Control of a Micro-Grid Based on Distributed Cooperative Control of Multi-Agent System

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***Abstract*— This paper focuses on proposing a multi agent system to control distributed in a microgrid aimed at intentional islanding and Load-Shedding. The multi agent system consists of three main agents such as Control, DER (Distribution Energy Resource) and Load agent. Each agent serves the different responsibility that will discuss in this paper. The proposed multi agent based control architecture is developed using the JADE platform and it is used to control a microgrid simulated in MATLAB/SIMULINK. To enable Microgrid model in Matlab/Simulink to exchange data with Multi-agent created under JADE Platform, the MACSimJX has been used. In order to validate the effectiveness of the proposed method, investigations are carried out for islanding scenarios simulated on the test network. The results of this study show the capability of developing a reliable control mechanism for islanding operation of microgrids based on the proposed concept.**

***Index Terms*—Microgrid, Multi-agent, Jade, Macsimjx, Load-shedding, distributed energy resources (DER), distributed generations (DGs).**

I. INTRODUCTION

Nowadays, the increase in the demand of electricity and the increase in frequency of natural hazards or fault are the mains problem in power system. As reported in [1], It show that world energy consumption will grow by 56 percent between 2010 and 2040. Total world energy use rises from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040. With this matter, it makes the security and resiliency of electric power supply to serve critical facilities are of high importance in today's world. Instead of building large electric power grids and high capacity transmission lines, an intelligent microgrid can be considered as a promising power supply alternative.

A Microgrid is a new type of power system, which is formed by the interconnection of various small-distributed energy resources (DERs). It can operate both in grid-connected mode, and island mode if disconnected from the grid [2]. However, there are multiple distributed energy resources (DERs) with significantly different power capacities and generation characteristics in a microgrid so they need a suitable control system; diverse control strategies exist in grid-connected mode, island mode. Therefore, how to control DERs in a microgrid efficiently and feasibly must be of prime consideration in microgrid design and operation.

In order to provide these local distributed control capabilities, development of distributed control systems are essential. Multi Agent Systems (MAS) is a technology coming forward in this aspect. MAS have been developed for a wide range of applications in power systems [3]. The use of MAS in microgrid applications has been evolving over the last decade with considerable amount of work being carried out regarding distributed control applications for microgrids [4]. Multi agent systems are complex systems composed of several autonomous agents with only local knowledge and limited abilities but are able to interact in order to achieve a global objective. These agents are able to act as autonomous social entities, which react to changes in their environment and take intuitive actions in order to realize their individual goals. The aim of a multi agent based control system is to apply this individual goal seeking in a manner such that the overall target required by the user is achieved efficiently and effectively as possible.

Since Microgrid become a potential part in Power system, many researches has been conducted in order to switch microgrid in islanding mode and perform load shedding such as [5]-[8]. Those researches based on TCP/IP to allow exchanging data between multi-agent system and microgrid simulation model.

In this research, the agents are incorporated in microgrid through a middleware called, MACSimJX. It means that the simulated microgrid and the agents exchange information and command through MACSimJX.

This paper is organized as follows: in the section II, An overview of microgrid systems is presented, A brief discussion about Multi-agent System architecture is presented in section III. The Integration of Multi-agent and Microgrid simulation model presented in Section IV. Section V describes the simulation carried out and their results, Finally the conclusions are given in section VI.

II. OVERVIEW OF MICROGRID

Microgrids are small-scale power system designed to supply electrical to loads for a small community, such as a housing estate or a suburban locality, or an academic or public community such as a university or school, a commercial area, an industrial site, a trading estate or a municipal region. Micro-grids can be created by embedding small-scale conventional generation units or Non-Conventional Renewable Energy Sources (NCRES) to existing electrical infrastructure. These NCRES can be mini-hydro, solar photo-voltaic (PV), wind, geo-thermal, small internal combustion (IC) engines, biomass or waste-to-energy systems [9]. These micrograms can be operated either in island mode, where the local loads are fully supplied by the local generation, or in grid connected mode, where the microgrid is either exporting or importing power from the main grid. The microgrid architecture provide in Fig.1.

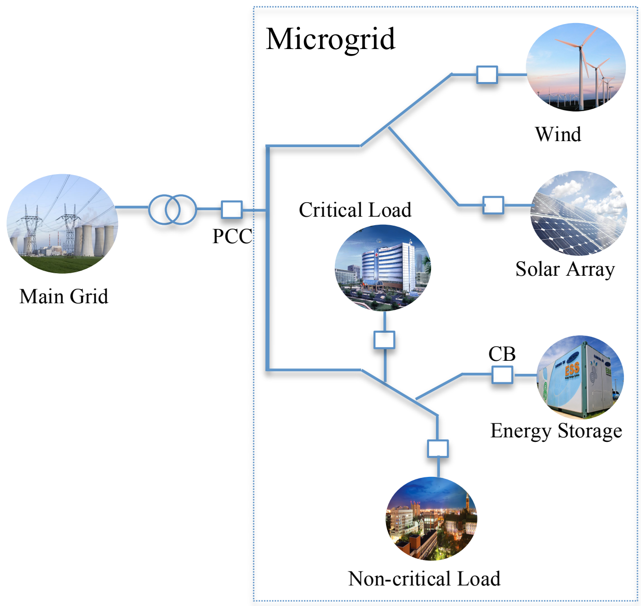

Fig. 1. Microgrid architecture

III. MULTIAGENT ARCHITECTURE

In this section, we design multi-agent system capable control distributed of a microgrid. The MAS is developed in JADE (Java Agent Development) platform [10] and it is used to control a micro-grid simulated in MATLAB/Simulink. There are several different multi-agent architectures have been presented in [11]-[13]. Based on the proposed control architecture, it is necessary to define the functions and roles of each agent accordingly. A function of an agent is defined by a set of behaviors. An agent can execute several behaviors in parallel or concurrently. Within this paper, multi-agent system consists of three agents such as Control agent, DER agent and Load agent. Each agent serves at different responsibility as show in Fig.2:

Control agent: use to control switch at common coupling point (the point of connecting between micro-grid and main system) in case of upstream fault or in order to run micro-grid in island mode and control switch of energy storage (charge when the price of electricity is low or over production from micro-grid) and perform load-shedding.

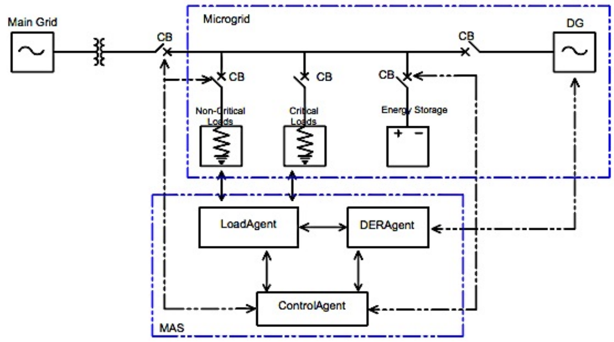

Fig. 2. Multi-agent system architecture

DER agent: will collect the information related to the DG such as availability, connection status, power rating, and energy source availability.

Load agent: use to monitor and control load and varying power consumption by load.

IV. INTEGRATION OF MULTIAGENT WITH MICROGRID SIMULATION MODEL

In this section, we will briefly discussion on available multi-agent system building framework and select a proper one for developing multi-agent in this research, microgrid simulation test bed and middleware, MACSimJx.

A. Multi-agent System

According to Wooldridge an agent may be defined by its characteristics as autonomous, reactive, pro activeness, with social ability [14]. To implement a multi-agent controller, there are numbers of open-source agent platforms available such as JADE [15], ZEUS [16], Voyager [17], SPRINGS [18] and Tracy [19]. In the context of the controlling microgrid, it is very important to select an agent platform that is based on a well-known standard, that is the IEEE standard on Foundation for Intelligent Physical Agents (FIPA) [20]. Based on the agent toolkits listed above, agent platforms that are FIPA-compliance are Zeus and JADE. In this research, the microgrid is modeled and simulated using MATLAB/Simulink, and each agent has to exchange data with MATLAB/Simulink. Recently, a middleware called MACSimJX has been developed to enable multi-agent on JADE platform to exchange data with MATLAB/Simulink. This helps simplify the adaptation of MAS for electrical engineer.

B. Microgrid Simulation Description

In order to implement the proposed Multi-agent system, a simulation test bed is developed in MATLAB/Simulink as a simplified distribution circuit. Fig. 3 illustrates a single-phase microgrid model that comprises of two distributed generators are independently controlled using droop control technique [21] for stable load sharing during islanding mode of operation. These generators are model based on power amplifier (programmable power supply) characteristics for the later experimental stage. Another generator is model as a PV generator, which uses the power generating profile obtained from the 3kW PV generator installed in the laboratory from 7 am to 6 pm of February 14, 2014. The PV generating power was sampled every 5 minute and is scaled to 1 second in this simulation. There are the fixed and the variable loads connecting in the microgrid, these loads divide in two groups: Critical (Load1 & Load2) and Non-critical load. The variable load has the profile of general service type surveyed by the Metropolitan Electric Authority of Thailand (MEA). The test bed was simulated for 140 sec to match with PV generator profile. The important parameters of the microgrid are presented in Table1.

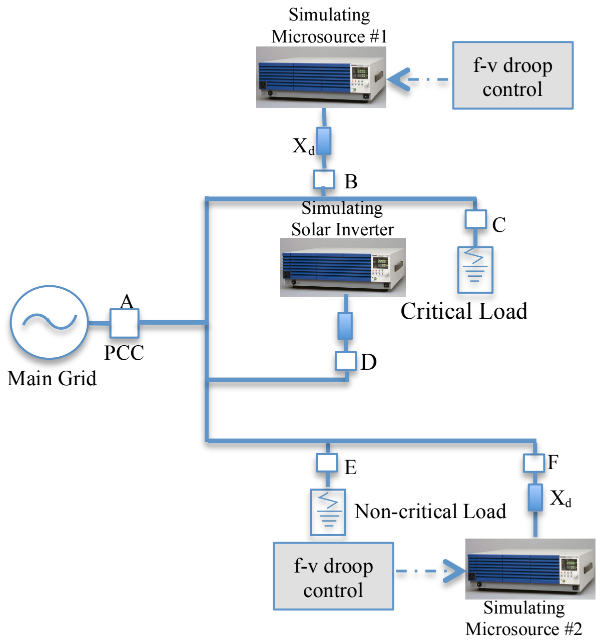

Fig. 3. Single-phase microgrid model

TABLE I. PARAMETERS OF SIMULATION MODEL

Microsource 1 and 2 (Gen 1, Gen 2)	
Model	Kikusui PCR2000M
Power Rating	220V, 50Hz, 2kVA
P-Angle Droop Coefficient (m)	$2\pi(0.000185)$
Q-V Droop Coefficient (n)	1/0.002592725
Digital Controller	Sampling Rate: 12.78kHz
X_d	4mH
Simulating Solar Inverter	
Model	Kikusui PCR2000M
Power Rating	220V, 50Hz, 2kVA
Digital Controller	Sampling Rate: 12.78kHz
LOAD	
LOAD 1	General Service Load Profile from MEA Study
LOAD 2	19.36+j14.52 Ω
Non-critical load	3kw

C. MACSimJX Middleware

This section, presents the detailed implementation of the communication middleware used in the controlling Microgrid Simulation Model. The communication middleware allows the MAS to send/receive data to/from the Microgrid model in the Simulink. The MAS needs to know the status of the agents to take the necessary control actions that are applied to the electric model. MACSimJX, or the Multi Agent Control for Simulink program is an interface that enables models of systems created in Simulink to exchange data with a multi-agent system created using JADE, described in [22]. It was purposely developed as a medium through which a program for implementing agent designs developed in C/C++ or Java might pass data to and from Simulink. MACSimJX has a client-server architecture, where the client part is embedded in Simulink through an S-function, and the server code is then incorporated in the separate program. The communication between the client and server is then performed through the use of named pipes in Windows as show in Fig. 4.

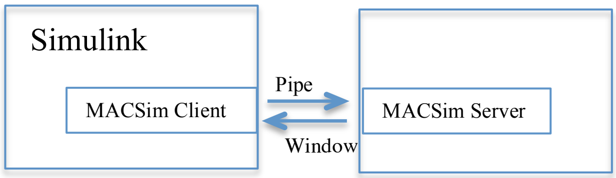

Fig. 4. Structure of Macsim

V. RESULT AND DISCUSSION

A MAS prototype was implemented and integrated with Electric simulation model. The goal of the MAS is to isolate Microgrid during fault condition or power failure and to serve loads with highest priority (critical loads) with the available power of DER sources. If load power becomes greater than both DER and GRID power or greater than DER in case of Islanded mode, then non-critical load should be disconnected. In order to test the operation of the MAS and to evaluate its performance, a microgrid test bed was simulated and multi-agent performs their task. In Fig.5, the agents are live in Jade's container and ready to start. Once the simulation starts, the multi agent can communicate and share information between each other as show in Fig.6; and Jade environment exchange data with Simulink through MACSimJX(agent coordinator).

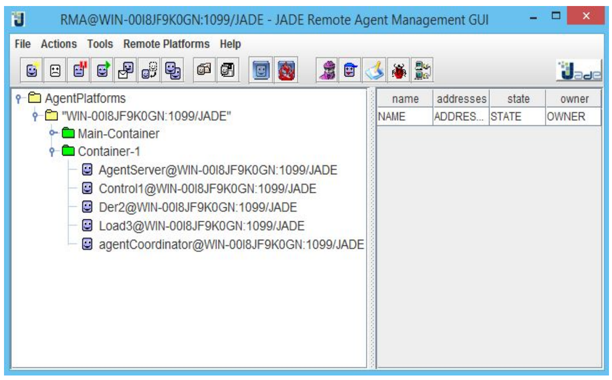

Fig. 5. JADE Remote Agent Management GUI

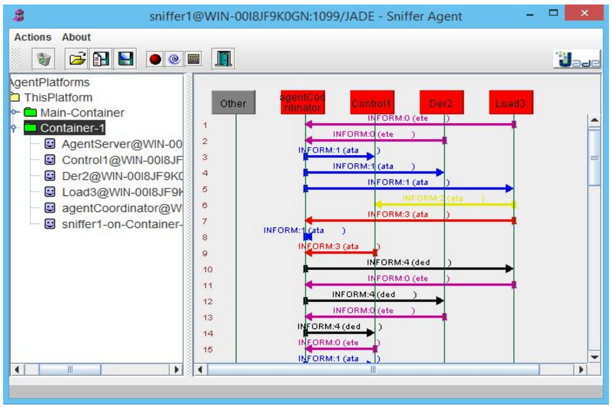

Fig. 6. Sniffer Agent

Then three scenarios and result are discussed below.

A. Grid Connected Mode

First of Simulink start, the microgrid is in islanding mode and take care only critical load. At the time of 50sec, control agent gets the present of main grid then sent closing signal to main circuit breaker at PCC to switch micro grid to Grid connected mode (Fig.7 Middle graph). During the grid-connected mode, the micro grid's voltage and frequency are controlled such that they follow the grid's voltage and frequency, which are roughly at $220\times\sqrt{2}$ V (Upper graph) and 50 Hz (Lower graph), respectively. The DER source and main grid can secure the entire loads in the system.

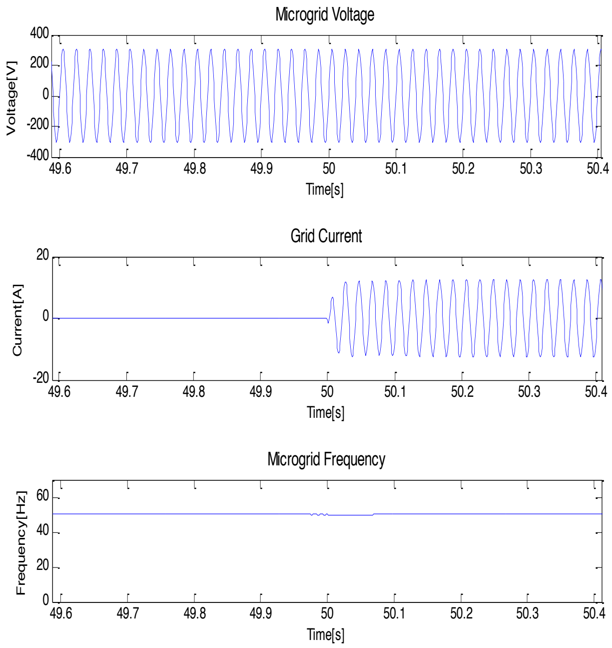

Fig. 7. (Upper graph) Microgrid's Voltage, (Middle graph) Grid's Current, (Lower graph) Microgrid's Frequency.

B. Transition Period

While the fault occur at t = 100sec, the control agent sense this fault and send signal to open the main circuit breaker A, at PCC as show in Fig.9 (Upper graph) to isolate microgrid from the main grid (Fig.8, Upper graph). After control agent give signal to switch microgrid in islanded mode, it perform one more task by request the power production and consumption from DER and Load agent. Once the power consumption from loads is greater than power production, control agent performs load-shedding by sending open signal (Fig.9, Lower graph) to disconnecting non-critical loads (Fig.8, Lower graph) from system in order to stabilize microgrid during the outage.

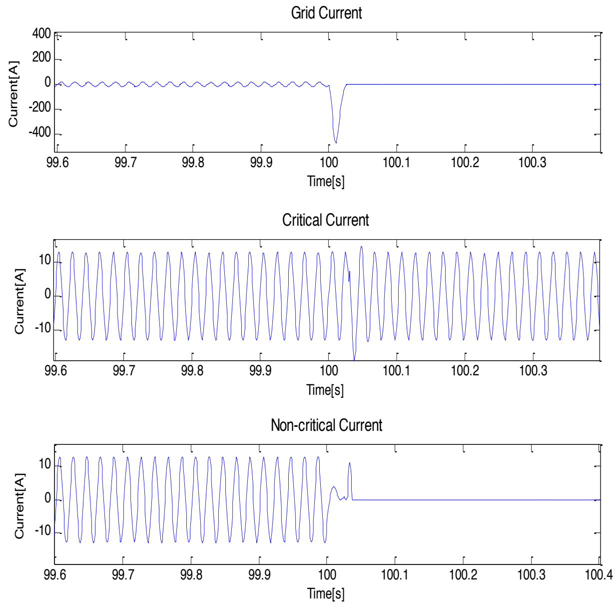

Fig. 8. Simulation result: (Upper graph) Main Grid Current, (Middle graph) Critical Load Current, (Lower graph) Non-critical Current.

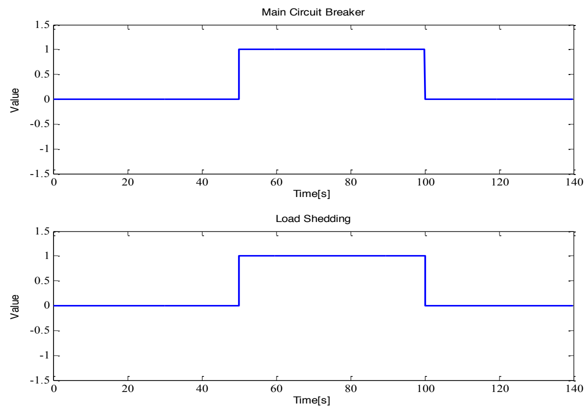

Fig. 9. Signal (0; 1) generate by agent.

C. Islanded Mode

After the fault has occurred at 100sec, the main grid is disconnected at 100sec (Fig.8, Upper graph) and the non-critical load has been cut from system (Fig.8, Lower graph), as microgrid can't secure. The critical loads are fully supplied from DER source (Fig.8, Middle graph). When the Microgrid is operated in the island mode, and consists of critical loads the voltage is maintain at $220\times\sqrt{2}$ V and the frequency is always controlled at 50Hz as show in Fig.10.

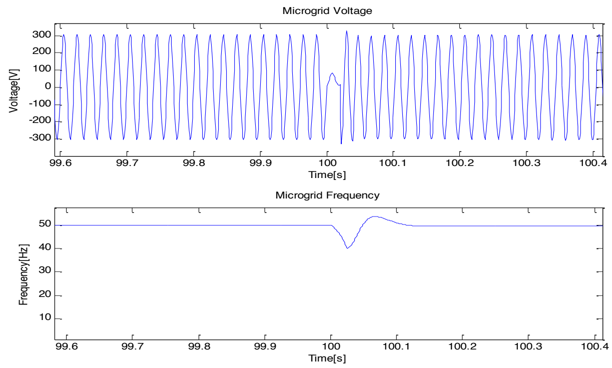

Fig. 10. Voltage and Frequency of Microgrid.

VI. Conclusion

In this paper, we presented a multi-agent system for controlling microgrid based on distribution in order to switch microgrid to islanding mode in case off Main grid failure and perform load-shedding. The multi agent system based control architecture is developed using the JADE platform and it is used to control a microgrid simulated in MATLAB/SIMULINK. The microgrid simulation test bed and multi-agent are capable of sharing data with each other through a middleware called, MACSimJX. The multi-agent system were designed and implemented; the microgrid simulation test bed created and ready to getting start. Once simulation started, the agents perform their task then three scenarios have discussed such as grid-connected mode, transition period and islanded mode. The results of experiments show the capability of the multi-agent system to effectively island in case of up-steam fault and secure the supply for its critical loads.

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