

**DEVELOPMENT OF MULTI-AGENT SYSTEM BASED
ENERGY MANAGEMENT SYSTEM FOR MICRO
GRIDS**

Happawana Vithanage Vimukkthi Priyadarshana

188118G

Degree of Master of Science by Research

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

March 2020

**DEVELOPMENT OF MULTI-AGENT SYSTEM BASED
ENERGY MANAGEMENT SYSTEM FOR MICRO
GRIDS**

Happawana Vithanage Vimukkthi Priyadarshana

188118G

Thesis submitted in fulfillment of the requirements for the degree of Master
of Science by Research

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

March 2020

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).



Signature:

30/04/2020

Date:

The above candidate has carried out research for the Masters/~~MPhil/PhD thesis~~/
Dissertation under my supervision.

Name of the supervisor: Prof. W.D.A.S Wijayapala

Signature of the supervisor:

5/6/2020

Name of the supervisor: Prof. K.T.M.U Hemapala

Signature of the supervisor:

5/6/2020

ABSTRACT

In this thesis, our objective is to introduce multi agent concept for the energy management of micro grids. This objective is very significant as micro grids are emerging as a method to integrate the operation of distributed energy sources (DES) in modern power systems. They introduced advanced communication technologies, optimizing techniques, sensing and monitoring features for the power distribution network. However, optimal energy management is still a challenge for microgrids when controlling renewable DES's with intermittent generating patterns. In this research, a Multi Agent System (MAS) based architecture is used for the operation of energy management system (EMS) of a microgrid. The objective of this research is to implement an agent based control architecture for DES's, loads and energy storage systems (ESS) of a microgrid to achieve optimal energy management. This document discusses the modeling, simulation and hardware implementation of agent based energy management system. Initially, JADE (Java Agent Development Environment) is used to implement the agent based control architecture. A microgrid is modeled in Matlab/Simulink and interlinked with agents developed in JADE through a middle layer. The decision making authority is shifted to ground hierarchy, enabling local agents to take control over DES's to optimize the renewable power consumption. The outcome of this research shows that MAS based control architecture can be used to optimize the energy management in a microgrid. This thesis presents a complete literature review about the background of this research and similar projects, and the results obtained through the research in both simulation and hardware implementation in developing a multi agent based energy management system for a micro grid.

Keywords— Agents, Multi agent systems, Energy management, microgrid, JADE

ACKNOWLEDGEMENT

I would first like to thank my research supervisors Prof. K.T.M.U. Hemapala and Prof W.D.A.S. Wijayapala of Department of Electrical Engineering, University of Moratuwa, Sri Lanka for their support, encouragement and correct guidance. I would also like to thank the experts who were involved in the validation of this research project, Prof J.P. Karunadasa and Dr.W.D.Prasad. Without their guidance and input, the research could not have been success.

I am grateful to the Faculty of Graduate Studies of University of Moratuwa for the administrative support given to the research and for the financial support given through grants under Senate Research Committee (SRC)

It is a great pleasure to acknowledge my research colleagues Eng. T.S.S. Senarathna and Eng. M.A. Kalhan Sandaru for support, suggestions and assistance given thought the research. I would also want to thank all the academic and non-academic staff members of Department of Electrical Engineering of the University of Moratuwa for all the assistance given.

Finally, I like to express my very gratitude to my family for giving a great support and encouragement as the accomplishment of research could not have been possible without them.

Thank you.

H.V.V. Priyadarshana.

TABLE OF CONTENT

DECLARATION	iv
ABSTRACT	v
ACKNOWLEDGEMENT	vi
CONTENTS	vii
LIST OF FIGURES	ix
LIST OF TABLES	xi
LIST OF ABBREVIATIONS	xii
1. INTRODUCTION	1
1.1. Overview.....	2
1.2. Research Background Objectives and scope.....	4
1.3. Microgrids and smart grid concepts	5
1.4. Microgrid Communication protocols and System architectures	5
1.4.1 Communication protocols.....	6
1.4.2 Wireless Technologies used in microgrid communication.....	7
1.5. Energy Management Systems (EMS)	9
1.6. Thesis Outline	10
2. Multi Agent Systems (MAS)	11
2.1. An Agent	11
2.2. Multi Agent Systems (MAS) Architecture	12
2.3. Categorization of Multi-Agent Systems	13
2.3.1. Hierarchy	13
2.3.2. Linear / Non- Linear Decision Function	13
2.3.3. Communication	13
2.3.4. Topology	13
2.4. Multi Agent based approach for micro grids.....	14
2.4.1 Server Agent (SA).....	16
2.4.2 Photovoltaic Agent (PVA).....	17
2.4.3 Wind Turbine Agent (WTA).....	17
2.4.4 Energy Storage Agent (ESA)	17
2.4.5 Critical Load Agent (CLA) & Non-Critical Load Agent (NCLA).....	17
3. Developing Multi Agent Systems	17
3.1. Agent Developing Toolkits (ADK)	17

3.2.	Agent Communication Languages (ACL).....	19
3.3.	Java Agent Development Framework (JADE).....	21
3.4	Simulating Multi Agent Systems.....	22
4.	Developing MAS based energy management system for a micro grid in JADE.....	24
4.1.	Implementing Agent Communication.....	24
4.2.	Operation of Agents in MAS energy management system for a micro grid.....	25
4.3.	Operation of Agents in MAS based EMS for a micro grid.....	26
4.3.1	Case Study 1	29
4.3.2	Case study 2	30
4.3.3	Case study 3.....	32
4.4	Results generated by MAS developed in JADE framework.....	34
5.	Hardware Implementation of Multi Agent System.....	36
5.0.	Hardware Implementation.....	36
5.1.	Selecting a Micro-controller	36
5.1.1.	ESP-12E 8266 Node MCU module.....	38
5.1.2.	Hardware Implementation of an Agent.....	40
5.1.3.	Implementing Agent Communication	46
5.1.4.	Modelling of renewables and loads	46
5.1.5	Programing the agents for the proposed algorithm	47
5.1.5.1	Server Agent Programming.....	48
5.1.5.2	Solar Agent programing	48
5.1.5.3	Load Agent programing	48
5.1.6	Implementing the test bed.....	49
6.	Results and analysis	52
7.	Conclusion	54
	REFERENCES	56
	APPENDICES	63
	[Appendix – A:	63
	Case 1.....	63
	Case 2.....	64
	Case 3.....	65
	[Appendix – B:	66

LIST OF FIGURES

- Figure 1.1: Centralized, Decentralized, Distributed Structures
- Figure 1.2: System Architecture of a micro grid
- Figure 0.4: Communication Network arrangement in a smart grid
- Figure 0.6: Basic EMS architecture of a micro grid
- Figure 2.1: Operation of an agent
- Figure 2.2 MAS system architecture
- Figure 2.4: MAS Architecture for micro grid management
- Figure 3.3: JADE system architecture
- Figure 4.1: Creating agents in JADE for micro grid management application
- Figure 4.2: Communication of agents developed in JADE
- Figure 4.3.1: Operating Algorithm of EMS
- Figure 4.3.2 Power generation of solar PV system within 24 hours
- Figure 4.3.3 Power generation of wind power system within 24 hours
- Figure 4.3.4 Power consumption of non-critical load within 24 hours
- Figure 4.3.5 Power consumption of critical load within 24 hours
- Figure 4.3.6 Availability of Diesel Generator within 24 hours
- Figure 4.3.7 Economical period of Diesel Generator within 24 hours
- Figure 4.3.8 Availability of utility grid within 24 hours
- Figure 4.3.6. JADE sniffer agent output for case 1
- Figure 4.3.7. Power generation and consumption (W)
- Figure 4.3.8 JADE console output for three cases
- Figure 4.3.9. JADE sniffer agent output for case 2
- Figure 4.3.10. Power generation and consumption (W)
- Figure 4.3.1.1. Results from JADE based EMS for Micro grid
- Figure 4.3.1.2. JADE sniffer agent output for case 3
- Figure 4.3.1.3. Power generation and consumption (W)
- Figure 4.3.1.4 JADE console output for case 3
- Figure 4.4.1: Switching Signal Generated by Wind Turbine Agent

Figure 4.4.2: Switching Signal Generated by Solar PV Agent

Figure 4.4.3: Switching Signal Generated by Critical Load Agent

Figure 4.4.4: Switching Signal Generated by Non Critical Load Agent

Figure 4.4.5: Switching Signal Generated by ESS Agent

Figure 4.4.6: Switching Signal Generated by DGA Agent

Figure 4.4.9: Operation of Decentralized communication architecture of MAS

Figure 4.4.10: Relay type communication process of MAS in a fault situation

Figure 5.1.0 ESP-12E 8266 Module

Figure 5.1.2 Circuit arrangement of a source agent

Figure 5.1.3 Circuit arrangement of power supply circuit

Figure 5.1.4 ACS 712 current sensor

Figure 5.1.5 CD4051B Multiplexer

Figure 5.1.6 Single channel 5V Solid State Relay Module

Figure 5.1.7 TFT LCD module

Figure 5.1.8 Voltage sensor connection to an agent

Figure 5.1.9 ZMPT101B Voltage

Figure 5.1.10 Circuit arrangement of Hardware implementation of an agent

Figure 5.1.11 Implemented Circuit arrangement of an agent

Figure 5.1.12 Completed Agent with display unit

Figure- 5.14 - Developed online database with firebase

Figure 5.1.6.0 - Single Line diagram of the test bed

Figure 5.1.6.1 - Implemented MAS based microgrid EMS

Figure 5.1.6.2 – 500W grid tied inverter

Figure 5.1.6.3 – Pinout diagram of the inverter

Figure 5.1.6.4 – Standalone inverter and charge controller

Figure 5.1.6.5 – Switching Operation of a source agent

Figure 5.1.6.5 – Switching Operation of a Load agent

Figure 6.0- Critical load consumption

Figure 6.1- PV system generation

Figure 6.2- Non-critical load consumption

Figure 6.3- Power import/export from the utility grid

Figure 6.4- Power generation of wind power system

Figure 6.5- Power generation of Diesel Generator

LIST OF TABLES

Table 1: Recent MAS based researches for microgrid management

Table 2: Categorization of multi agent systems

Table 3: Qualitative analysis of Agent Developing Toolkits

Table 4: Qualitative analysis of FIPA ACL Performatives

Table 5: CEB Tariff Applicable for I2 Customers

Table 6: Comparison of micro controllers

Table 7: Overview of I/O pins of ESP8266 module

Table 8: Specifications of ACS712 Current sensor

LIST OF ABBREVIATIONS

ABEMS	Agent Based Energy Management System
ACL	Agent Communication Language
ABM	Agent Based Modeling
ADK	Agent Development Toolkit
AMS	Agent Management System
CLP	Critical Load Power
CEMS	Centralized Energy Management Systems
DEMS	Distributed Energy Management Systems
DER	Distributed Energy Resource
DSM	Demand-side management
DF	Decision Function
EMR	Electro Mechanical Relay
EMS	Energy Management Systems
GHG	Green House Gas
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
JADE	Java Agent Development Environment
LCD	Liquid Crystal Display
MEMS	Multi-agent Energy Management Systems
MAS	Multi Agent System
NCLP	Non-Critical Load Power
NCRE	Non-Conventional Renewable Energy
PCC	Point of Common Coupling
RER	Renewable Energy Resource
SCADA	Supervisory Control and Data Acquisition
SSR	Solid State Relay
TSD	Two Stage Dispatch
TLP	Total Load Power
TFT	Thin Filmed Transistor
TRP	Total Renewable Power
WTP	Wind Turbine Power