynamic environments. These agents can operate in the environment, work with other agents to accomplish particular goals, and recognize alterations in the environment [8, 9].

Multi-agent system based distributed control and detecting fault in the micro grid system is presented in this paper. During abnormalities in the power network, the multi-agent system detects the faults and sent the response signal to the corresponding circuit breaker to disconnect the microgrid from the grid i.e., island mode and also used to disconnect the non-critical load from the power system to protect the critical loads. During normal operating conditions of the power network, the multi-agent system act as distributed controller i.e., the agent monitor load power and control the distributed energy sources for attaining the maximum efficiency of the microgrid system.

This article is structured as the following: the overall system explained in the section 2. The Simulink model of the proposed distributed and fault control using MAS in microgrid is described in the section 3. The simulation results are presented in the section 4. Concluding remarks are presented in the section 5.

2. THE PROPOSED DISTRIBUTED AND FAULT CONTROL USING MAS IN MICROGRID SYSTEM

Many suggestions were implemented to control microgrids utilizing multi-agent system. The primary precept of the suggested approach is to design a representative agent for each component of the microgrid, and one extra agent, which controls and represents the microgrid in its outer environment (main grid). The suggested methodology of this study is depended on the ability of data interchange among agents and their associated elements in the microgrid. This interchange of data is bi-directional, the first direction to regain measures (power, voltage, current, etc.) and the second direction works upon the physical part of the microgrid, so as to execute various tasks as connect/disconnect and to change the operation modes of the microgrid (grid mode- island mode). So, the multi-agent system submits the intelligent interface of the microgrid, when each agent is installed in a system set up with its associated element in the microgrid.

As portrayed in Figure 1, the microgrid model comprises two distributed energy resources (PV panels with battery storage and generator) and three loads. The elements of the microgrid are represented by local agents: power generation agent for distributed energy resources, load agent for loads, control agent to control point common coupling (PCC) and monitoring agent for the microgrid.

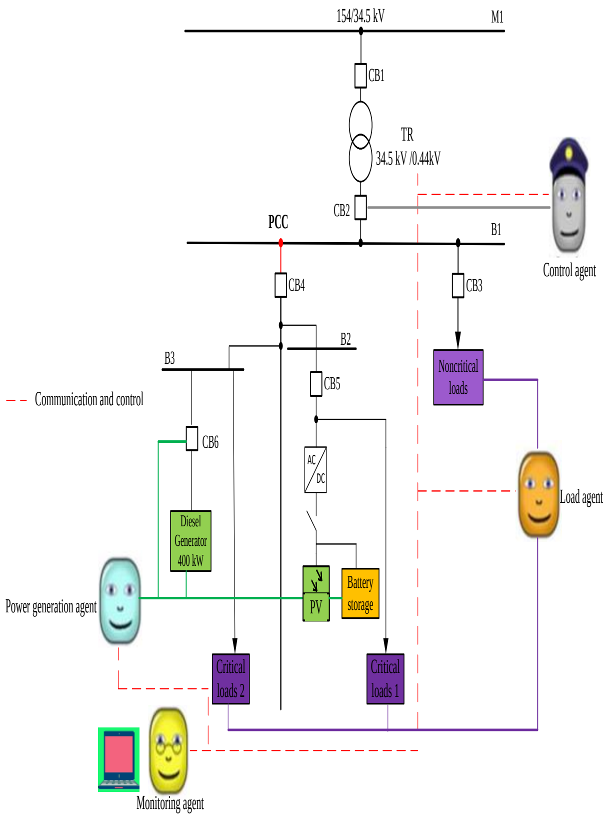

Figure 1. Distributed and fault control using MAS in microgrid system

2.1. Distributed Control

Distributed control is a way to divide complex control tasks into small control tasks assigned to several entities. Also, the technique of the decentralized control presents many essential advantages such as expandability and openness of the system, non-intensive computing, and minimum data interchange with the central server.

The precept of the suggested management approach (distributed control) depends on information exchanged by messages between agents to make appropriate decisions. The suggested algorithm for the management of operation is exhibited in Figure 2. It is imperative to take note that the drawn graph shows both the program of management and the cooperation among agents.

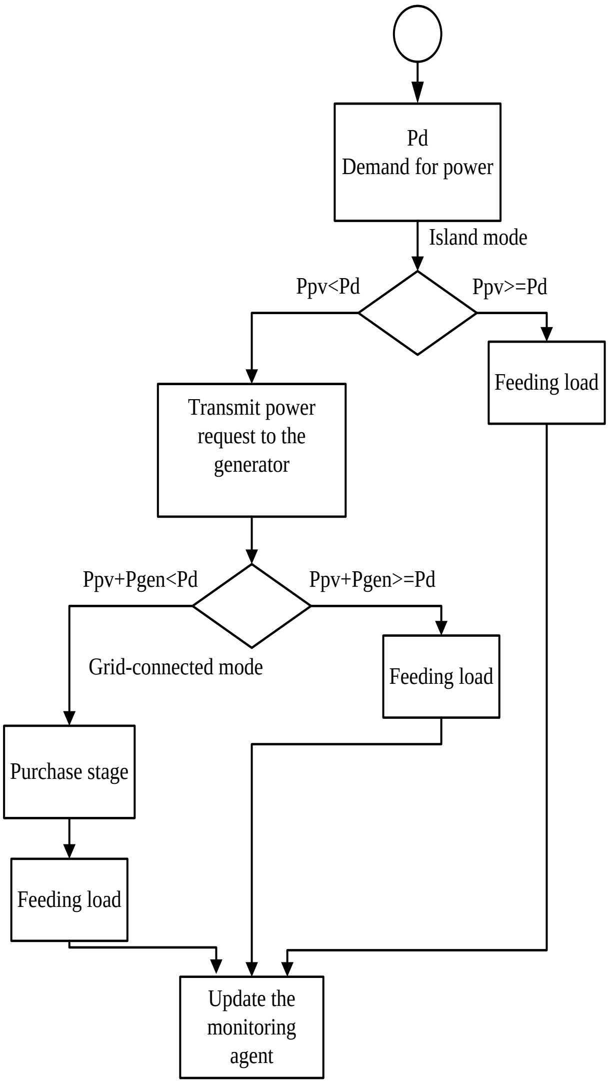

Figure 2. Distribution control of microgrid.

Where: Pd is demand for power, Ppv is the produced power from PV panels and Pgen is the produced power from the generator. The multi-agent system should be capable to manage events, for example, the demand for power. For this event, and as we know there are two operation modes for microgrid; grid-connected mode and island mode. In this study, two cases are possible for island mode:

- If the amount of power from the PV panels is greater than or equal to the demand for power Pd, loads are fed based on the messages exchanged between the power generation agent and load agent.
- If not enough the power generation agent sends power demand to the generator to be compensated for power shortages.
- If the amount of power from PV panels and generator is not enough to feed all loads, the management of this case relies upon the operation mode. The control agent connects the main grid to the microgrid and starts a power purchase stage. The multi-agent system takes decisions dependent on an optimization algorithm which determines the minimal cost of power.

2.2. Fault Control

In this case, the fault in the system is isolated using following algorithm and it is shown in Figure 3.

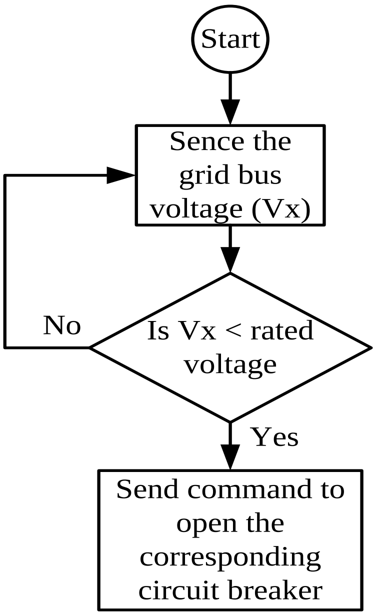

Figure 3. Flowchart for fault control in microgrid

In this algorithm, sense the voltage of the grid bus and it is processed via multi agent platform. In multi-agent system, the sensed voltage is compared with rated voltage of the grid bus. If actual voltage is less than rated voltage than multi-agent system sends the command signal to open the corresponding circuit breaker.

3. SIMULINK MODEL OF THE PROPOSED DISTRIBUTED AND FAULT CONTROL USING MAS IN MICROGRID SYSTEM

To implement the suggested MAS, a test bed was simulated in Matlab/Simulink in form of a distribution network comprised of two DERs (PV panels 24 kW and emergency generator 400 kW), grid interface for connecting the PV panels to the network (MPPT controller, boost converter and inverter), three loads (critical load1 17 kW, critical load 219.5 kW and non-critical load 520 kW) these loads have been connected to circuit breakers to control it and a step-down transformer (31.5 kV/400 V, 800 kW), these are shown in Figure 4. Using the MAS makes the system to be more controlled and boost the system intelligence since it divides the complex task into small ones assigned to several entities (agents). It performs actions in compliance with messages exchanged between its agents.

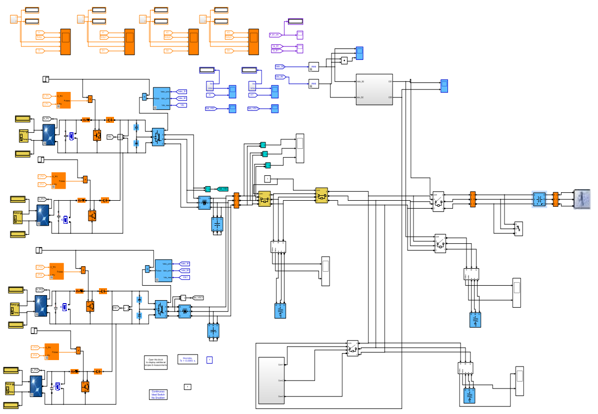

Figure 4. Matlab/Simulink model of proposed distributed and fault control using MAS in microgrid system

3.1. PV System Model

Model of the grid connected PV system is shown in the Figure 5. The system consists of the four PV panel, DC-DC converter, incremental conductance MPPT algorithm, battery storage system, three level voltage source inverter. The P-V and I-V characteristics of the PV panel are shown in the Figure 6. The output power of the PV panel depends on the irradiance level and temperature. In this system, temperature is fixed at 25°C and irradiance level is varied dynamically. For 1000 W/m^2 irradiance level, PV panel supply 6 KW of power and power level decreases as decreases in irradiance level.

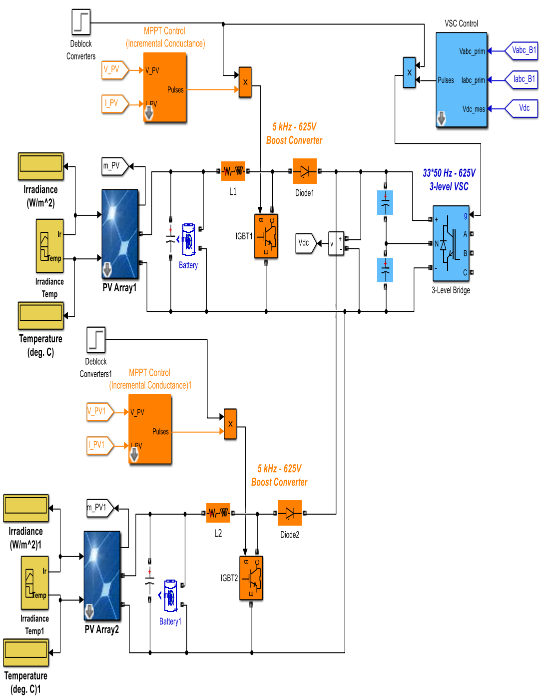

Figure 5. Simulink model of the PV system

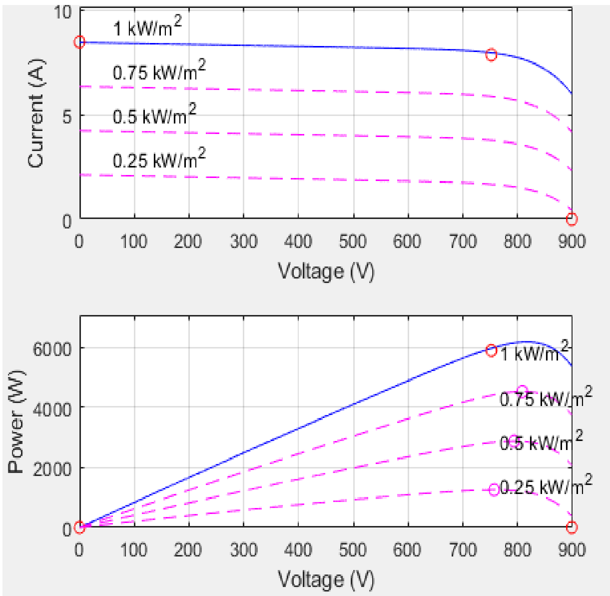

Figure 6. I-V and P-V characteristics of the single PV panel

3.2. Emergency Diesel-Generator Model

The figure 7 shows the emergency diesel-Generator model. This model consists of the diesel engine governor, excitation control and permanent magnet synchronous generator. The diesel engine governor used to supply the mechanical power to generator for rotates the rotor and it is proportional to real power generation of the generator. Excitation is used to supply the excitation current to rotor to induce the voltage in the stator of the generator. The permanent magnet synchronous generator used to generate the three-phase electrical power based on mechanical input from diesel engine and excitation system [10].

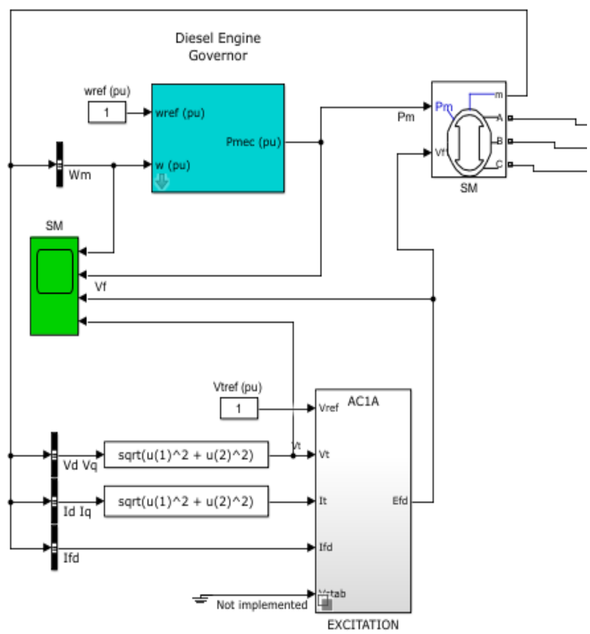

Figure 7. Simulink model of the emergency diesel generator

3.3. Utility Grid Model

The utility grid model is shown in Figure 8.

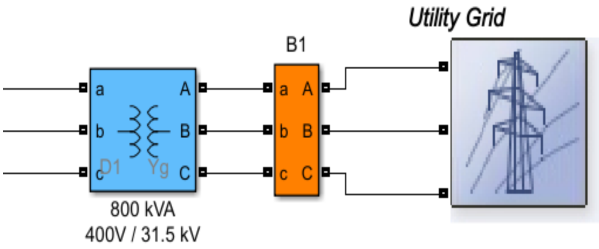

Figure 8. Simulink model of the Utility Grid

This model consists of three phase programmable voltage source, two step down transformer. The ratings of the three phase programmable voltage is 75MVA, 50 Hz, 154kV, the rating of the first transformer is 47 MVA , 154 kV / 31.5 kV, and the rating of the second transformer 800 kVA, 400V / 31.5 kV.

3.4. Multi-Agent System

The MAS was designed adopting the platform JAVA Agent Development Framework, abbreviated as (JADE). This is a JAVA frame used to create multi-agent systems in agreement with the foundation for intelligent physical agent (FIPA) features [11, 12]. JADE provides an appropriate distributed platform to the designers to concentration on developing agents to control and monitor the operation of the microgrid [13].

JADE is an open source platform which can promote plug and play competencies as well can be scaled without greatly modifying control scheme [14]. The agent exists inside a container and a group of containers forms a platform. Agent management service (AMS) is in charge of the management of the platform of the agents, which will maintain a directory of agent identifiers (AIDs) as well as agent situations. Every agent has to be registered in an AMS to obtain a proper agent ID. A directory facilitator (DF) offers the essential basic yellow page services inside the platform, which permits the agents of discovering the other ones in the network in accordance with the services they require [15]. Figure 9 shows JADE platform.

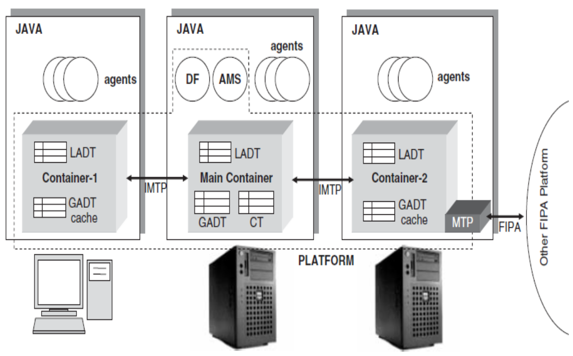

Figure 9. JADE platform [16]

3.5. Multi Agent Control for Simulink with JADE Extension (MACSimJX) Middleware

Within MATLAB/ Simulink, the S- functions are incapable of handling many execution threads, which represents a core feature of MAS: they become not stabilized when a number of processes operate in the same time inside Simulink. For overcoming this issue, we utilize an interface MACSimJX, in order to act as a link between models of system simulated in Simulink and the MAS, turning MAS as close as possible to the practicable implementations [17].

MACSimJX contains client-server structure, which separates the MAS from Simulink as displayed in Figure 10.

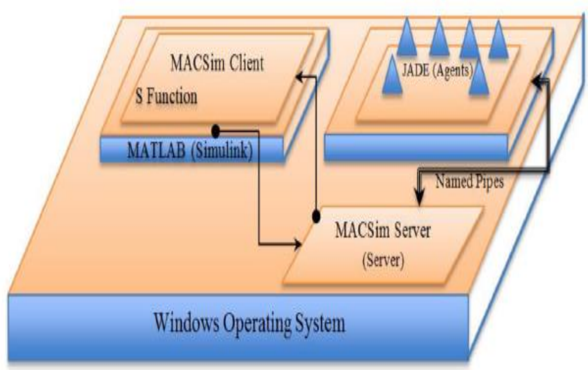

Figure 10. MACSimJX structure [18]

DERs take advantage of a decentralized approach of MAS for concurrent running in order to enhance the operational proficiency of the microgrid. In Simulink the S function permits programs scripted in other languages such C++ and JAVA to operate on MATLAB [19]. For that reason, the agents are possible to be created in JAVA and operate on Simulink. MACSim uses the S function capability of Simulink but just as a gate to transfer data to JADE with parallel processing capability. Inside the client-server structure of MACSim, the client part is installed in Simulink through an S function and the server code is integrated in the independent program. The client and server communicate by using designated pipes in Windows operating systems. Pipes in use are two, one of them is used to pass configuration information while the other to pass simulation information. This permits that the two operations run without synchronization. The MACSim server handles the correspondent operations of JADE and passes information to and from the MACSim client, which is installed in Simulink by an S function [20, 21]. The Simulink logic of the MAS system is shown figure 11.

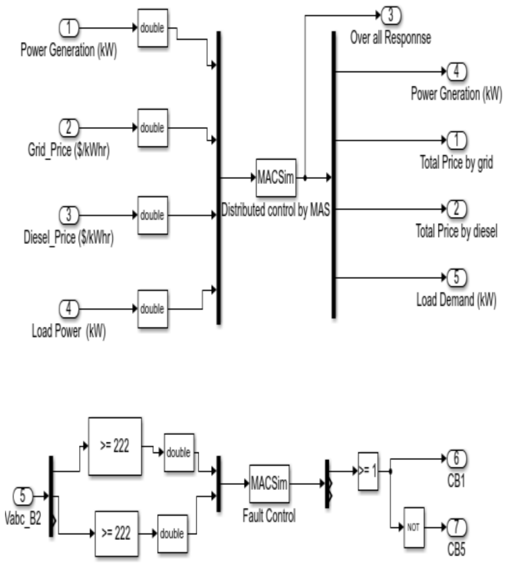

Figure 11. Simulink model of the Distribution and fault control using MAS

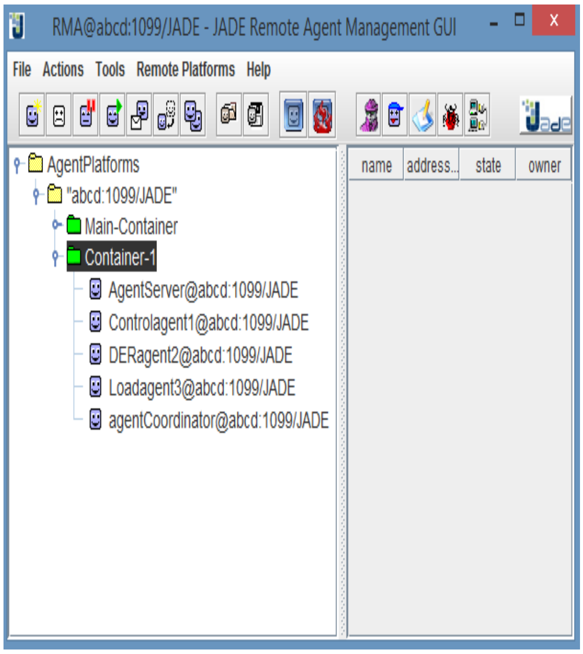

Figure 12. JADE remote agent management

4. SIMULATION RESULTS AND DISCUSSION

The Simulink model of the microgrid system with MAS is created using MATLAB 2015b platform in intel i3 processor having 2.3 GHz speed. The JAVA programming having created for distribution and fault control for implementing MAS via S-function option of the MATLAB software. Two case studies are considered to verify the effectiveness of the proposed distributed and fault control of the microgrid with MAS system such as case study 1: fault detection and isolation, and Case study 2: Power flow control. Case studies are explained as follows,

4.1. Case Study 1: Fault Detection and Isolation

A multi-agent system was executed and merged with microgrid simulation model. Disconnecting microgrid during fault status or power outage for securing loads with greatest priority (critical loads) with the available energy of distributed energy resources is the main goal of the multi-agent system. In islanded operation mode, if the loads are greater than the capacity of distributed energy resources, then non-critical loads should be disconnected. For the purpose of examining the operation of the multi-agent system and to estimate its functioning, a microgrid was simulated and multi-agent system performs its task. Figure 12 displays the agents exist in the container of JADE and is prepared to start.

Once as the simulation begins, the agents initiate communications and share information between each other and JADE exchange information with Matlab/Simulink through MACSimJX. Figure 13 demonstrates a graphical user interface (GUI) of the sniffer agent, which is a tool used to document conversations between agents. The left side of Figure 13 is similar to the browser that of the remote management agent in Figure 12. The right side shows a graphical performance of the messages interchanged between agents, where each arrow represents a message.

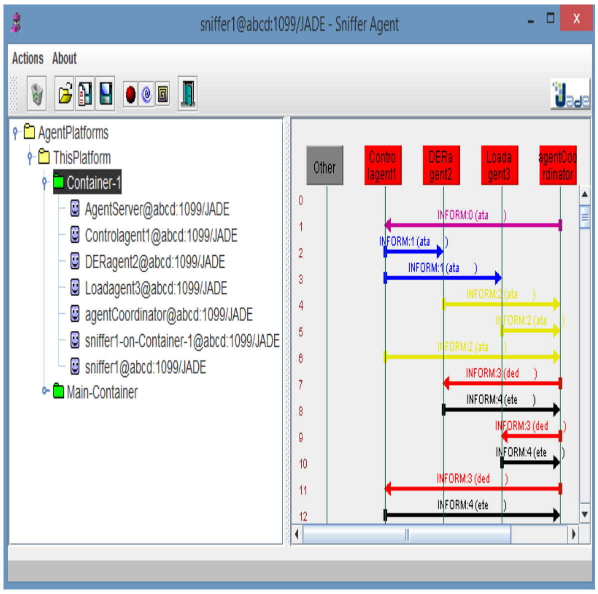

Figure 13. Sniffer agent GUI

4.1.1. Fault scenarios

The results of simulation exhibit the MAS capability of disconnecting the microgrid from the main grid and ensuring flow power for critical loads once the power interruption nearby the main grid takes place. Figure 14 demonstrates the variation of voltage waveforms before and after upstream blackout enforced to the network at 0.05 sec and cleared at 0.09 sec, again upstream blackout between t=0.3 sec to t=0.34 sec.

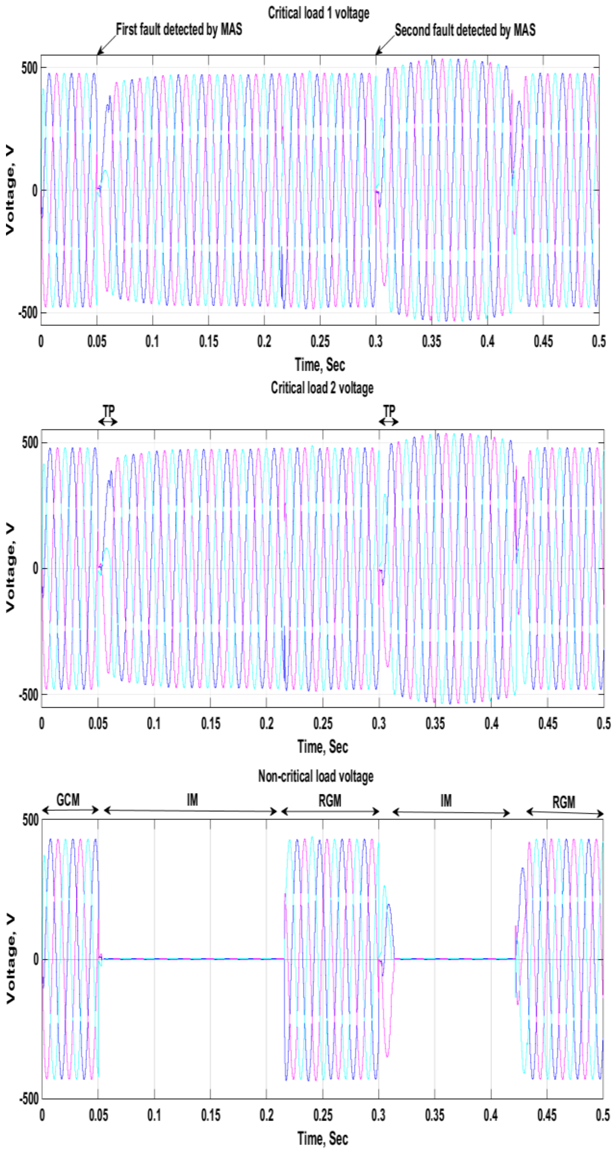

Figure 14. Simlation results (Upper graph) critical loads1 voltage, (Middle graph) critical loads2 voltage, (Lower graph) non-critical loads voltage

Within the first 0.05 seconds, the system is in the grid-connected mode. At the second 0.05, a fault occurred and control agent sensed the alterations by sensing the voltage of the system from the physical circuit in a simulated microgrid and it exchanged data between agents and control signal is put into effect in order to disconnect the microgrid from the main grid by opening the main circuit breaker. The fault case was revealed when the voltage level went lower than the preset limit.

4.1.2. Agents operation

The operation of agents can be divided into four scenarios as the following:

4.1.2.1. Grid-connected mode (GCM)

Both voltage and frequency of microgrid are controlled to pursue the voltage and frequency of the main grid, which are 400 V, 50 Hz respectively. The total loads of the microgrid are 775 kW divided into 235 kW critical loads1, 20 kW critical loads2 and 520 kW non-critical loads as demonstrated in Figure 15.

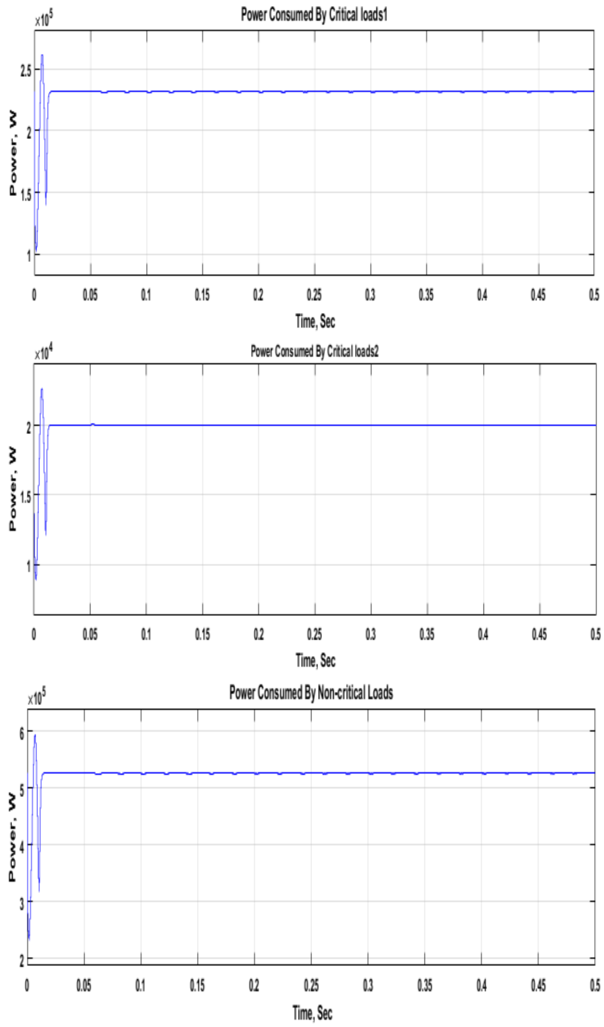

Figure 15. Power consume by microgrid loads

At the time when the grid-connected mode from t=0 sec to t=0.05 sec, the PV panels supplies 24 kW, the main grid supplies 800 kW and the generator will turn off. The entire power needed for both critical and non-critical loads is supplied by PV panels and main grid. More details about DERs and loads are displayed in table 1.

Table 1. Details of DERs and loads of microgrid.

DER	Units number	Min. Power. kW	Max. Power. kW
Diesel generator	1	375	400
PV Panel	4	21	24
Critical loads1	20	225	235
Critical loads2	3	17	20
Non-critical loads	35	500	520
Total		742	775

4.1.2.2. Transition period (TP)

Once the control agent senses the fault at t=0.05 sec, it notifies the DER and load agent. Control agent transmits the signal of control to the main circuit breaker to disconnect the microgrid from main grid and executes one more task by demand the power production and consumption from DER and load agent. In this study, the distributed energy resource agent connects generator of 400 kW to secure the critical loads. Load agent examines the consumed power from loads (critical loads and non-critical loads) if it is exceeding the produced power from distributed energy resources (PV and generator), it will disconnect the non-critical loads that is least priority.

4.1.2.3. Islanded mode (IM)

After the fault occurred at 0.05 sec, the main grid is separated and the microgrid will transform from grid-connected operation mode to islanded operation mode, the critical loads are fully fed from distributed energy resources (PV panels and generator). In islanded operation mode, both the frequency and voltage of critical loads are controlled at 440 V and 50 Hz respectively as shown in (Figure 14, Upper and Middle graph). The total load of the system is of 775 kW and the distributed energy resources (PV and generator) produce 424 kW to feed these critical loads. The rest of non-critical loads (520 kW) will be thrown out by the load agent for conserving the stabilization of the system.

4.1.2.4. Restoring to grid connected mode (RGM)

As soon as the voltage attains to the allowable value, the control agent senses it and it notifies to the DER and load agent. Control agent transmits the signal of control (closes) to the main circuit breaker to transform from islanded operation mode to grid-connected operation mode. Distributed energy resource agent sends the signal of control (opens) to disconnect the generator after coordination with the control agent. Load agent examines whether a sufficient power is available and reconnects the non-crucial loads as shown in (Figure 14, lower graph) in the intervals between t=0.23 sec to t=0.3 sec and from t=0.43 sec to t=0.5 sec. The control signals from JADE are directed to MATLAB/Simulink via the MACSimJX as shown in Figure 16.

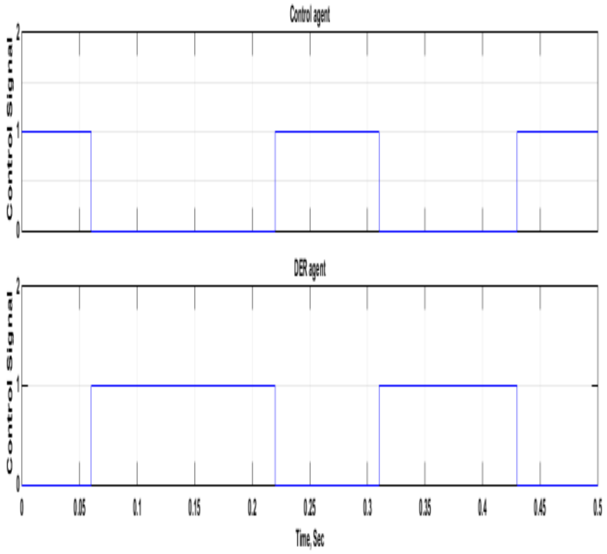

Figure 16. Control signals from JADE environment

4.2. Case Study 2: Power Flow Control

Make power balance between load demand and power generation with maximum efficiency and reduce cost is the main goal of the multi-agent system. Load profile setting (is a how much amount of maximum load connected to the system) with seven cases has been used for purpose of testing the proposed approach. The load profile setting is illustrated in table 2.

Based on load profile setting the amount of power that load generation units will supply to the loads is the main task of the MAS.

Table 2. Load profile setting

Time (Sec)	Load1 (kW)	Load2 (kW)	Load3 (kW)	Total(kW)
0-0.1	17	0	0	17
0.1-0.2	0	195	0	195
0.2-0.3	17	195	0	212
0.3-0.4	0	0	550	550
0.4-0.5	17	0	550	567
0.5-0.6	0	195	550	745
0.6-0.7	17	195	550	762

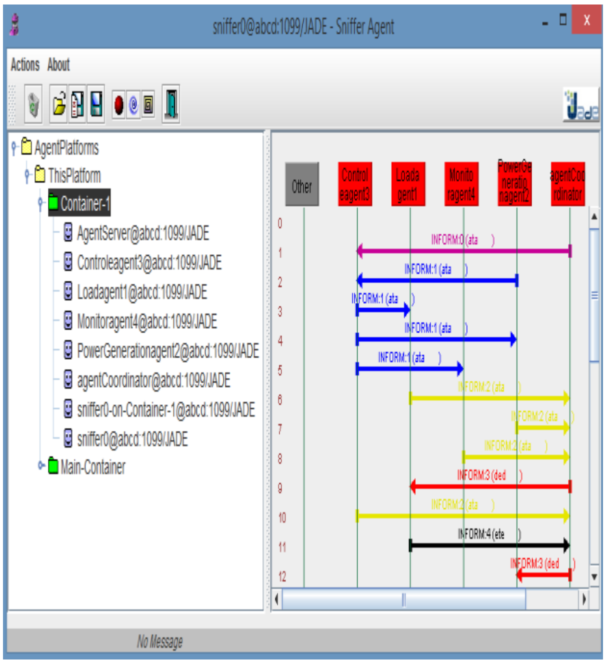

Figure 17. Cooperation among agents.

4.2.1. Agents operation

Once as the simulation begins, the agents initiate to perform their tasks. The agents initiate communications and share information between each other and JADE exchanges information with Matlab/Simulink through MACSimJX. Figure 17 demonstrates a graphical user interface (GUI) of the sniffer agent. The outcomes of performance of the proposed multi-agent system (Agents) have been displayed in three monitoring windows as shown:

4.2.1.1. Monitoring window 1 (performance of the suggested MAS)

This monitoring window contains four figures: Figure 18 shows the Load power of the system.

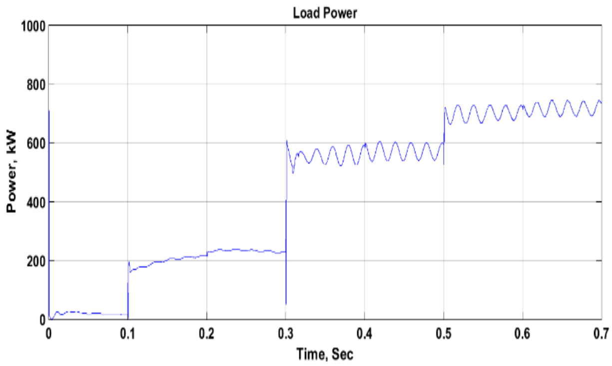

Figure 18. Load power of the system.

Figure 19 shows the generation power.

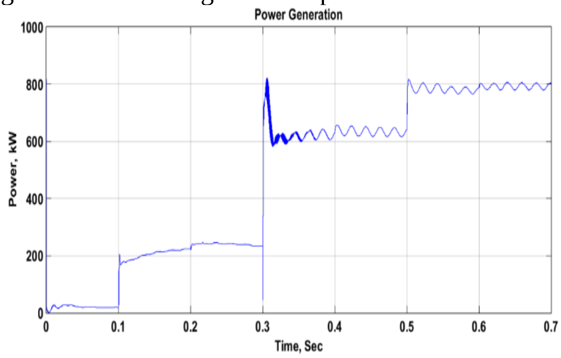

Figure 19. Power generation of the system

Figure 20 shows the balance power of PV panels + generator + main grid (total generation – actual load power). In other words, the balance power of PV panels + generator + main grid is how much power which will save after power supplied the required loads.

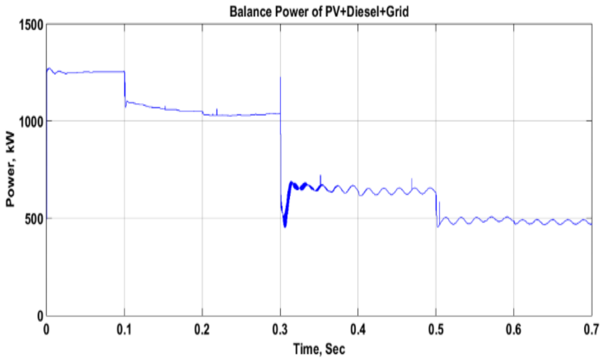

Figure 20. Balance power of PV panels + generator + main grid

Figure 21 shows the efficiency of the microgrid system (the ratio of actual load power to the power generation).

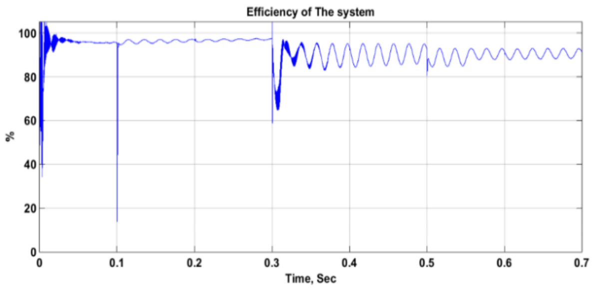

Figure 21. Efficiency of the system

4.2.1.2. Monitoring window 2 (control signals of the suggested MAS)

This monitoring window contains four figures: Figure 22 shows the Load profile of the system.

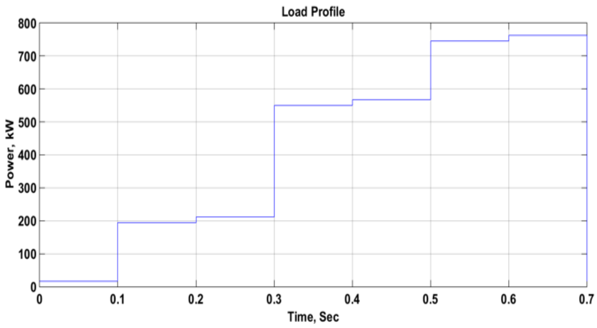

Figure 22. Load profile of the system

Figure 23. shows the PV ON and OFF conditions.

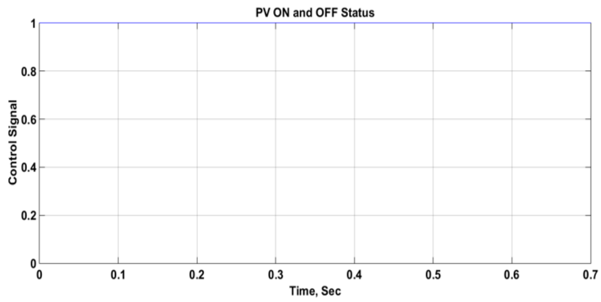

Figure 23. Control signals of PV panels

Figure 24. shows the generator ON and OFF conditions.

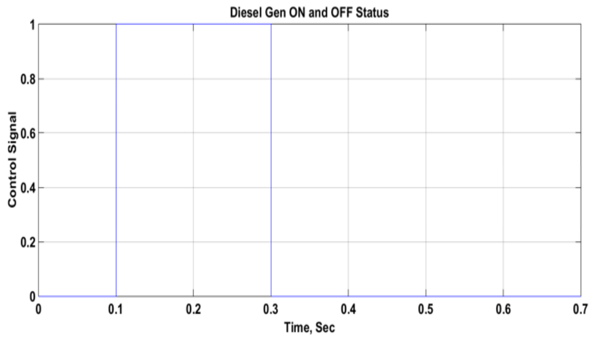

Figure 24. Control signals of the generator

Figure 25 shows the main grid ON and OFF conditions.

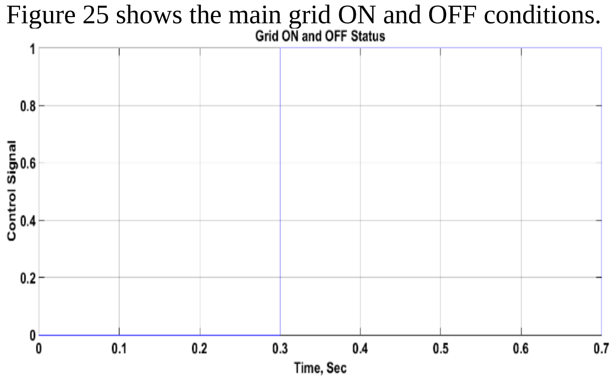

Figure 25. Control signals of the main grid

We can summarize these states in table 3 from monitoring windows 1, 2:

Table 3. Operation modes of the microgrid during different loads

Time (Sec)	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7
Load (kW)	17	195	212	550	567	745	762
Operation mode	Island mode	Island mode	Island mode	Grid mode	Grid mode	Grid mode	Grid mode

Time 0-0.1 Sec:

During this time load profile setting is 17 kW, actual load power is around 20 kW, power generation is around 20.9 kW, the efficiency of the system is 95.6 % and the connection is in an island mode. Figures 23, 24 and 25 show the control signal for PV panels is one and control signals for generator and the main grid are zero. Total load is 17 kW and PV panels can supply up to 24 kW and no need to purchase power from the main grid that's why the system is in an island mode.

Time 0.1-0.2 Sec:

During this time load profile setting is 195 kW, actual load power is around 210 kW, power generation is around 220 kW, the efficiency of the system is 95.4 % and the connection is in an island mode. Figures 23, 24 and 25 show control signals for generator and PV panels are one and control signal for the circuit breaker of the main grid is zero. The total load is 195 kW the PV panels and generator can supply up to 424 kW and no need to purchase power from the main grid.

Time 0.2-0.3 Sec:

During this time load profile setting is 212 kW, actual load power is around 225 kW, power generation is around 234 kW, the efficiency of the system is 96.1 % and the connection is in an island mode. Figures 23, 24 and 25 show control signals for generator and PV panels are one and control signal for the circuit breaker of the main grid is zero. The total load is 212 kW the PV panels and generator can supply up to 424 kW and no need to purchase power from the main grid.

Time 0.3-0.4 Sec:

During this time load profile setting is 550 kW, actual load power is around 588 kW, power generation is around 628 kW, the efficiency of the system is 93.6 % and the connection is in a grid- connected mode. Figures 23, 24 and 25 show control signals for PV panels and the main grid circuit breaker are one and the control signal for the circuit breaker of the generator is zero. The total load is 550 kW the PV panels and generator can supply up to 424 kW but the current load is 550 kW so the PV panels and the main grid will supply the power to the load and the generator is in shut off condition.

Time 0.4-0.5 Sec:

During this time load profile setting is 567 kW, actual load power is around 590 kW, power generation is around 650 kW, the efficiency of the system is 90.7 % and the connection is in a grid- connected mode. Figures 23, 24 and 25 show control signals for the PV panels and main grid are one and the control signal for the circuit breaker of the generator is zero. The total load is 567 kW the PV panels and generator can supply up to 424 kW but the current load is 567 kW so the PV panels and the main grid will supply the power to the load and the generator is in shut off condition.

Time 0.5-0.6 Sec:

During this time load profile setting is 745 kW, actual load power is around 730 kW, power generation is around 787 kW, the efficiency of the system is 92.7 % and the connection is in a grid- connected mode. Figures 23, 24 and 25 show control signals for PV panels and main grid are one and the control signal for the circuit breaker of the generator is zero. The total load is 745 kW the PV panels and the generator can supply up to 424 kW but the current load is 745 kW so the PV panels and the main grid will supply the power to the load and the generator is in shut off condition.

Time 0.6-0.7 Sec:

During this time load profile setting is 762 kW, actual load power is around 745 kW, power generation is around 803 kW, the efficiency of the system is 92.7 % and the connection is in a grid- connected mode. Figures 23, 24 and 25 show control signals for PV panels and main grid are one and the control signal for the generator is zero. The total load is 767 kW the PV panels and generator can supply up to 424 kW but the current load is 762 kW so the PV panels and the main grid will supply the power to the load and the generator is in shut off condition.

4.2.1.3. Monitoring windows 3 (Loads windows*)*

Load 1 Window: It contains three figures: Figure 26 shows the instantaneous voltage across load 1.

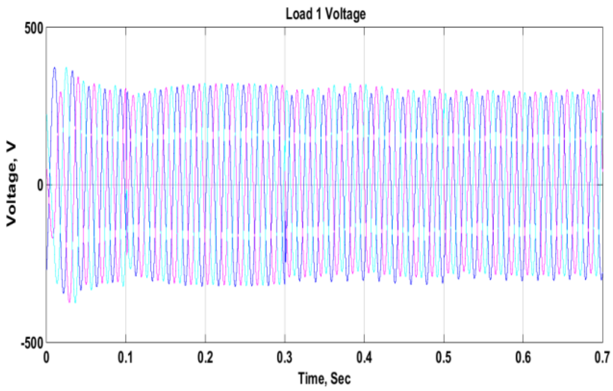

Figure 26. The instantaneous voltage across load 1

Figure 27 shows the instantaneous current through load 1.

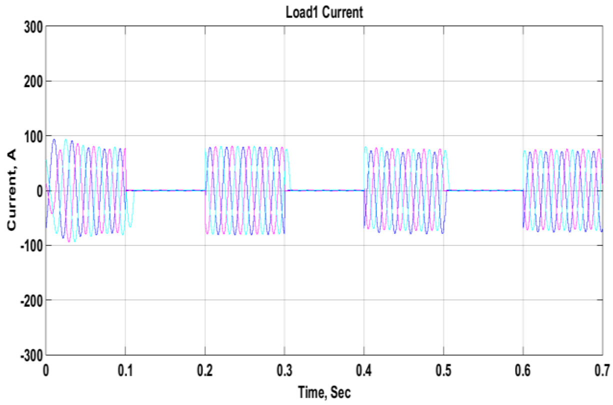

Figure 27. The instantaneous current through load 1

Figure 28 shows the actual power for load 1. Load 1 is connected to system during these periods 0-0.1, 0.2-0.3, 0.4-0.5 and 0.6-0.7 Sec as per load profile setting in Table 2.

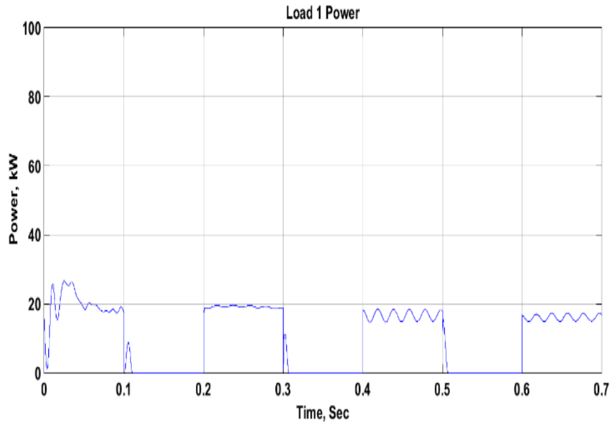

Figure 28. The actual power for load 1

Load 2 Window: It contains three figures: Figure 29 shows the instantaneous voltage across load 2.

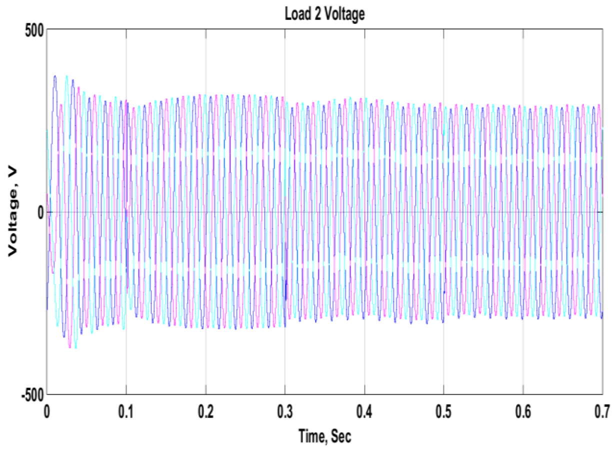

Figure 29. The instantaneous voltage across load2

Figure 30 shows the instantaneous current through load 2.

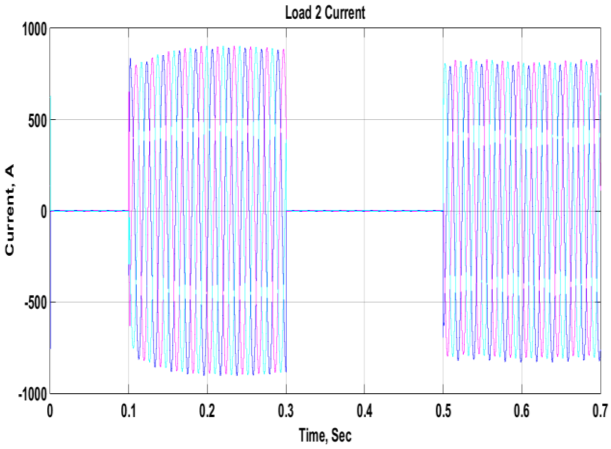

Figure 30. The instantaneous current through load 2

Figure 31 shows the actual power for load 2.

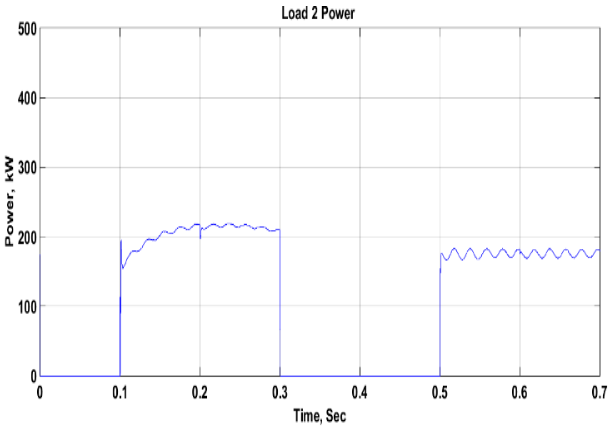

Figure 31. The actual power for load 2

Load2 is connected to the system during these periods 0.1-0.3 and0.5-0.7 Sec as per load profile setting in Table 2.

Load 3 window: It contains three figures: Figure 32 shows the instantaneous voltage across load 3.

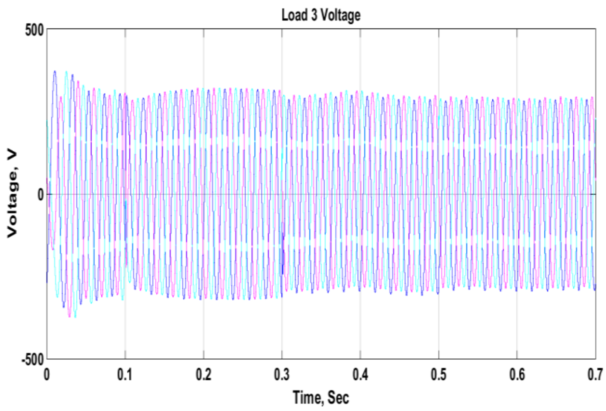

Figure 32. The instantaneous voltage across load 3

Figure 33 shows the instantaneous current through load 3.

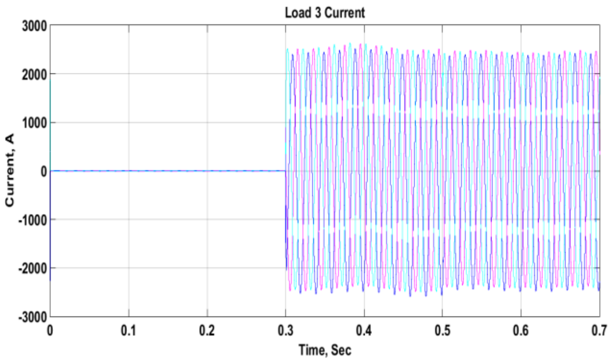

Figure 33. The instantaneous current through load 3

Figure 34 shows the actual power for load 3. Load3 is connected to the system from 0.3 to 0.7 Sec as per load profile setting in the Table 2.

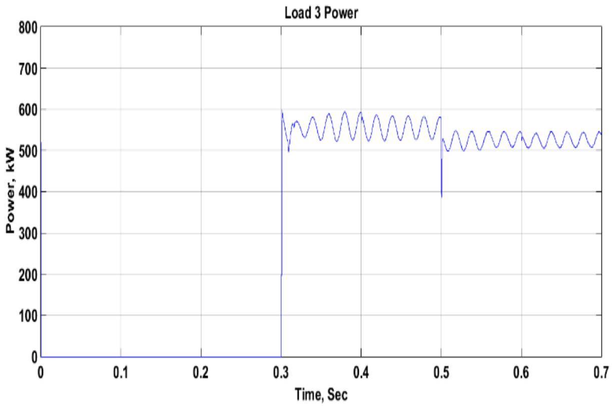

Figure 34. The actual power for load 3

From these two case studies, the developed control techniques for fault control and distribution control using MAS is effectively control the operation of the microgrid system.

5. CONCLUSION

This study suggested a management approach of microgrid utilizing techniques of the multi-agent system. In light of the distributed nature of microgrid, the multi-agent system offers an appropriate intelligent interface for the microgrid. The task of this interface is to ensure the power balance between the demand for power and supply in both operation modes of the microgrid and also work perfectly during fault conditions. A management algorithm based on agent's negotiations has been implemented. A multi-agent system has been developed which contains four agents control agent, power generation agent, load agent and monitoring agent to manage and control the power flow from and to the microgrid. These agents can interact and take appropriate decisions depending on the information exchanged by messages between agents. The MAS was developed in the JADE environment in order to control microgrid simulated in MATLAB/Simulink. MACSimJX was used to act as an interface among the microgrid in the

Matlab/Simulink and the agents in the JADE environment. The simulation outcomes exhibited the capability of the multi-agent system to make a power balance among load demand and power generation with maximum efficiency and reduce fuel cost and also work effectively during fault conditions.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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