Multi Agent System Based Control for Energy Management of Hybrid Microgrid System

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Abstract*—Microgrids are decentralized power generation systems installed on customer premises, incorporating various capacity generating sets and modes. These systems not only cater to the specific energy needs of the consumer but also contribute excess power back to the main grid. Often integrating renewable sources like solar PV cells, wind energy, and battery energy -storage systems, microgrids have gained global popularity due to their potential for compact size and adaptable configurations. To ensure stable operation amidst the diverse array of power sources, a Multi-Agent System (MAS) is employed. This MAS is specifically designed for modeling and autonomous decision-making. The study concentrates on a microgrid, equipped with 1.5 kW wind energy, 1 kW solar PV power, a battery (24V 150Ah), and a local electrical load. Together, these components develop the Hybrid Microgrid System (HMGS). The simulation design is constructed using the Java Agent Development Environment (JADE), enabling effective management of the heterogeneous system components. The primary objective is to investigate the performance and reliability of the HMGS, with a particular emphasis on the crucial role played by MAS in coordinating the intricate interplay of various power sources to achieve sustainable and efficient operation.

Keywords*—Microgrid, Renewable Energy, Multi-Agent System, JADE, Energy Management System

I. INTRODUCTION

The contemporary global energy demand landscape grapples with an enduring challenge underscored by the escalating necessity for energy juxtaposed with the depleting resources of conventional fossil fuels. In response to this predicament, a prevailing paradigm involves a departure from fossil fuels in favor of the assimilation of micro-grids powered by renewable energy sources [1]-[2]. A micro-grid, seamlessly integrated into electrical power distribution system, encompasses modest generating capacities meticulously tailored for electrical local loads, exhibiting the capability to function autonomously or in conjunction with the primary grid [3]. The overarching objective is to attain equilibrium between demand and supply, effectuate cost reductions, and refine energy procurement and storage facilities. Given the intermittent and low inertia characteristics inherent in micro-grids [4], the achievement of efficient energy management (EM) mandates adroit control and administration.

Predictive model control is one of the centralized control strategies that have been proposed for micro-grid power management [5]. Adaptive fuzzy logic and PI controllers are two strategies that have been recommended for stabilizing micro-grids under various conditions, including variations in load and voltage [6]. In the islanded mode, several cooperative control techniques have been introduced, such as the direct control vector and the droop control approach [7]. Smart microgrid (SMG) systems can now monitor and control real power flow with the help of rule-based Energy Management Systems (EMS) [8]. When it comes to AC/DC micro-grids with batteries and renewable energy sources (RES), the EMS is essential to maintaining energy stability [9].

Despite these developments, there are still issues, most notably the lack of runtime adaptation and communication overhead. Resolving these concerns requires the micro-grid monitoring procedure to incorporate autonomous control mechanisms and effective communication. A solution that has been suggested involves a Multi-Agent System (MAS), a method that was first presented by Bogaraj and Kanakaraj [10]. This method gives software agents the ability to work together to solve issues that are more complex than they can be solved by a single agent.

A model Micro-grid EMS was proposed in [11] that combined distributed storage and disaster recovery strategies to reduce peak demand and electricity expenses. The ability of the decentralized MAS algorithm to lower power imbalance costs while considering consumer preferences in decision-making was highlighted [12]. A communications system linking power management to the electrical power system was used in [13] to address real-time management (RTM) challenges in smart grid system.

An enhanced distributed energy management system for solar micro-grids was described in [14] employing a smart grid design and dynamic energy management with MAS implemented in JADE. The MAS coordination approach was applied in [15] to intricate demand-side control of a solar primarily focused on developing and implementing real-time intelligent control for micro-grids.

The following summarizes the paper's organizational structure: Hybrid micro-grids are introduced in Section 2. A thorough explanation of MAS is given in Section 3. In Section 4, JADE is explained. In Section 5, the problem statement is defined. The thorough description of EMS implementation for a hybrid micro-grid in a micro-grid and distributed energy management. In [16], a multi-agent system using the JADE environment was proposed as an intelligent agent-based control system for hybrid micro-grids. To accomplish energy management goals, the agents cooperate and communicate with one another. This work is ion results. Finally, Section 8 concludes the paper.

II. HYBRID MICROGRID SYSTEM

A hybrid microgrid system is an integrated energy solution that blends different power sources, such as solar and wind, along with energy storage like batteries. This system is designed to operate both connected to the main grid and independently, ensuring flexibility and reliability in power supply. Controlled by advanced systems like Multi-Agent Systems (MAS), the microgrid optimizes local power distribution, adapts to changing conditions, and prioritizes sustainability, offering a resilient and efficient alternative to traditional centralized power setups. The block diagram of hybrid microgrid system is shown in figure1.

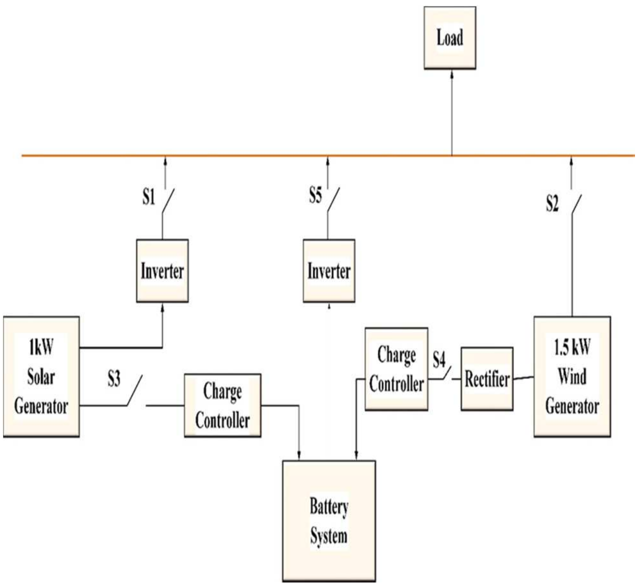

Fig. 1. Block diagram of hybrid micro grid System

III. MULTI AGENT SYSTEM TECHNOLOGY

A MAS achieves a collective goal through the utilization of Multi-Agent Systems (MAS), employing smart agents to represent each component of a microgrid. These agents exhibit three essential characteristics: proactive, reactive, and social abilities, facilitated by agent communication language (ACL) [17]. They operate autonomously, responding to environmental changes swiftly, initiating goal-oriented actions independently, and possessing social aptitude for effective communication with humans and other agents. Key features of intelligent agents include autonomy, reactivity, proactivity, social aptitude, data collection capabilities for environmental awareness, well-defined communication protocols, and a collaborative approach.

In the field of electrical power system engineering, MAS have gained prominence over the past decade, finding application in diverse scenarios. The application of MAS to power systems is comprehensively addressed in [18], where the authors discuss principles, methods, technical considerations, and potential benefits. The publication explores standards, resources, auxiliary technologies, and design approaches relevant to the implementation of MAS in power systems.

distributed scenario using JADE is outlined extensively in Section 6, while Section 7 presents a case study and the simulat

IV. JADE (JAVA AGENT DEVELOPMENT FRAMEWORK)

A software framework called JADE (Java Agent Development Framework) is used to create MAS in Java. It offers a collection of libraries and tools for building, implementing, and overseeing multi-agent systems [19-25]. The following are some of JADE's salient characteristics:

Agent Communication: Using a range of communication protocols, agents can communicate with one another thanks to the communication infrastructure that JADE offers. Agents are able to communicate and take action in response to messages they receive.

Agent Behaviors**:** JADE allows developers to define the behavior of agents using a concept called "behaviors." Behaviors represent the tasks or activities that an agent can perform, and they can be programmed to respond to events or stimuli.

Agent Mobility: JADE supports mobile agents, allowing them to migrate across different platforms and environments. This mobility feature enables dynamic and flexible multi-agent systems.

Agent Platform: JADE provides a runtime platform where agents can execute. The platform manages agent lifecycle, communication, and resource allocation. Multiple agents can run on a single platform, facilitating coordination and cooperation.

Agent Directory Service: JADE includes a yellow pages service that allows agents to advertise their capabilities and discover other agents' services. This facilitates dynamic agent discovery and collaboration.

FIPA Compliance**:** The Foundation for Intelligent Physical Agents (FIPA) requirements are complied with by JADE. Interoperability with other FIPA-compliant systems is guaranteed by JADE's compliance with the requirements set out by the FIPA organization for agent-based systems.

Security: JADE includes some basic security features, allowing developers to configure authentication and encryption for communication between agents.

Development Tools: JADE comes with a set of development tools, including a graphical environment for monitoring and managing agents during runtime.
To work with JADE, developers typically define agent classes, behaviors, and communication protocols. JADE's runtime environment takes care of managing agent interactions and provides a foundation for building complex multi-agent systems.

V. PROBLEM FORMULATION

The Energy Management System's (EMS) mathematical framework is built around the integration of wind and photovoltaic (PV) power. The electrical load and the battery's state of charge (SOC) are included in the input signals. Concurrently, the output signals indicate whether the grid is on or off, as well as the state of the electrical load, battery charging, and battery discharging.
The cumulative energy generated from renewable sources (RES) is,

$$P_{pv} + P_{wp} = P_E \tag{1}$$

where Ppv represents the electricity generated by solar PV panels, and Pwp denotes the power generated by wind power. Additionally, consider the total load,

$$P_{L11} + P_{L22} = P_L \tag{2}$$

Where PL11 represents the combined load in Room Nos: 303 and 304, and PL22 denotes the load in Room No: 305.
Following the comparison between PE and PL:
If PE > PL, proceed to charge the battery using renewable energy sources.
If PE < PL and the battery capacity exceeds 0.9, then discharge the battery to meet additional load requirements not covered by renewable energy.
If the State of Charge (SOC) is less than 0.9, check Pgrid to supply extra electrical load.
If Pgrid > 0, supply power to the additional load. In such a scenario, deactivate a reasonable load if Pgrid lacks sufficient additional power to accommodate the load.

VI. HYBRID MICROGRID SYSTEM EMS IMPLEMENTATION USING MAS

JADE is an essential component that plays a crucial part in the implementation of the suggested agent-based system. It is an open-source framework built on the Java programming language that has been carefully designed to produce a variety of co-systems. JADE is built on a peer-to-peer architecture that allows intelligence, initiative, information, resources, and orders to be distributed fairly among a wide range of hosts and devices over wired and wireless networks. Every agent in this system is capable of sophisticated peer-to-peer negotiation and communication, actively searching for win-win solutions to complex challenges.

The Hybrid microgrid system consist of a 1.5 kW wind turbine generating system, a 24 V, 150 AH battery bank system, a localized load, and a 1 kW solar PV system. Real time microgrid system Installed on the EEE department's rooftop. The EEE department's Power System Research Laboratory is equipped with strategically placed control systems, measuring tools, and sensors. In the EEE department, Microgrid system provide power to connected loads in Room Nos. 303, 304, and 305. Figure 2 shows the micro-grid control scheme.

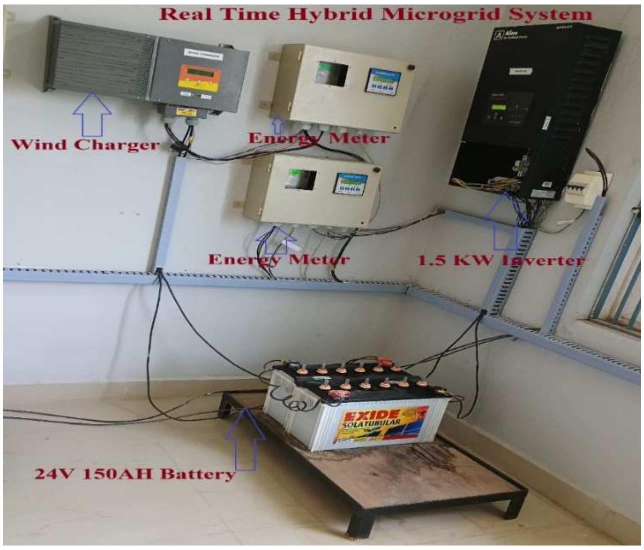

Fig. 2. Proposed Real time hybrid microgird system

The sensors rigorously monitor solar and wind energy in real-time on an hourly basis, taking into account all electrical loads. By utilizing hourly-monitored metrics including solar power, wind power, load, and battery state of charge (SOC), the agent independently determines the best course of action for dynamic energy management in distributed hybrid micro-grid.

The agents listed below represent a Multi-Agent System (MAS) in a JADE environment:

The load agent (LA): Known also as the Purchasing Agent, the Load Agent determines the necessary amount of power to be acquired and initiates contact with the generating agent by looking through the yellow pages provided by the Directory Facilitator, which offer power distribution options.
Solar Agent (SA): Solar agent is the power generation by solar PV panels and act accordingly LA
Wind Agent (WA): Wind agent is the power generation by Wind generator and act accordingly LA
Battery Agent (BA): The BA is responsible for monitoring the battery's level of charge and enables two-way communication between other agents and the availability and demand of power.
Control Agent (CA): The Control Agent (CA) is in charge of overseeing, coordinating, settling disputes, and carrying

out power exchanges amongst the micro-grids. The Agent's relationship map is shown in Figure 3.
A thorough flow chart that summarizes the several possible uses for micro-grid is shown in Figure 4.

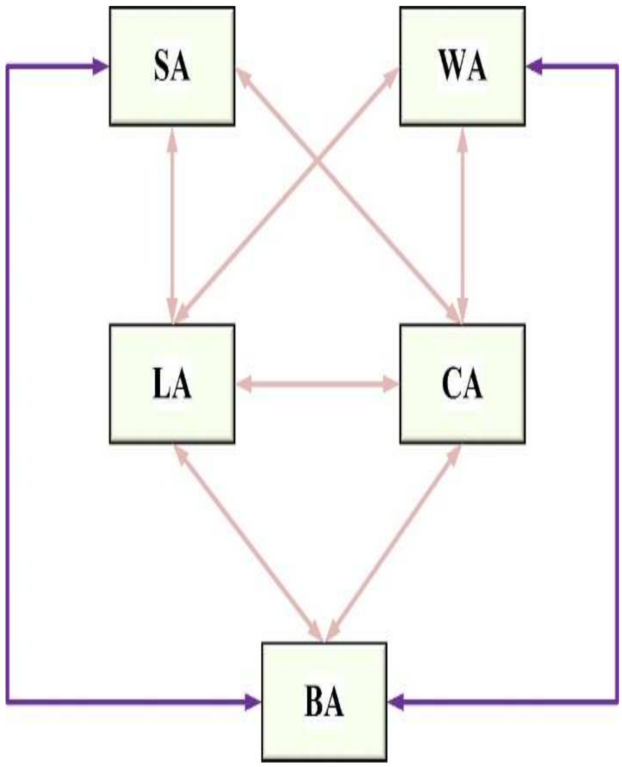

Fig. 3. Proposed Agents relationship in microgrid system

The procedural steps are as follows:
Initialization (Step 1):
SA initiates a power request to LA through an ACL message.
LA receives power from SA, and if there is an excess, it is supplied to BA.
BA receives any surplus power, demonstrating local decision-making by LA and coordination with other agents for global decisions.
Power Procurement Sequence (Steps 2-4):
If SA lacks sufficient power, LA contacts WA to obtain available power.
Battery Charge Utilization (Steps 5-6):
If power is still needed, LA checks BA's charge status and utilizes BA if fully charged.
.Optimal Energy Management (Step 9): Based on load requirements and the availability of solar and wind power, the agent determines the best energy management plan for the dispersed environment each hour.
This dynamic use of the JADE platform's multi-agent system efficiently controls the energy of the hybrid micro-grid powered by solar and wind power for distributed optimization.

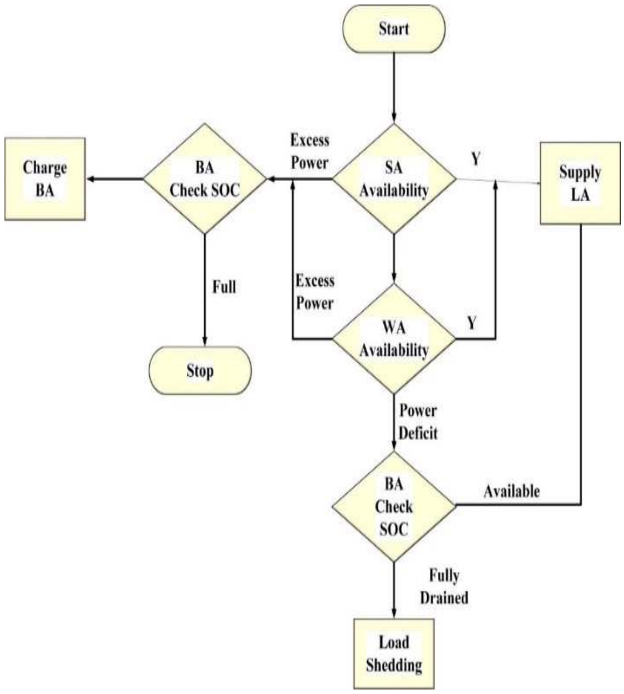

Fig.4. Proposed flow chart of Energy management system using MAS

VII. SIMULATION RESULTS

The hybrid micro-grids were operated continuously for a full day, covering every possible scenario that was explained in the flowchart. The JADE framework was used to carefully program each of the seven agents in charge of managing hybrid micro-grids that combined solar and wind power. The agents were then run within the IntelliJ IDEA environment. Sniffer diagrams and console output are used to explain the examination of agent interactions and transaction data in a variety of carefully scrutinized scenarios. Figure 5 shows a snapshot of the exchanges of information between a sniffer agent and a regular agent.
The energy complexities of solar power, wind power, battery, and load for Microgrid are explored in detail in this case study at 11:00 am. The following is how the operations play out in order:
(i) Microgrid has a load need of 1100 W. The total power generated, including 550 W from wind and 740 W from solar, is 1290 W. As so, there is a surplus of 190 W.
(ii) A 190 W surplus electricity is observed in this instance.
(iii) The extra power is used to recharge the batteries in light of the excess power in Micro-grid.
(iv) Using the extra power from Microgrid, the control agent assesses the batteries' State of Charge (SoC) and charge the batteries.
(v) Here the battery SoC increased from 69.68676 to 72.25202 due to charging.
(vi) The control agent stops additional charging if the batteries achieve full charge, as is the case in this instance.
Energy management of proposed hybrid microgrid system for a day is given I table1

TABLE 1. MICROGRID OPERATION AND CONTROL USING MAS FOR A DAY

Time	Micro Grid Load	Total generation	Solar Power	Wind Power	Micro Grid Credit (watts)	Micro Grid Debit (Watts)	Battery SOC	Battery state
0	200	100	0	100		100.0	87	discharge
1	200	150	0	150		50.0	85.52642	discharge
2	200	300	0	300	100.0		84.78886	charge
3	200	120	0	120		80.0	86.145744	discharge
4	200	50	0	50		150.0	84.96617	discharge
5	200	60	0	60		140.0	82.75257	discharge
6	200	120	50	70		80.0	80.68309	discharge
7	500	380	260	120		120.0	79.49857	discharge
8	900	660	460	200		240.0	77.72005	discharge
9	1000	750	610	140		250.0	74.157524	discharge
10	1100	1050	700	350		50.0	70.434265	discharge
11	1100	1290	740	550	190.0		69.68676	charge
12	1000	1130	730	400	130.0		72.25202	charge
13	800	1020	670	350	220.0		74.00894	charge
14	900	770	550	220		130.0	76.9841	discharge
15	1000	660	380	280		340.0	75.05313	discharge
16	1100	490	170	320		610.0	69.993866	discharge
17	900	540	0	540		360.0	60.869873	discharge
18	500	620	0	620	120.0		55.422405	charge
19	400	430	0	430	30.0		57.031025	charge
20	200	320	0	320	120.0		57.43357	charge
21	200	240	0	240	40.0		59.044155	charge
22	200	120	0	120		80.0	59.581512	discharge
23	200	130	0	130		70.0	58.368618	discharge

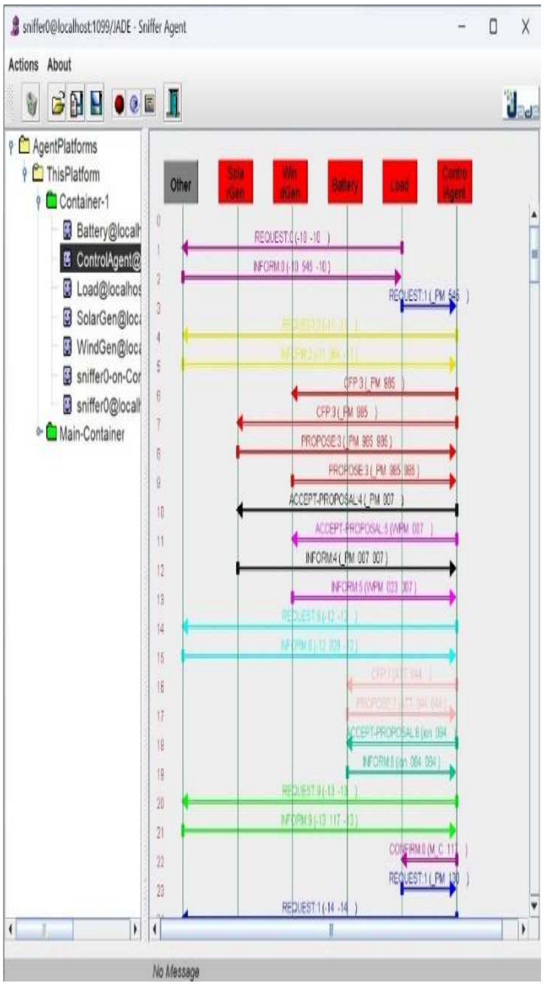

Fig. 5. Snapshot of sniffer diagram and agents communication.

VIII. CONCLUSION

The micro-grid concept and demonstration at AITS are covered in detail in this paper. Full details are provided regarding the benefits of the Multi-Agent System (MAS) based microgrid control system. We have successfully created agents with the capacity for communication and decision-making via message exchanges using the data that we have collected through our simulation research. The results demonstrate that the suggested multi-agent-based control system is effective at controlling energy during instantaneous microgrid operations comfortably.

To enhance the resilience of the micro-grid control system, upcoming research endeavors will fuse JADE with MATLAB/Simulink/LabVIEW, delving into the potential benefits of integrating the Internet of Things (IoT). This integration seeks to amplify the system's functionalities, prioritizing software verification before transitioning to hardware validation on the AITS micro-grid.

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