A Survey on Multi Agent System and Its Applications in Power System Engineering

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Abstract – An Intelligent Agent (IA) is a type of autonomous entity in the field of Artificial Intelligence (AI) that gathers information about its surroundings using sensors, takes action in response to that information using actuators ("agent" part), and guides its behavior to achieve predetermined results (i.e. it is rational). Agents that are both intelligent and able to learn or utilize information to accomplish their tasks would be ideal. Similar to how economists study agents, cognitive scientists, ethicists, philosophers of practical reason and researchers in a wide range of other disciplines study variations of the IAmodel used in multidisciplinary socio-cognitive modelling and computer social simulation models. In this article, the term "Multi-Agent System" (MAS) has been used to refer to a system in which two or more autonomous entities communicate with one another. The key objective of this research is to provide a critical analysis of MAS and its applications in power systems. A case study to define the application of MAS in power system is also provided, using a critical implementation of fuzzy logic controllers.

Keywords – Multi-Agent System (MAS), Multi-Agents (MA), Intelligent Agent (IA), Artificial Intelligence (AI).

I. INTRODUCTION

An agent refers to a piece of software that relies heavily on its surrounding environment. The environment in which agents operate, which may include sensors, relays, and other devices, is referred to as the "power system environment." The agent's primary function is to facilitate communication between the power system's software and hardware. The term "multi-agent system" [1] is used to describe a network in which several agents work together to achieve a common goal. The Multi-Agent's (MA's) fundamental characteristics remain constant across contexts. For instance, in a power system, the usage of Multi-Agents (MA) at a substation and a control center is constant; what changes is the nature of the underlying program that feeds into the MA. Computers that have been programmed with Artificial Intelligence (AI) are connected to Multi-Agent Systems (MAS). Depending on context and purpose, agents may have a number of different meanings.

However, there is no agreed-upon definition of an agent, although it is widely accepted that agents exist in environments, have the ability to act (through effectors), and may potentially alter their surroundings as a result of their activities. It is also presumed that the agent has some kind of sensory capability that allows it to detect changes in its surroundings (using sensors). Associative competence is another characteristic often postulated of agents. That is, it is expected that a given agent may interact with other agents in its immediate surrounding and coordinate their activities. It is considered that an agent's behaviors are the outcome of decisions it makes in response to information it gathers about its surroundings and the task at hand. In addition, any decision-making on action must be intelligent. Knowledgebase rules or any other sort of knowledge representation method might provide the basis for such intelligence.

Multi-Agent Systems (MASs) have quickly risen to prominence as a primary area of study in the field of Artificial Intelligence (AI). Based on findings in other subfields of AI and in computer science, this subfield is gradually splitting off from Distributed AI to become its own field of study. As discussed by McKee, Leibo, Beattie, and Everett [2], many different agents work together to achieve both shared and independent goals (in some environments they may also compete). It is common for an agent in MAS to have critical functions and distinct motivations. Maintaining global coherence, or functioning well as a system when no explicit global control is in place, presents a challenge for multi agent systems. Structured organization is beneficial. Some agents in a hierarchical organization are made to recognize and control relationships between the activities of other agents. This agent may be given the ability to direct the actions of other agents, giving it sway over their motivations and other aspects of its operation. The alternative, decentralized systems, in which no centralized authorities exist, might be compared with this kind of organization.

In order to describe, plan, and govern different processes, multi agent systems have become a popular paradigm. In most cases, it employs strategies for decentralized negotiation to accomplish predetermined ends. The multi-agent system can replan locally with only minor adjustments to the overall strategy, in addition to the standard centralized planning and optimization mechanisms. Agent-Based Simulation (ABS) continues to be a potential area for the development of new methods, tools, and approaches, including useful ABS applications. We refer to actual computer simulations built on agent-based modeling of a real (or imagined) system in order to address a specific issue as "Agent Based Simulation application" here. An Agent Based Simulation program replicates the behavior of a real-world system by simulating interactions between those entities. It is possible to view the Agent Based Simulation as MAS composed of different software agents. Therefore, the (real) entities and the agents in the MAS correspond to those in the real system.

A "smart grid paradigm" describes the direction in which the power system is heading [3]. Improvements in communication networks have allowed power electronics interfaces to take real-time, scalable, and efficient command of complex power systems. Due to their ability to efficiently distribute data and compute algorithms for complicated networks, Multi-Agent Systems (MAS) are a great technical option for this use case. This paper provides a critical analysis of Multi-Agent Systems (MAS) and its application in power systems. The remaining part of this paper has been organized as follows: Section II provides a review of intelligent agent. Section III focuses on a discussion of multi-agent system structure, features of a multi- agent, MAS in power system, and application of fuzzy in power system. Section IV provides a survey of MAS application in power system engineering using a case study that employs Fuzzy Logic Controllers (FLC). Section V draws final remarks to the research on MAS implements in power engineering.

II. INTELLIGENT AGENT

Zhu et al. [4] defines an Intelligent Agent (IA) as a computational entity that is capable of perceiving its surroundings, acting independently to accomplish objectives, and potentially enhancing its performance via learning and the application of acquired information. A thermostat is an example of a basic IA, as are humans, and any system that satisfies the description, including businesses, governments, and ecosystems **Fig 1** provides a simplified reflex agent illustration.

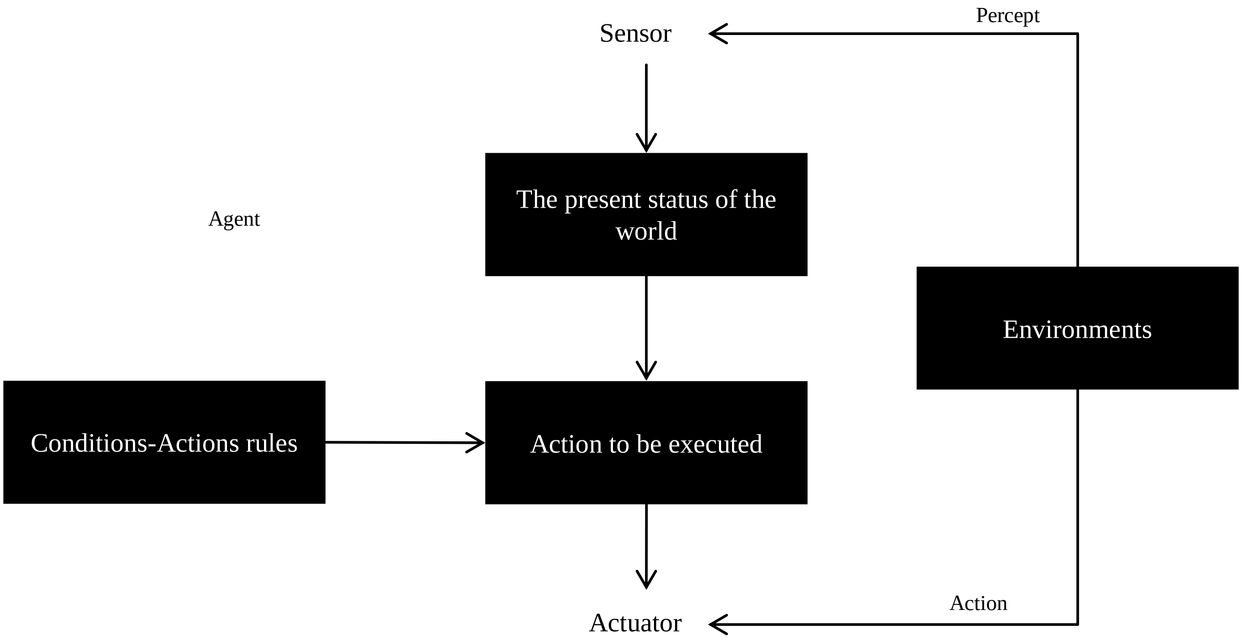

Fig 1. Simplified Reflex Agent Illustration

The study and construction of IAs is at the heart of leading AI textbooks' notion of "artificial intelligence," which places an emphasis on goal-directed behavior. An economics-derived phrase, "rational agent," is frequently used to characterize goal-oriented agents. The "objective function" of an agent represents the overarching purpose of an IA. The goal of such an agent is to generate and carry out any plan that, once implemented, will result in the greatest possible expected value for the objective function. A "reward function" in a reinforcement learning agent and a "fitness function" in an evolutionary algorithm are two examples of functions that determine the behavior of IAs. These functions enable programmers to train the IA to do tasks in accordance with their preferences. Similar to how economists study agents, cognitive scientists, ethicists, philosophers of practical reason, and practitioners of a wide range of interdisciplinary socio-cognitive modeling approaches and computer social simulation framework all study the IA paradigm variants. The concept of an "IA" is often simplified and compared to a computer program in terms of its abstract functional system. Abstract IAs (AIA) are theoretical representations of IAs that are distinct from their concrete realizations. A fully autonomous IArequires no human interaction to carry out its intended tasks. There is a close relationship between IAs and software agents (an independent computer application that completes tasks for people).

There has been a lot of focus on agent technology in recent years, and as a consequence, businesses are starting to wonder how they might incorporate it into their own offerings. An Intelligent Agent (IA) is a piece of software that may act autonomously on behalf of a user or another piece of software, making decisions based on the user's or other program's aims and wishes. Agent technologies originate in AI and computer science, including concepts like component-based computer programming, decentralized decision making, parallelism and decentralized computing, unsupervised computing, enhanced techniques of interoperability and application integration. Agents are self-sufficient, hardware- or software-implemented entities that communicate with one another to carry out tasks in an agent-based system. Multi-agent systems excel in resolving computational processes that are amenable to natural decomposition or potentially distributed computation. Furthermore, the multi-agent system has excellent integration capacity, dynamic remodeling, and unsupervised delegation capabilities during runtime. They can easily include people, new software, and updated hardware, and they are reliable. Recently, agent technology has emerged as one of the most active and quickly developing fields in IT. Researchers working in the field of Agents have proposed their own unique definitions. There is a wide spectrum of complexity among these explanations. All of these definitions may be summed up as follows:

“An Intelligent Agent is a software component designed to carry out certain duties on behalf of its owner. An agent is entrusted with a mission, and it works on behalf of its master to see it through. It improves its performance by incorporating what it has learned about its surroundings, its owner, and other agents into the tasks it does. Based on this concept, communities of IAs provide a platform for creating user-tailored, flexible, enterprise-wide and inter-organizational systems for decision support”

Aiding and acting on behalf of humans, IAs are a kind of software. IAs are effective because they enable humans to hand over tasks that they have already completed to computer programs [5]. With enough complicated data, agents may develop an understanding of your needs and provide personalized suggestions. Software agents, thus, are distinguished from other applications by their enhanced mobility, autonomy, independence from the presence of their user, and capacity for adaptive thinking. If the agent can understand the user's knowledge, attitudes, and beliefs, then it will be able to process information from the user's external surroundings including networks, databases, and the Internet. In light of this description, **Table 1** identifies the defining features of IAs that set them apart from other kinds of software programs:

Table 1. Defining features of IA

Autonomy	The IA is able to take charge of their own emotions and behavior.
Reactivity	When an Agent is constantly communicating with and adapting to its surroundings, we say that it is reactive (in time for the solution to be helpful).
Pro-activeness	An Agent is proactive if it can create and work toward objectives on its own, rather than being reactive to circumstances.
Social Ability	Agents have the capacity to communicate with one another and perhaps collaborate with one another using an agent-communication language. Ability of agent to communicate is another name for it. This is so the smart agent can get all the relevant data it needs from a variety of sources.
Capacity for Cooperation	An IA is one that works with others to accomplish a common goal.
Capacity for Reasoning	The IA may be endowed with the faculty of drawing conclusions and making predictions based on available data and experience.
Adaptive Behaviour	An IA is one that adapts to its environment or gains new skills as a result of its experiences.
Trustworthiness	The user must have complete faith that its agents will carry out its instructions, report accurately, and look out for the user's best interests.

In addition, **Table 2** presents other characteristics of agency that are occasionally debated:

Table 2. Occasionally debated features of an agent

Mobility	The capacity of an agent to navigate a computer network
Veracity	Whether an agent will actively disseminate incorrect information
Benevolence	Whether agents are fundamentally helpful and whether they have competing agendas.
Rationality	Whether an agency will act to attain its aims and would not purposefully take action to prevent those goals from being realized.
Learning/adaptation	Whether or not agents become better with experience.

No IA has a particularly distinctive design. We should not presume that every IA will possess the same design collection. It is possible that subsets of agents vary depending on the kind of agent being considered. When we look at outliers like Newton, Mozart, and idiot savants, we see that there is tremendous variability even among people. Therefore, it is erroneous to assume that an IA has a static architecture, as learning and development often involve modifications to the architecture (e.g., the addition of entirely new collections of capabilities and the establishment of new connections between previously existing ones). Some people seem to keep expanding and improving their structures for longer than others.

III. MULTI AGENT SYSTEM

Centralized control, as is employed in today's power systems, slows down operations, reduces dependability, and makes power management and control less intuitive. Energy management and the use of renewable sources of energy need the use of cutting-edge technologies that are capable of autonomous operation and control. A smart grid represents a potential for future power systems to be managed and operated more effectively. Due to the nature of the centralized grid, hardware and software protocol have to be able to talk to one another. The interchange of control signals and grid status is an integral part of modern grid automation. These so-called multi-agent systems employed automated technological agents for monitoring and controlling purposes. Integrating this technology into the current power infrastructure is a good idea. This strategy involves coordinating the actions of several actors in order to accomplish a single, overarching goal within a complex system. When an unexpected operational situation arises on a grid, MAS is designed to step in and handle things on its own at the local level. Awareness is preventing the introduction of MAS technology into the electricity grid. The MAS may be used to effectively and precisely incorporate renewable energy sources into the existing electrical system. This section, which is structured as follows, discusses the MAS architecture, intelligent technologies, and associated implementation.

As the name implies, a single agent system only interacts with a single device. Not to mention, it won't even come close to assisting in the systems' overall objective of doing what they're supposed to do. As a result of improved methods of communication, coordination, and collaboration among the agents, a larger number of agents may be used in a MAS to do the same task. The current power grid relies on a centralized SCADA system for efficient communication and control of all power-related processes. The gadget could not operate independently due to SCADA's restrictions. Lack of real-time performance is caused by SCADA's transmission of command and control signals. A multi-agent system is being developed to address the shortcomings of the current system. Distributed system control is made possible. A controlling agent, such as an intelligent technological gadget or piece of software, is used. Because of this, it will be able to make decisions depending on environmental factors. Every agent has tasks that it has to complete by a certain date. Control agents, distributed agents, monitoring agents, centralized control agents, data base agents, etc. are just a few of the numerous sorts of agents that may be broken down by their function.

Multi-Agent System Structure

The multi-agent system was responsible for integrating the requisite hardware and software. Operating conditions determine whether a given agent is hardware or software. Each independent agent pursues its own agenda. Multiple agents, each with their own objectives, are deployed in a multitiered power structure. The agents' collective goal is to integrate smart grid technologies into the existing electrical infrastructure. The agent is a self-acting piece of hardware or software that is tied into a certain operating environment. Agents have the capabilities of reaction, initiative, and social interaction. The rudimentary framework of MAS is seen in **Fig 2**. The complex issues with the electrical grid are broken down into manageable chunks. Individual MAS deal with these little issues. This will make the system simpler, making it easier to pinpoint and isolate.

As an autonomous system, MAS may make decisions without waiting for instructions from above. It is possible for an agent to report its current task status to another agent in the area, as well as offer information on the location and activity of other agents in the area. Intelligent functioning of the system requires coordination and collaboration amongst the MAS if the desired outcome is to be achieved. In order to achieve the system's overarching goal, MAS must collaborate to provide seamless, real-time information transmission. This collaborating agent reserves the right to either ignore or defend signals from other cooperating agents. As a result, collaboration is a vital part of how MAS systems work. The agents are able to exchange information on their progress and success. This helps facilitate the efficient pursuit of the objective by other actors. The operation is conducted using a unified command structure and a shared vocabulary.

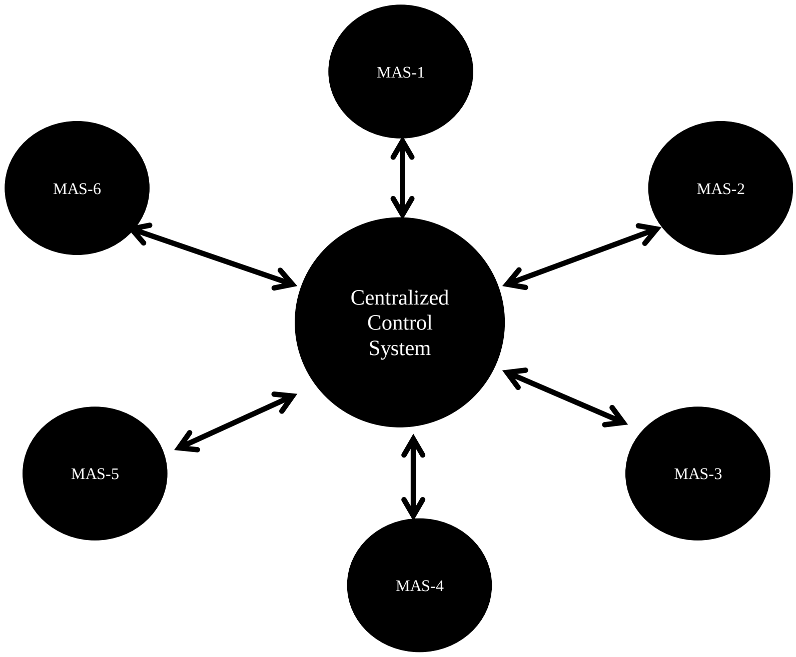

Fig 2. MAS Structure

Features of a Multi-Agent

The features of a multi-agent are illustrated in **Table 3**

Table 3. Typical Features of a Multi-Agent

Knowledge of the environment	When an agent is equipped with knowledge of the environment, such as the voltage of the bus system and the bus used to generate power, it may do certain tasks with help from the environment. Other bus factors are taken into account as well while making decisions (decision making and autonomous).
Capacity to exchange data	An agent's capability to exchange real-time data with other agents in close proximity over a high-speed communication network. Consumers may adjust their energy consumption patterns, for instance, if they have access to real-time data on power generating costs via a centralized control agent (cooperation and coordination).
Autonomous	A degree of autonomy in decision making is present in an agent. To achieve its goal, the agent will act autonomously, making use of the information and capabilities it has at its disposal. If any stage of generation fails, the agent will make the call to ensure a steady supply based on information received directly from the end user in real time (self-healing).

MAS in Power System

The power grid is a massive interconnected system, the management and operation of which carry a substantial amount of inherent danger. Controlling and monitoring production, finding faults, identifying sources of overload and surplus production, etc., are all included in this system. The MAS is designed to handle these potentially disastrous circumstances and faults without compromising the integrity of the system. Aging power system elements including circuit breakers, switching devices, and transformers contribute to inefficient functioning under the current system design. A complete system replacement is very costly to implement. The intelligent devices of the smart grid provide the solution to averting a costly investment, as they are easily adapted to work with the infrastructure already in place. The smart grid architecture is depicted in **Fig 3**.

Improvements in smart grid operations need the use of computational intelligence at all levels.The implementation of these improvements requires the use of intelligent technologies, such as fuzzy logic, neural networks, etc. Sensor devices are becoming more sophisticated, and their performance in real-time will ultimately determine the system's viability. The system's smart functioning is predicated on the data sent from the sensors to the control centers. In case the sensors are faulty, the entire system would fail. Every step along the way from production to consumers results in a steady stream of data being sent to the devices through the sensor devices. The devices are also aware of the up-normal and normal operations of the sensor datasets in relation to reference values. One of the most important aspects of the smart grid is the ability for devices to communicate with one another wirelessly. High-security data transport across modern communication networks is crucial for protecting against cyberattacks. When there is a block out, the incorrect data from the control center is used to steer the system.

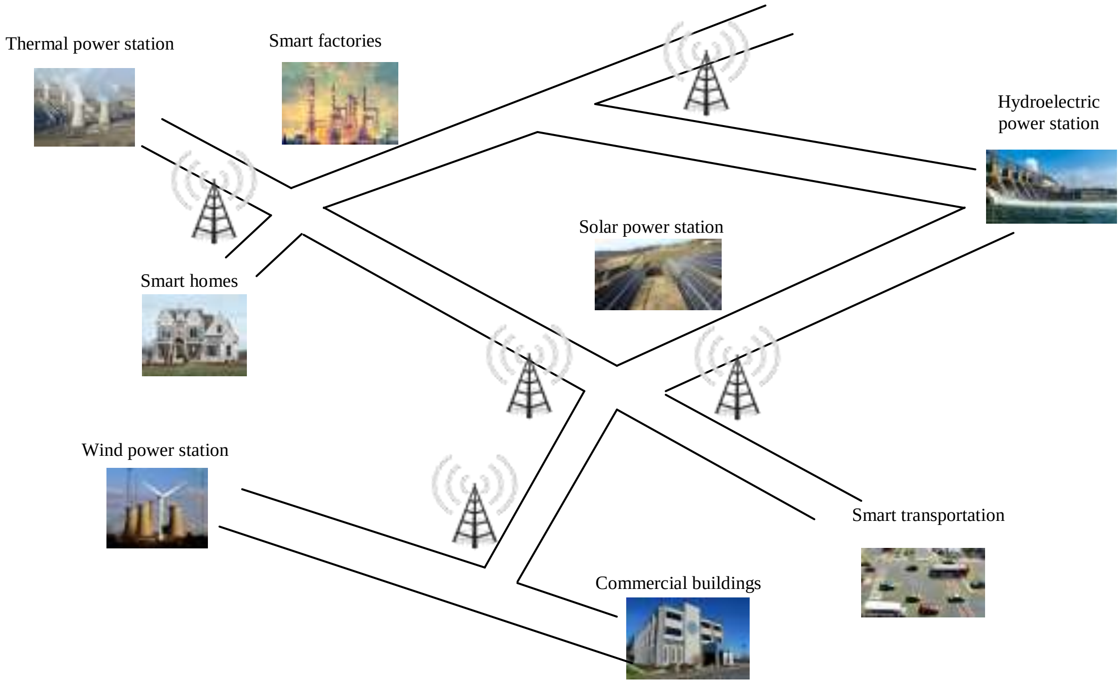

Fig 3. Smart Grid System

Relevance of MAS for Power Systems

It is fundamental to understand the development of power grids over the past few decades before discussing the relevance of MAS-oriented control over traditional approaches for implementation in power systems. It is possible to integrate the classical control mechanisms used in SCADAs into the modern grid. However, current innovations aimed at the future smart grid would need the integration of thousands of devices, including intelligent loads, distributed storage, and distributedenergy resources. Therefore, control systems will have to operate effectively at a broad scale, irrespective of the fact that failures may occur at far separated locations. The following characteristics of MAS (distributed, proactive, and social) will be examined in further depth in order to assess the practical benefits of MAS for dealing with these problems.

Distributed Architecture

The three main characteristics of distributed MAS are (i) flexible interactions, (ii), local knowledge and (iii) bottom-up methodology to control. If agents only know what's going on in their immediate vicinity, their knowledge is very narrow. Agents' field of view can be restricted to their immediate vicinity, cutting down on the amount of data transmitted between them. To give one concrete example, in a microgrid, a distributed generator's agent need not be concerned with the status of a small load that may be located miles away. This means that a scalable distribution grid benefits from a MAS design that is itself distributed. When the circumstances call for it, a flexible MAS design can incorporate robust, and fault-tolerant and plug-and-play processes. For instance, the MAS will recognize and adjust to changes in the system if a load agent or generator is disconnected, i.e., switched off or on (irrespective of whether it is scheduled or not) or loses contacts. Once the event is detected, it will be taken into account when decisions are made to achieve its goals (such as keeping the system stable). When contrasted to traditional analytical control approaches, which require anticipating all possible changes, faulty conditions, and events before designing the control system, this trait represents a significant improvement. Also, the cost of development and maintenance might go down if the MAS can have features added or taken away without having to rewrite the whole thing from scratch. This quality is reminiscent of the plug-and-play nature of computer systems. It might be useful, for instance, in the context of electric car operating in conjunction with the distribution-grids for charging (see **Fig 4**)

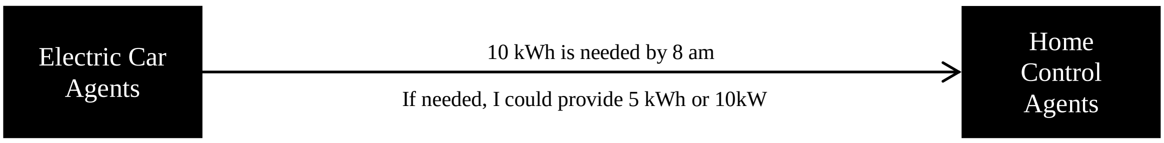

Fig 4. An Agent Joining Another

MAS, it introduces itself and what it can do to the other agents so that they may work together with him. The image gives an illustration using an electric car as an example. Bottom-up regulation is made possible by characteristics one and two. Complex and widely dispersed issues are a good fit for this feature. Individual agents may act independently, working with or against one another as needed. Distributing duties across communicative agents greatly reduces the control systems' complexity. This feature might be crucial for MAS establishes for smart grids in which dispersed energy sources are heavily used. Each microgrid would have its own set of local power sources, storage units, loads and the whole grid would be broken up into thousands of them. To further improve the structure, intermediate layers, such as collections of microgrids, may be included. This would be a bottom-up strategy, where choices would be made at the sub-regional or regional level, as opposed to the top-down approach used in today's power networks.

Pro-Activity

According to Kraus, Wagner,Riekenbrauck, and Minker [6], goals for proactive agents might be either local or global in scope. Unlike a collection of agents, a single agent can only think about what's happening in its immediate vicinity. For electricity generators, for instance, it is more important to keep the voltage stable at the local level, but the global aim of striking a balance between production and supply necessitates collaboration across several entities. AI with data based on knowledge about the surrounding environment (e.g., the grid) and, when necessary, with additional information by requesting other agents, and knowledge of needed actions asked by other agents through communications might allow such pro-activity, which could contribute to the achievement of global objectives. Based on this online information and their objectives, agents may make plans for and carry out the necessary activities. **Fig. 5** and **Fig. 6** show how a storage manager could plan a distribution operation, such as charging a battery to capacity ahead of time if it anticipates that traditional generating sources won't be able to keep up with peak demand. The system would then be prepared for any future demand spikes. Reactive power planning and starting, syncing, and reconnecting a turbine to the grid are two further examples.

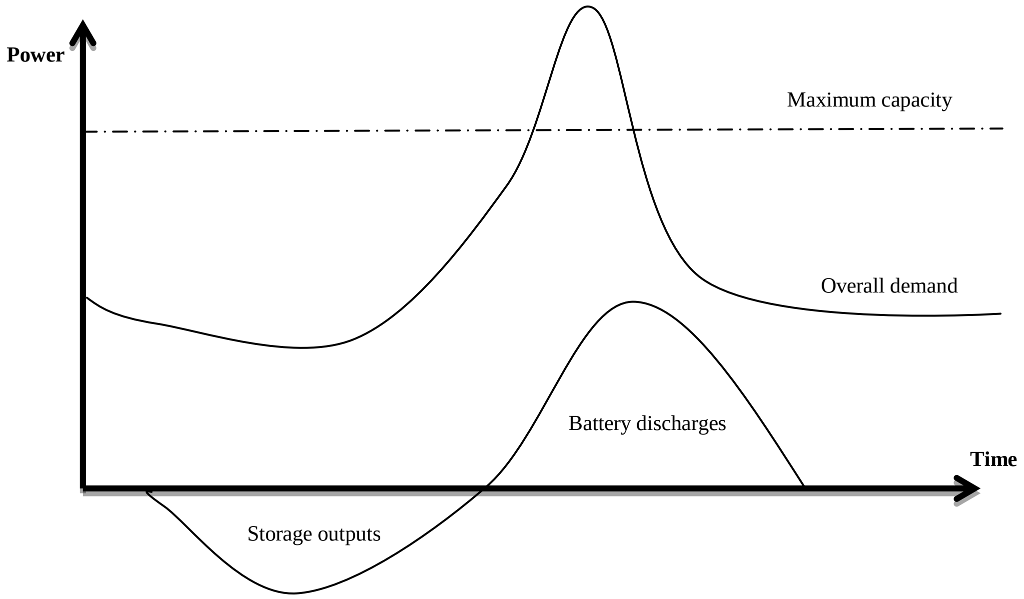

Fig 5. Peak Demand Exceeds the Available Generating Capacity.
Storage Allows this Need to Be Met, Even at The Peak, Although Charging Must Precede Discharging.

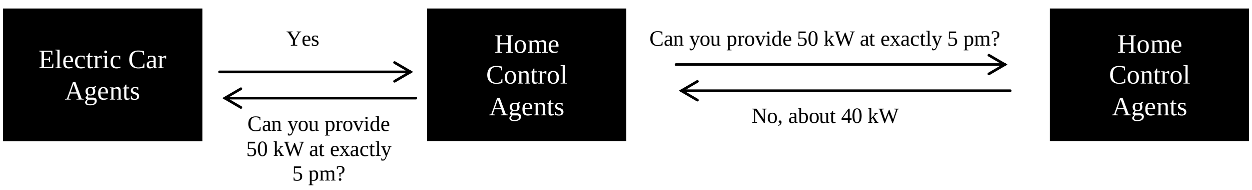

Fig 6. Simplified Illustration of how Three Agents Could Work Together to Resolve a Capacity Issue

Social Behavior

According to Chen, Zhang, Qu, and Wang [7], agents need to exhibit social behaviors that are agreeable to other agents. They can self-organize and coordinate in order to achieve objectives that a single agent would not be capable of; and their social structure and decision-making processes can shift over time and across different systems. Through conversations, requests, and contracts, agents may affect the activities of others or serve as interfaces. Before the MAS resolve that the battery should absorb the peak, it may "discuss" the matter with other potential agents, (e.g., the power distribution brokers) to determine if loads could be captured by other sources and, if so, whether a more cost-effective and technically superior alternative exists. As another example, consider a smaller DC micro-grid where bus voltages are is kept constant by a battery. In order to regulate the voltage on the bus, the battery agent may request the assistance of other agents if the battery shows signs of running down.

Practical Implications

According to Ding, Shi, and Luo [8], smart grids depend heavily on MAS, and the latter makes it possible to describe communication features that are otherwise seldom taken into account in research on power systems. This feature allows MAS-basedprototype technologies to be more practically deployable and widely deployed. Specifying the necessary hardware is made easier when the roles of the various components of the system are defined.

Application of MAS for Power System Control

The control of a smart grid necessitates a system that is adaptable and scalable, both of which are built into MAS [9]. As can be seen in **Fig. 7**, MAS allow agents connected to actuators, sensors, a communication network, and grids to potentially to communicate with one another and make informed decisions about how electricity is distributed and used. Smart-grid technologies including VAR/voltage controls, power management, regeneration, fault diagnosis, and surveillance have shown promising results when implemented using MAS as a control framework.

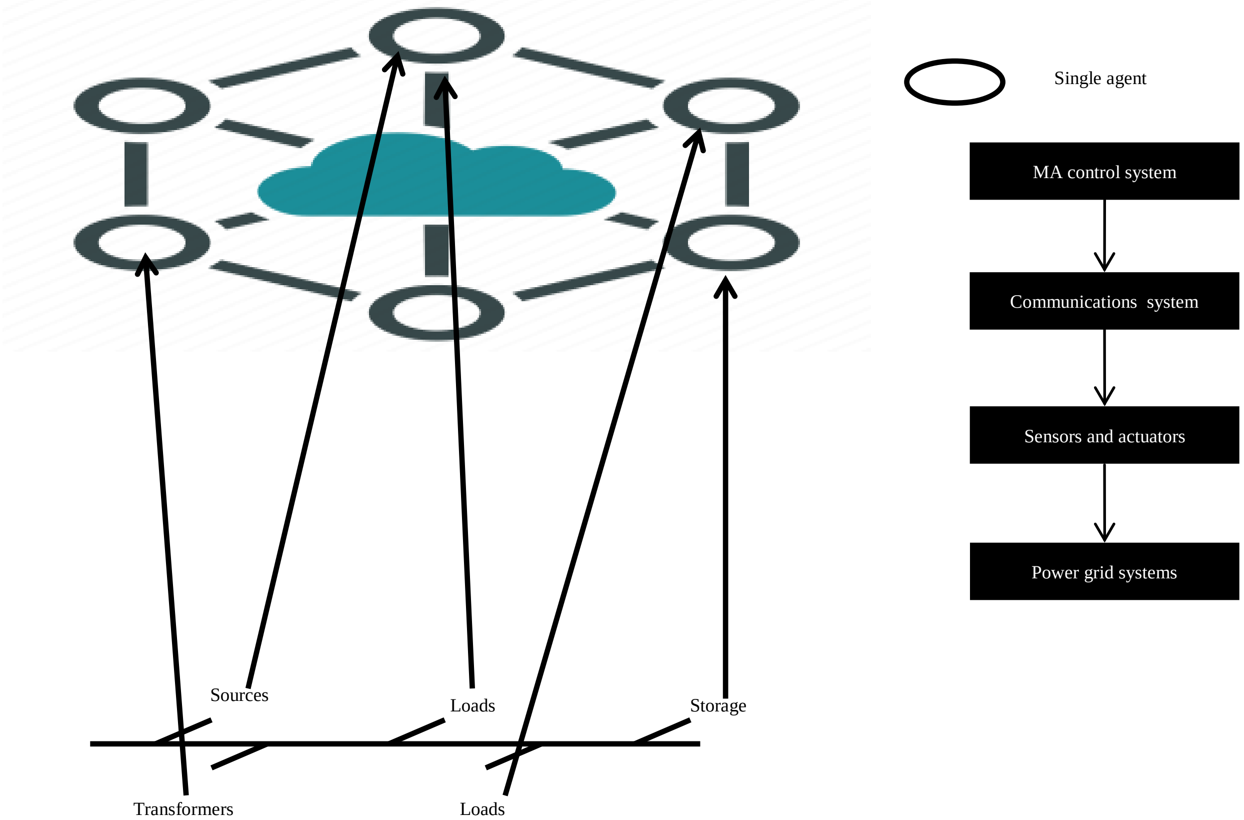

Fig 7. Power Grids, particularly Smart Grids with their Heavy Reliance on Connectivity and dispersed assets, are well suited for MAS monitoring and Control.

Application of Fuzzy in Power System

The entire realm of classical mathematics has embraced fuzzy theory. Better outcomes may be achieved by incorporating Fuzzy into the electricity system. The use of fuzzy logic has become more important in the engineering and business sectors. For complex consumer choice and control issues, this gives a user-friendly solution. Fuzzy set techniques provide several useful characteristics and capabilities, including (i) the ability to combine logical and numerical approaches. (ii) Soft constraint models. (iii) Norms for settling disputes involving many competing goals. (iv) A solid mathematical basis for modifying the aforementioned representations.

Many different sources of uncertainty contribute to the complexity of power systems issues. Fuzzy modeling may be used for this. Different issues with systemic awareness have emerged. These issues must be fixed for the system to function as intended. Uncertainty in the system may be traced back to flawed models of the system, while the decision-making process is responsible for introducing new restrictions and goals. Numerous applications within the power system need the use of fuzzy sets, including: reactive voltage/power control, load forecasting, security evaluation, reactive voltage/power management, load management, and contingency analysis.

Each rule in the power system's rule-base has an associated probability that is utilized to make decisions. Assume an overcurrent has caused a distribution circuit breaker to trip. Uncertainties of "high" and "frequently" are to be modeled, and both are best captured by a fuzzy set and fuzzy measure, respectively. The numerical numbers connected with the improbability are taken into account while the mathematical model is constructed.

According to Pedrycz, Dong, and Hirota [10], the evolution of fuzzy sets has traditionally been governed by a control architecture known as the "fuzzy controller." A series of rules are used by the controller to make a call, including (i) IF Temp is positive and higher (ii) AND Temp change is fundamental and negative (iii) THEN control out is negative and minimal. The extent of permissible output and input values determines the membership functions that may be used. Traditionally, fuzzy a logic controller has been presented for stability control in power systems. Decisions and optimization in fuzzy systems take optimum power flow into account. Minimizing expenses, making fewest possible changes to controls, and producing fewest possible emissions of pollutants are all possible goals. Voltage limitations on generator and load buses, flow rates on lines, and safety margins for failure are all examples of physical constraints that must be met. The field of fuzzy mathematics offers a rigorous mathematical foundation for such problems.

IV. MAS APPLICATION IN POWER SYSTEM ENGINEERING

Case Study

To further understand how multi-agent systems may be used for power system tariff management, a case study is shown below. In this approach, several kinds of multi-agent systems are used for the command and control hub, the data collecting, and the smart operation. System 1 and 2 are emulated using solar and wind power plants, respectively, with MATLAB Simulink acting as the intermediary between the two and the grid. In system 3, where the fuzzy logic controller was created, we use the TCP/IP protocol for inter-system communication.

Demand side management for the smart grid was simulated in MATLAB/Simulink. Here, efforts were made in three distinct virtual worlds. System 1 simulates solar power production combining photovoltaics with battery storage. These use a fuzzy controller to regulate the connection between the batteries and solar panel module. Here, we assume that the sun's radiation is always the same. Connecting both the critical and non-critical load to the grids facilitates load analysis. Circuit Barker 1 connects this solar output to the power grid. At each step, the measuring devices take readings of vital grid characteristics such line current, line voltage, load current, load frequency and load voltage. Fuzzy Logic Controller(FLC) receives the converted data from the sensors.

Controller Functioning and Design

In this study, we use Fuzzy Logic Controllers (FLC) [11] due of the space-saving nature of its architecture. FLC may accommodate an arbitrary number of input and output variables. When compared to the results obtained without using the else-if conditional, the FLC's output is superior. It would be optimal to use the else-if condition in more sentences. In this example, we apply a fuzzy inference training model to the process by which converters produce their output. It is fundamental to note that fuzzing operations of these two methodologies are identical; the only difference is that the Sugeno model produces constant or linear output, while the Mamdami model generates variable outputs.

PV solar modules consisting of 36 sun cells wired in series and producing 230 W were used to design the solar power plant. Twenty kilowatts (kW) of power may be generated by combining series and parallel configurations. Battery storage is an important part of this system since it allows us to make use of the solar plant's overflow. A circuit breaker that can communicate via IP is used to connect the solar power plant to the grid. With the goal of maintaining consistent power quality, a 5 MW self-operated wind power plants with capacitor banks were developed in MATLAB Simulink. The wind farm's output is linked into the larger power grid by use of IP-based circuit breakers.

Several sensors measure and record the wind's effect on the voltage, power, current, and power factor. In order to communicate with the FLC, the sensor readings are normalized into standard parameters. For the intelligent tariff management system to work, FLC has to receive data from the main grid and the solar power plant. The FLC produces defuzzing output in the 1-10 range. The output from the defuzzing process is used as inputs to the IP-based circuit breakers. Depending on the fuzzy rules used, the statuses of the circuit breakers will shift correspondingly.

The simulation models are built in three distinct settings for a more complete picture. System 1 was devoted to the model of the solar power station, whereas System 2 was devoted to the design of a wind power plant. In the third system, a fuzzy logic program was developed. After collecting data from sensors, the transformed parameters are saved in an Excel spreadsheet for analysis. The instruction from the energy control center steps pulse from the FLC to trip the breakers (ECC). Fuzzy instructions translate the control frameworks into the Excel value, which is then imported into a dataset agent via a MATLAB command, and transfer it to the workspace before simulation. FLC makes a call on what to do based on the values of the input voltage. The ECC is in charge of keeping tabs on and regulating the size of the solar and wind sector's voltage generation on a consistent basis. Information generated by solar and wind power facilities is sent using TCP/IP networks (see **Fig 8**).

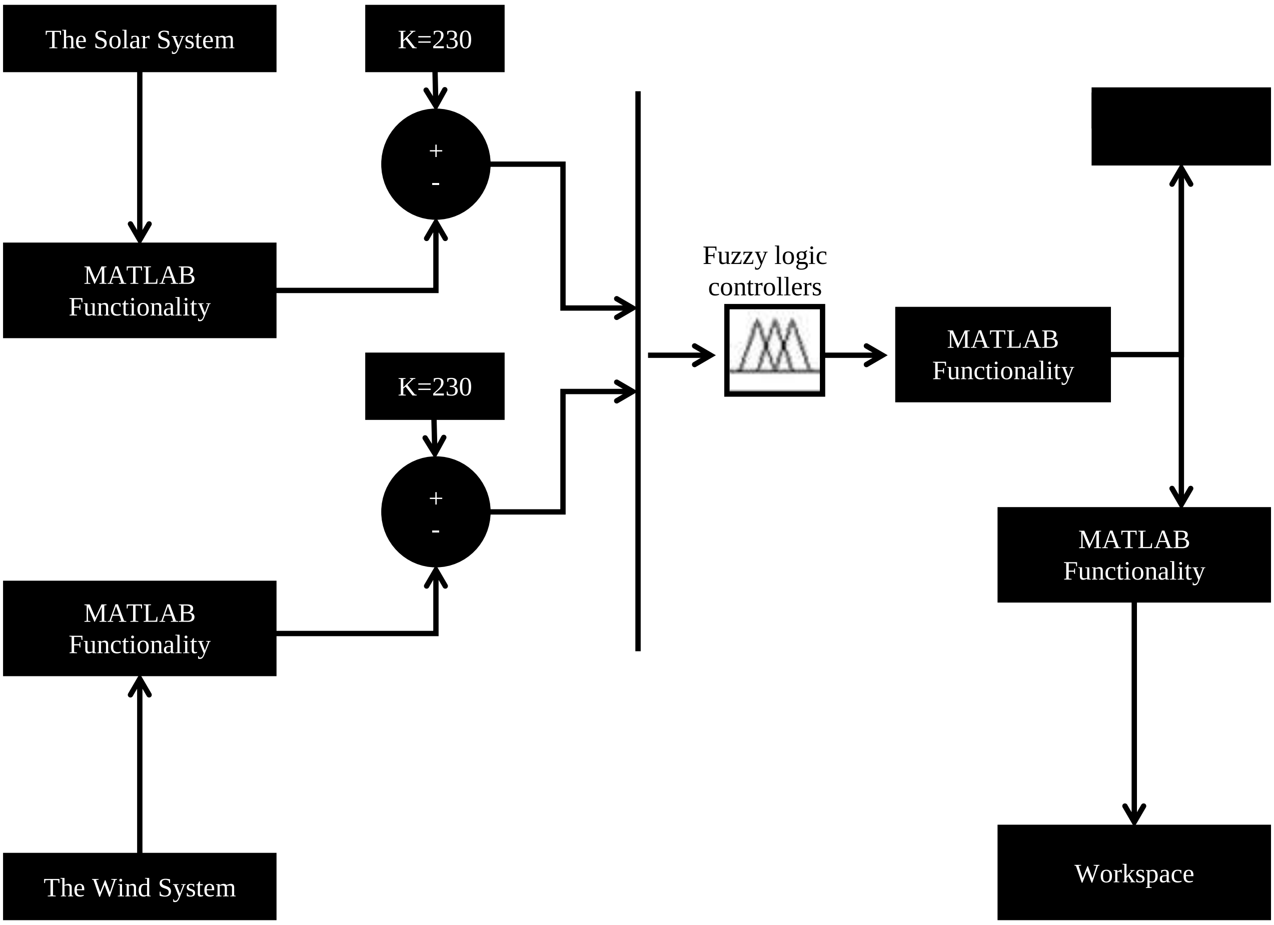

Fig. 8: Fuzzy Logic Controller within the System Operation model

V. CONCLUSION

The Multi-Agent System (MAS) was created using TCP/IP and other common communication methods. Multi-agent systems are used in the smart grid and micro grid to provide efficient demand-side control. With MATLAB commands and a Simulink model, the system provides an algorithm for demand responsiveness that takes into account tariff rates and time of use. The systems for the sun and the wind are created in separate Simulink settings for simulation. Import and export data from wind, solar and grid components by use of MATLAB commands were discussed, as were the creation and deployment of a MAS developed using the fuzzy logic toolkit. Data flow, design process, parameter definition, and a surrounding environment, which generates multi-agent codes are necessary for developing a multi-agent system. These limitations are taken into account while writing the fuzzy logic controller's code. Information agents are created with the purpose of ensuring the system runs well and can be relied upon for future use. Excess energy produced by solar power systems may be stored in batteries for later use. In order to reach the system's ultimate aim, these agents are now gathering its current condition. Data collected by many agents is compiled into an Excel spreadsheet using MATLAB commands and then sent back to the controller. Two distinct simulation environments, one each for solar and wind, are created, with their own dedicated control agent development system, for this purpose. It was highlighted how the TCP/IP protocol allows for safe and dependable communication between systems. Finally, the system has been put through its paces, and the results have been tabulated and graphically shown to illustrate how much better off consumers will be under the real-time tariffs in comparison to time-of-day tariffs.

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