Journal of Positive Sciences (JPS) **eISSN: 2582-9351, https://positive-sciences.com** **JPS. 2023 May; 3(3): 1-22**

Article info
Received on: 01.05.2023
Accepted on: 28.05.2023
Published on: 31.05.2023
doi: https://doi.org/10.52688/ASP70580

Research Article

Design And Implementation Of Energy Management Systems By Using Fuzzy Logic

Zuhair Shakor Mahmood [1, *]

[1] Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq

[*] zuherkazanci@ntu.edu.iq

ABSTRACT

This research offers a comprehensive analysis of the design and implementation of a Fuzzy Logic Controller (FLC) with a moderate level of complexity, specifically including a total of 25 rules. The major goal of the controller is to provide seamless integration into an Energy Management System that is specially customized for a residential microgrid, which is interconnected with the primary electrical grid. The microgrid system is outfitted with sustainable energy sources and has the capability to store energy. The underlying assumption of the system is that the operator lacks control over both the renewable energy generation and the load demand. Instead of using forecasting-based methodologies, the suggested methodology integrates the rate-of-change of energy inside the microgrid and the state of charge (SOC) of the battery to control the power delivered or absorbed by the primary power source. This functionality enables the ability to adjust, reduce, or maintain levels of power. In order to enhance the operational efficiency of the microgrid, adjustments are made to the design features of the controller, specifically focusing on the membership functions and rule- base. The purpose of these enhancements is to optimize a predetermined set of quality criteria that are pertinent to the functioning of the microgrid. This study offers a comparative analysis of several approaches that seek to attain a shared outcome at the simulation level.

Keywords: Smart grid, renewable energy sources, fuzzy control, microgrid, energy management

INTRODUCTION

Due to the positive environmental economic and implications linked to the mitigation of carbon dioxide emissions and transmission losses, there is a growing likelihood of expanded use of distributed renewable producing technologies in the development of forthcoming intelligent grids. Microgrids are well recognized as essential elements of smart grids in the current context, and they have attracted considerable attention in the last decade owing to their projected potential[1][2]. Numerous scholars and researchers have undertaken comprehensive investigations pertaining to the concept of Microgrid (MG). Furthermore, within the particular context of a microgrid (MG), it is highly recommended to use Energy Storage Systems (ESS) such as batteries, flywheels, and ultracapacitors, in conjunction with Energy Management Systems (EMS). With consideration of the probabilistic characteristics inherent in renewable energy sources and the power used by the load, the objective of this endeavor is to enhance the stability and performance of the system. In general, microgrids have the capability to operate in either a connected or autonomous manner with respect to the main power grid. In essence, a microgrid may be defined as a low-voltage system that integrates various kinds of loads, storage devices and distributed generation units[3]. The aforementioned components are linked to the main power grid at a single Point of Common Coupling. The Energy Management System is responsible for overseeing and controlling power fluctuations within the various components of the Microgrid (MG), with the aim of achieving certain pre-established objectives. The study goals may include the reduction of operating expenses for the microgrid (MG) and the enhancement of income via bids from Distributed Generators (DG) and the current energy market pricing[4][5]. Moreover, it is essential to prioritize the power architecture of the energy management system (EMS) in order to effectively address the power management. capabilities of the microgrid (MG) components. The methodology entails the identification of sources, loads, and storage components that may be effectively controlled. After the establishment of the power hierarchy and the identification of particular goals, the implementation of the Energy Management System (EMS) design may be approached via many techniques. Within the current setting, there exists a wide array of literature that delves into an assortment of power dynamics, objectives, and methodologies. An example of an energy management system (EMS) involves the utilization of local forecasting and local prediction, in combination with (SDP), to effectively regulate and prolong the operational lifespan of an energy storage system (ESS) integrated within a gridconnected microgrid (MG) that encompasses both diesel and renewable generation sources. Moreover, the Energy Management System (EMS) has been especially designed to prioritize the use of a predictive control

---

[*]**Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

methodology for the purpose of efficiently governing the Energy Storage System (ESS)[6][7]. The primary aim of this effort is to address the hourly oscillations that occur within a projected energy system inside a grid-connected Microgrid (MG).

Furthermore, the use of Fuzzy Logic Control has been utilized in the advancement of Energy Management Systems (EMS). This scholarly work presents a novel Energy Management System (EMS) that integrates fuzzy control. The system indicated above functions as an additional focus point in combination with autonomous systems for a Direct Current Microgrid (MG). The main aim of the fuzzy logic controller is to prioritize the sale of surplus electricity generated by Renewable Energy Sources (RES), while simultaneously ensuring that the State of Charge (SOC) of the battery remains above 50% to maximize its lifespan. Moreover, this study presents a novel Energy Management System (EMS) that integrates a Flexible Load Controller capable of accounting for price fluctuations throughout a 24-hour timeframe, energy demands, power generating capabilities, and temporal variables. The primary objective of the Energy Management System (EMS) is to ensure the cost-effectiveness and reliability of the electrical grid[9][10]. There has been a lack of academic attention given to the prioritization of decreasing oscillations in the grid power profile as a fundamental objective of the Energy Management System (EMS). In contrast, the main focus of this study is in the establishment of a power architecture that revolves on a microgrid (MG) linked with a residential grid. The microgrid under consideration integrates both wind and solar power generation to meet the energy demands of residential consumers. It is crucial to acknowledge that the scope of control for this system is only confined to the battery. In addition, the existing dataset contains historical yearly data pertaining to the generation of electricity from renewable energy sources (RES) and the consumption of power load. It is noteworthy to mention that the dataset lacks options for forecasts about generation and demand. The following scenario presents a systematic framework for the integration of renewable energy sources into existing infrastructure. The integration of renewable generators, such as wind and solar, in combination with a battery energy storage system (ESS), enables the seamless integration of renewable energy sources into pre-existing systems[8]. The use of this approach has garnered interest from power electronics makers, The primary objective in this particular context is to enhance the uniformity of the power profile sent to the grid. The achievement of this objective has significant relevance as it enables improved supervision for the grid operator, along with several other benefits.

In summary, the focus of the EMS design for the examined case should be on achieving power exchange with the grid in a more consistent manner, while also ensuring the continuous fulfillment of load demand without implementing demand side management. Furthermore, it is imperative for the design to consider the constraints and specifications of the Energy Storage System (ESS). The other hand, Barricarte et al. put forth an Emergency Management System (EMS) design that makes use of heuristic knowledge pertaining to the intended behavior of a microgrid (MG). The proposed design entails the utilization of adjustable analytical expressions to compute power allocation to the grid and the storage system. The aforementioned expressions consider the relative distribution of power between consumption and generation, as well as the level of charge in the battery, which are regarded as the primary variables[11].

In the specific context being examined, it is recommended to use Fuzzy Logic Control as the favored methodology for the development and implementation of the Energy Management System (EMS). This paradigm facilitates the seamless incorporation of human knowledge, as opposed to only relying on a quantitative representation of the system. The Fuzzy Logic Controller (FLC) design was established by scholars and had a concise collection of 25 rules. The aforementioned criteria were established based on the use of identical input data. The previous research shown that this specific design led to relatively little improvements in both the battery State of Charge (SOC) and the grid power profile. This research provides a comprehensive examination of the design aspects of rule-based systems and Membership Functions (MF), with specific emphasis on the optimization of parameters, including their quantity and mapping. The primary aim of this fine-tuning procedure is to enhance the performance of the MG behavior by conforming to a predetermined set of quality requirements. The optimization methodology was implemented by using a simulation of an offline educational procedure[12][13]. Furthermore, a study was carried out to propose a better layout of an Energy Management System (EMS) using the same design process, with an emphasis on the use of Fuzzy Logic Control (FLC). An FLC with 50 rules was developed for the present design, which takes into account the MG Net Power Trend (NPT) as an additional input. Based on the data, it seems that power outages and other major fluctuations in the system are rather rare and small. However, an increase in controller complexity has been seen. Moreover, a common constraint of the aforementioned designs is their limited capability to operate efficiently in scenarios characterized by substantial fluctuations in renewable energy source (RES) production from one day to the next. In these situations, there is a possibility that the battery's state of charge (SOC) might surpass the predetermined limits, thereby posing a risk to the overall longevity of the battery. This study presents a novel Energy Management System (EMS) that makes use of Fuzzy Logic Controller (FLC) to improve the efficacy of the aforementioned designs and streamline the complexity of the FLC, with a focus on reducing the number of controller inputs and its rule-base. The considered EMS setup has 25 rules and two input variables and one output variable. The novel architecture's primary goal is to take the MG Energy Rate-of-Change (ERoC) into account as a parameter, enabling advanced foresight into and prediction of the system's behavior. The strategy for the design will be in accordance with the optimization method and technique outlined for the offline controller settings. The purpose of this research is to examine the similarities and differences between the SMA technique, the Fuzzy EMS-NPT method, and the Fuzzy EMS-ERoC method. The simulation level is where we'll undertake our testing and assessment, with an emphasis on dissecting the unique characteristics of the Fuzzy EMS-ERoC approach. A real-world home microgrid environment will be used for the evaluation. The paper is structured in the following fashion. Section II provides a comprehensive analysis of the architectural components and characteristics associated with the MG. In Section III of the paper, a comprehensive collection of quality criteria is presented, with a special focus on assessing the grid power profile. In this study, Section IV provides a thorough analysis of prior methodologies used in the field of emergency medical services (EMS). In this section, a thorough examination of the conception and structure of the proposed fuzzy Energy Management System (EMS)

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

is provided. The fundamental basis of this system is predicated upon the assessment of the energy's rate of change inside a Microgrid (MG)[14[15]. In this research, Section VI provides an analysis of the simulation and comparative data pertaining to the Energy Management Systems (EMSs). The primary emphasis is in the evaluation of the performance of these systems, particularly with regards to the quality requirements associated with the grid power profile. Section VII of the document presents a comprehensive elucidation of the validation procedure for the proposed EMS design, substantiated by empirical data. In this scientific journal, Section VIII presents a succinct summary of the main results and their corresponding consequences.

DESCRIPTION OF A MICROGRID

The investigation methods used in this study are shown in Figure 1. A small Wind Turbine (WT) with a power output of 5.5 kW, a Photovoltaic (PV) array with a power output of 4 kW, and a lead-acid battery bank with a storage output of 70 kWh make up the components of the Microgrid (MG). Figure 1 depicts the power architecture that is a direct result of the INGECON® HYBRID system.

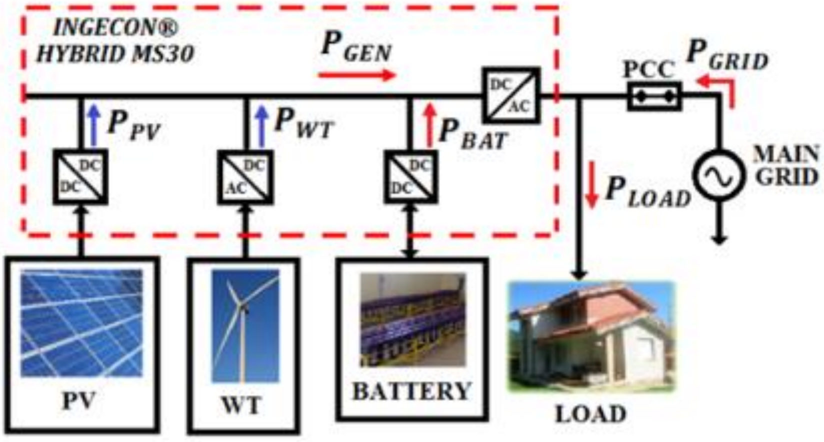


Figure 1: A microgrid that connects homes to the main power grid is

The subject of an ongoing research project. The MS30 commercial power stage is extensively utilized in a variety of commercial applications. The power stage is comprised of a wind turbine (WT), a photovoltaic (PV) power conversion module, and a battery charger, all operating on a common direct current (DC) bus. To control the flow of energy between the system and the mains grid, a bidirectional inverter-rectifier module has been included into the power stage. The power fluxes depicted in Figure 1 are deemed positive in accordance with the directional indicators symbolized by the arrows. The mathematical equations representing the net power, denoted as

$$P_{GEN} = P_{WT} + P_{PV} \qquad (1)$$

$$P_{GRID} = P_{LG} - P_{BAT} \qquad (2)$$

$$P_{LG} = P_{LOAD} - P_{GEN} \qquad (3)$$

Within this particular framework, the variable P_{load} signifies the amount of power consumed by the load. P_{GEN}, on the other hand, denotes the quantity of power generated from renewable sources. More specifically, PPV represents the power generated by photovoltaic systems, while P_{WT} represents the power generated by wind turbines. Lastly, P_{BAT} signifies the power that is stored in batteries. The performance-based availability test (P_{BAT}) is influenced by the state of charge (SOC) of the battery. It is crucial to maintain the SOC within specified limits, namely SOC_{MIN} and SOC_{MAX} in the order to optimize the battery's lifespan,

$$SOC_{MIN} \leq SOC(n) \leq SOC_{MAX} \qquad (4)$$

Where:

---

[*]**Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

$$SOC_{MIN} = (1 - DOD) \cdot SOC_{MAX} \qquad (5)$$

The term "Depth of Discharge" (DOD) pertains to the extent of battery discharge within the framework of the Department of Defense (DOD). This study examines the impact of a maximum depth of discharge (DOD) of 55% on the lifespan of this particular battery type, as operating at high DOD levels has been found to significantly decrease its longevity. To prevent the battery from being discharged or overcharged beyond safe thresholds, it is necessary for the Energy Management System (EMS) strategy to interrupt the flow of power being supplied to or absorbed by the battery. In these instances, when P_{BAT} equals zero, or as stated in equation (1), when P_{GAIN} is equal to P_{GRID} is equal to P_{LG}, it can be inferred that the grid effectively manages all power fluctuations. The estimation of the battery's State of Charge (SOC), as illustrated in Figure 2, is utilized to determine the current SOC of the battery. The SOC (System-on-a-Chip) is commonly denoted as:

$$SOC(n) = SOC(n-1)\Delta SOC(n) \qquad (6)$$

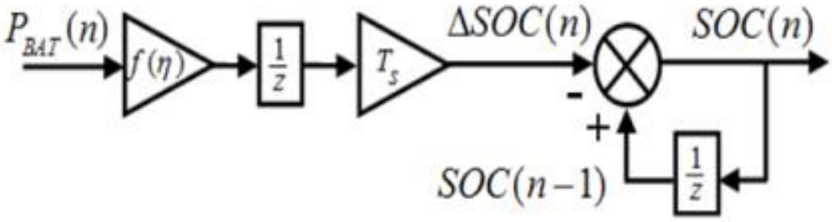


Figure 2: The block diagram for battery energy computation.

The percentage of charge retained by the battery during the course of the sampling interval T_S is denoted by the symbol ΔSOC (n). This may be estimated using the universal concept of energy change, ΔEi, which is linked to a power variable Ti over a certain time interval, ΔT. If the integration and sampling times of the sampled variables are the same (i.e., $\Delta T = T_S$), then the change in state of charge (ΔSOC) at time n may be represented mathematically as:

$$\Delta E_i(t) = \int_{t}^{t+\Delta T} P_i(\tau)\, d\tau \qquad (7)$$

$$\Delta SOC(n) = \int_{(n-1)T_S}^{nT_S} f(\eta) P_{BAT}(\tau)\, d\tau = f(\eta) P_{BAT}(n-1) \cdot T_S \qquad (8)$$

The function f(η) represents the efficiency of a battery, taking into consideration the separate efficiencies related to the charging and discharging procedures.

$$f(\eta) = \begin{cases} 1/\eta, \forall P_{BAT} \succ 0 \\ \eta, \forall P_{BAT} \prec 0 \end{cases} \qquad (9)$$

The present case study assumes that the extraction of maximum renewable power is carried out by the wind and photovoltaic (PV) modules, while the power consumption of the AC load is not subject to control. To clarify, it is not possible to exert control over P_{LOAD} and P_{GEN} consequently, the control of P_{LG} is also unattainable. Conversely, the power that is transferred to and from the grid, denoted as P_{GRID} , will be regulated by the use of a bidirectional inverter-rectifier. Simultaneously, the battery charger will

---

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

effectively control the power of the battery, represented as P_{BAT}, based on equation (1), provided that it has the required capacity to do this task.

In addition, the load power (P_{LOAD} generation (P_{GRID}) and renewable power P_{GRID} were observed over a period of one year, from February 2022 to February 2023. Power analyzers were utilized to collect data at regular intervals of 20 minutes (i.e., a time for a sample of T_S = 915 seconds) throughout the duration of the study. Figure 3 displays the recorded power P_{LG} . The forthcoming sections will demonstrate the utilization of this data in the design of the EMS.

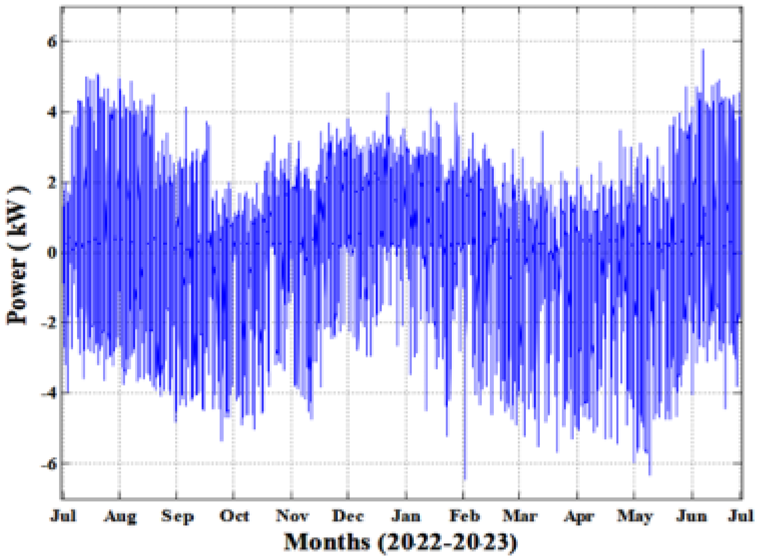


Figure 3: The power profile of a microgrid as seen at its point of interconnection.

The purpose of the power inverter-rectifier is to reduce the impact of the grid's power fluctuations and peaks on the power profile that is ultimately sent to the grid. Simultaneously, it ensures the preservation of the battery's state of charge (SOC) within a range that is considered to be safe. In this part, a set of established criteria is presented for evaluating the amount of smoothness achieved by a design of an Energy Management System (EMS) while examining the numerical value of the grid power profile.

REQUIREMENTS FOR ELECTRICITY GRID QUALITY

Indicating that a higher degree of performance in the Energy Management System (EMS) is connected with a drop in the value of these criteria is the point of defining a set of quality criteria for grid power profiles.

POWER SURGES, BOTH POSITIVE AND NEGATIVE ON THE GRID

The variables P_(G.MAX) and P_(G.MIN) denote the upper and lower limits of power peaks inside the grid, correspondingly. The aforementioned numbers represent the maximum power production and input to the grid for a one year timeframe.

$$P_{G,MIN} = \min\left(P_{G,RID}\right), \qquad (10)$$

$$P_{G,MAX} = \max\left(P_{G,RID}\right), \qquad (11)$$

DERIVATIVE OF POWER AT ITS PEAK AND AVERAGE VALUE

The Maximum Power Derivative (MPD) is a statistic used to measure the highest rate of change of the grid power profile over a specified period of one year. The computation entails the determination of the slope between two successive samples, with a fixed sampling interval of 20 minutes. The Maximum Peak-to-peak Deviation (MPD) is operationally defined as the highest magnitude

---

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

of the absolute values of the slopes observed within a given calendar year. The concept of the Average Power Derivative (APD) can be mathematically expressed as the modulus of the annual average value of the gradients between two successive samples. Both criteria are denoted in watt-hours (W/h) and are computed in the following manner:

$$\dot{P}_{GRID}(n) = \left(P_{GPID}(n) - P_{GPID}(n-1)\right)/T_S \qquad (12)$$

$$MPD = \max\left(\left|\dot{P}_{GRID}\right|\right) \qquad (13)$$

$$APD = \frac{1}{N}\sum_{n=1}^{N}\left|\dot{P}_{GRID}(n)\right| \qquad (14)$$

Within the given framework, the variable P_{GRID} denotes the rate at which the grid power profile undergoes a change in magnitude over time. The variable N represents the total number of samples taken within a year, while T_S denotes the duration of each individual sampling period. Lastly, the variable n refers to the index of each individual sample.

THE PPV THE POWER PROFILE VARIATION

The specified criterion, as delineated in the provided source, measures the level of variability in the grid power profile through a computational process.

$$PPV = \sum_{f=f_i}^{f_f}\sqrt{P^2_{GRID,f}}\Big/P_{DC} \qquad (15)$$

The variable #$%&.8 represents the harmonic power of the grid at a specific frequency f. The variables 5 and the frequencies at the beginning and end, respectively. Additionally, The given metric denotes the mean power value throughout a yearly duration. It is crucial to recognize that this specific criterion only evaluates frequencies that exceed 5 = 1.50×10-5 Hz, which corresponds to variations lasting one week or fewer. The rationale behind implementing an energy management strategy lies in its objective to effectively address the daily fluctuations that arise in energy consumption. In addition, the computation of positive predictive value (PPV) necessitates a maximum frequency that is equivalent to the sampling frequency divided by two, denoted as 8 = 4.95×10 -4 Hz, which corresponds to the Nyquist frequency.

PRIOR EMS APPROACHES

To provide a comprehensive comparison, this section introduces two strategies documented in the existing academic literature. The purpose of these methods is to dampen the power profile's fluctuations.

THE MOVING-AVERAGE-BASED (MMA) APPROACH

To identify the microgrid's power sources by frequency, the SMA method employs a fundamental moving average filter with a window size of one day. With this method, a more stable power profile for the grid may be attained. Therefore, the high-frequency component is either supplied by the battery during low-battery states or drawn from the battery during high-battery states. The low-frequency part, on the other hand, is sent into the grid in one of two ways: either as an injection during times of surplus power or as a drawdown during times of scarcity.

$$P_{GRID}(n) = P_{AVG}(n) \qquad (16)$$

$$P_{AVG}(n) = \frac{1}{M}\sum_{k=n-M}^{n-1} P_{LC}(k) \qquad (17)$$

$$P_{BAT}(n) = P_{LG}(n) - P_{AVG}(n) \qquad (18)$$

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

The low-frequency component of ": is denoted by , and the total number of samples collected in a given time period is denoted by M. The Simple Moving Average (SMA) method's block design is shown in Figure 4. To separate the low-frequency component of , the current technique employs the usage of a low-pass filter (LPF). Figure 2 also shows how the state-of-charge (SOC) estimator is implemented inside this specific strategy.

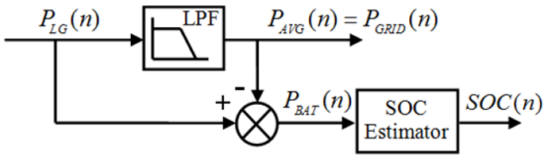


Figure 4: Structure of an EMS using a simple moving average.

The simulation results, including battery state-of-charge (SOC) and SMA approach grid power profile, are shown in Figure 5. The results were achieved by using a low-pass filter (LPF) on the data collected over a 24-hour period, which was applied to both electricity generation and consumption. When this method is put into action, the grid's power profile shifts significantly, bringing the battery close to its safety thresholds at varying times. Here, we'll offer a detailed study of the SMA technique's simulated outcomes, with an emphasis on the regular evaluations.

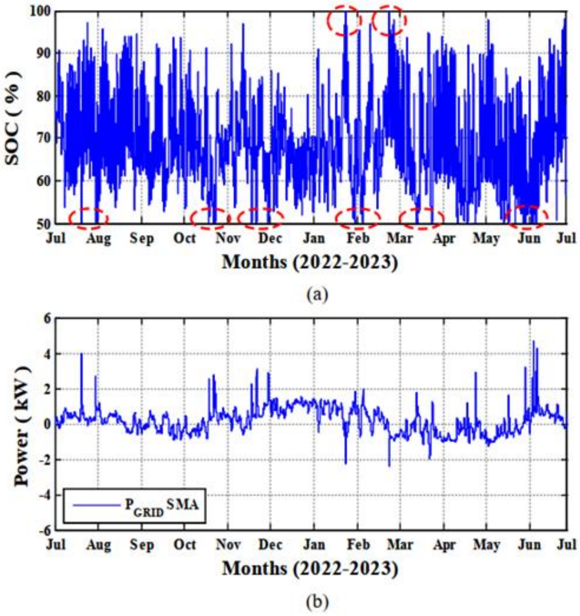


Figure 5: The SMA strategy's simulation outcomes are shown. Battery state-of-charge (SOC) is shown in Figure (a), with dashed lines denoting the times at which the battery approaches its SOC limitations. The power profile of the Page 7 of 30 grid is shown in Figure (b).

DEVELOPMENT OF A FUZZY EMS UTILIZING THE MG NPT

A proposition was presented to formulate a plan for the development of a design for an Energy Management System (EMS) based on Fuzzy Logic Controller (FLC) technology, with the objective of resolving the previously described issue. The present design will be delineated in order to facilitate a comparative analysis. Fuzzy Logic Controller (FLC) with Three Inputs and One Output Following is a diagram of a fuzzy logical controller (FLC) that clearly illustrates the idea. Fifty separate rules make up the FLC as a whole.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

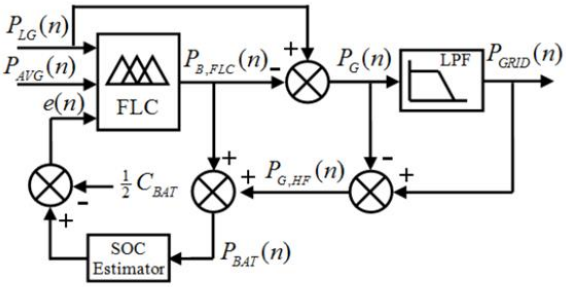


Figure 6: The design of a fuzzy emergency management system is derived from the block diagram representation of the MG net power trend.

The Evolutionary Multi-Objective method (EMS) differs from the Sequential Minimal Optimization (SMA) technique by including supplementary input variables with the MG net power (n) inside its recently constructed framework. The elements under investigation include the state of the battery in relation to its half useable capacity, denoted as e(n), together with the average power "# (n) (18) of the net power "# (;# (n). The criteria described above are used for evaluating the consumption or production trend inside the microgrid. The Fuzzy Logic Controller (FLC) utilizes a predetermined set of rules to concurrently optimize the power profile and improve the State of Charge (SOC) of the battery. To provide an example, a regulation can be exemplified as follows: "If the net power (n) of the microgrid (MG) exhibits a marginal negative value [i.e., "#"# (n) < 0, indicating an excess of generation compared to consumption], and the battery indicates a moderate level of charge [i.e., e(n) > 0, or equivalently SOC (n) > /2]." In circumstances when the MG trend shows significant consumption, it is advisable to prioritize the recharging of the battery as a method to offset this consumption tendency in the immediate future. Logic Controller (FLC) assumes in facilitating the desired advancement of the low-frequency battery power, referred to as . Given the assumption that the battery follows this power development, it is possible to ascertain the corresponding grid power profile in the following manner:

$$P_G(n) = P_{LG}(n) - P_{B,FLC}(n) \qquad (19)$$

However, the power being discussed comprises the high frequency components of (n), which may be attenuated by implementing a low-pass filter (LPF) as suggested in the previously referenced reference. As a consequence, the outcome is the attainment of an elevated degree of uniformity and steadiness in the efficient infusion of electrical power into the grid. Mathematical representation of this phenomenon may be expressed as:

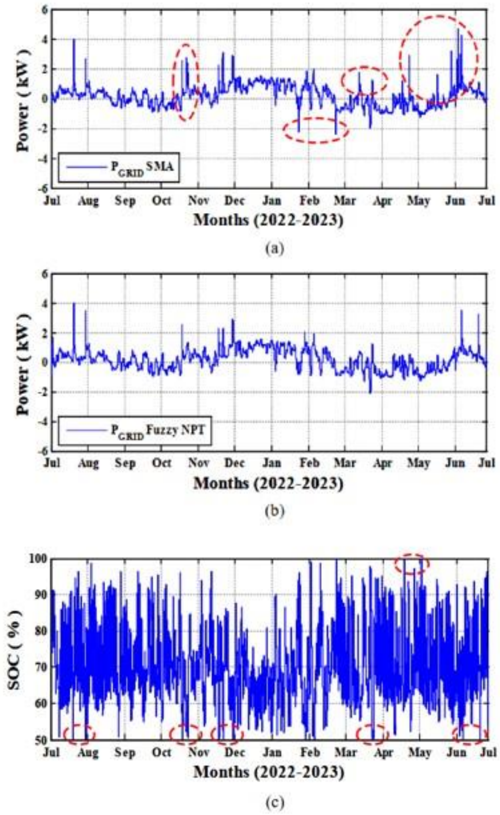
$$P_{GRID}(n) = P_{G,LF}(n) \qquad (20)$$

The symbol (n) is employed to represent the low frequency component of (n). Therefore, the power being controlled by the battery can be mathematically represented as:

$$P_{BAT}(n) = P_{B,FLC}(n) + P_{G,HF}(n) \qquad (21)$$

Within this particular framework, the variable (n) is used to represent the high-frequency component of The power profile of the grid obtained by the use of the SMA approach is shown in Figure 7(a). In comparison, the grid power profile and battery state of charge (SOC) resulting from the use of the fuzzy approach employing the Microgrid Non-Parametric Tracking (MG NPT) method are shown in Figures 7(b) and 7(c), respectively. It is important to recognize that the consumption and generation data used in both techniques are identical. The parameters of the fuzzy logic controller (FLC) used in the simulation may be found among the accessible resources.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq



(a)

(b)

(c)

Figure 7: The subsequent findings of the fuzzy EMS simulation provide a comparison between two methodologies using the MG NPT: (a) the SMA approach and (b) the grid power profile.

The state-of-charge (SOC) of the battery is shown in the graph, with dotted lines indicating instances when the SOC exceeds its prescribed limits. The findings shown in (d) are obtained from a simulation that compares the performance of the microgrid non-proportional-integral-derivative (NPT) based fuzzy energy management system (EMS) method. In contrast to the simple moving average (SMA) strategy, this particular approach demonstrates a notable capacity to successfully alleviate fluctuations within the grid power profile. Nevertheless, it is evident from Figure 7(c) that the battery's state of charge (SOC) may reach the desired safe levels. However, this is achieved within shorter time periods as compared to the SMA approach. In addition, the incorporation of new information into the structure of the Energy Management System (EMS) results in an increase in the number of inputs for the fuzzy logic controller (FLC), as well as its rule-base, hence leading to a heightened level of complexity.

COGNITION ENERGY RATE OF CHANGE (EROC) USED IN DEVELOPMENT OF THE FUGGETED EMS CONCEPT.

METHODS OF REGULATION

This section proposes a concept for an enhanced Energy Management System (EMS) that integrates the use of a Fuzzy Logic Controller (FLC). The primary goal of this design is to reduce power peaks and fluctuations in the grid power profile, while simultaneously maintaining the battery's State of Charge (SOC) within acceptable thresholds. Furthermore, the objective is to decrease the intricacy of the fuzzy logic controller. The suggested EMS design introduces a novel approach for the calculation of grid power, showcasing innovation in the field. The procedure involves the incorporation of the average net power value of the microgrid, denoted as (n), with an additional component known as (n). The primary objective of the Power Frequency Load Control () is to efficiently regulate the power distribution grid's profile to constantly keep the state of charge (SOC) of the battery within safe thresholds. The grid power profile may be characterized in the following manner:

$$P_{GRID}(n) = P_{AVG}(n) + P_{FLC}(n) \qquad (22)$$

The suggested design proposes the use of a fuzzy logic controller (FLC) to calculate the supplementary component (n). This specific component is susceptible to the influence of data obtained from two separate sources. RID AVG FLC. The FLC employs

---

*Corresponding author
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

the State of Charge (SOC) of the battery, represented as SOC (n), as an input parameter to effectively monitor its instantaneous value. The use of this methodology is executed with the intention of conforming to the constraints imposed by the maximum Depth of Discharge (DOD) of the battery and guaranteeing the maintenance of its durability. Furthermore, the variable (n) supplies the fuzzy logic controller (FLC) with information on the degree of energy modification occurring inside the microgrid (MG) between two successive samples, as seen in Figure 8.

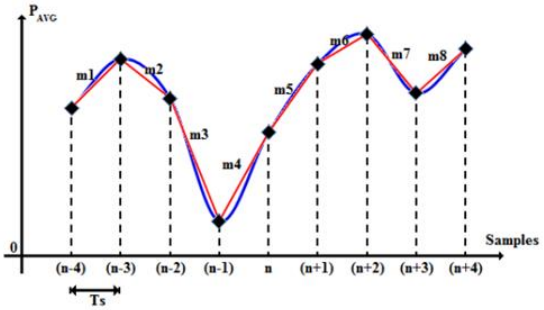


Figure 8: The determination of the slope involves the comparison of two successive samples, represented by a solid red line, from the conventional net power profile, shown by a solid blue line.

In relation to this matter, the observed trend in Figure 8, particularly in the data points m1, m4, m5, m6, and m8, indicates a decrease in the production of renewable energy or an increase in the demand for electricity inside the microgrid (MG). Conversely, a negative slope (denoted as m2, m3, m7) indicates an increase in the output of renewable energy or a decrease in the consumption of load within the context of a microgrid (MG). The variable Ṗ (n) possesses the characteristic of being able to be interpreted as the localized forecast of the future dynamics of the battery state of charge, assuming no modifications are made to the grid power. Hence, utilizing the SOC (n) and Ṗ (;# (n) data, the FLC undertakes the task of modifying (n) to either augment, diminish, or sustain the power transmitted/consumed by the mains (22). The implementation of this modification is aimed at efficiently managing the power consumption while also maintaining the state of charge (SOC) of the battery within acceptable and secure norms. Therefore, the microgrid (MG) and the main power grid (MG-NG) may communicate with one another thanks to the controller's output. Table I provides a detailed breakdown of the interplay. Figure 9 depicts the control block diagram of the aforementioned approach. The diagram depicts the process of obtaining the average power, Ṗ (n), from the instantaneous power, (n), through the utilization of a low-pass filter. Moreover, the calculation of the average power, denoted as Ṗ (n), is achieved by employing a digital filter. This filter is designed to effectively manage the amplification of highfrequency elements and mitigate the noise typicallyassociated with the derivative term. Figure 9 depicts the State of Charge (SOC) Estimator for the battery, as originally presented in Figure 2. It also includes the subsequent discussion regarding the design of the fuzzy controller.

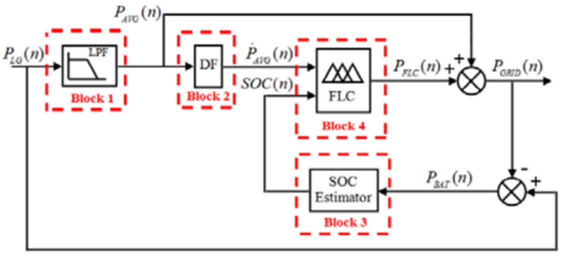


Figure 9: The fundamental components of a fuzzy Energy Management System (EMS) consist of the block diagram representing the rate of change of MG energy.

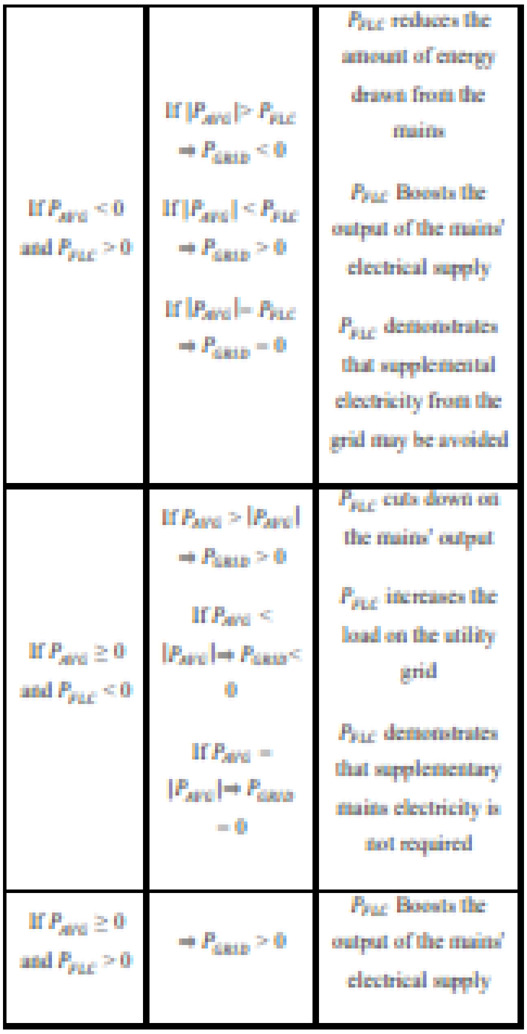
THE PROCESS OF DEVELOPING A FUZZY CONTROL SYSTEM

The current block consists of a Fuzzy Logic Controller (FLC) that utilizes a Mamdani-based inference and defuzzification approach. The Fuzzy Logic Controller (FLC) is designed to accept two inputs, namely Ṗ (n) and SOC(n), and produce a singular output referred to as (;# (n). The variable FLC(n) corresponds to the second element of the grid power, which is formally described in equation (22).

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

Table 1: Power Grid Distribution Affected by FLCs.

Condition	The Power of the Grid	Description
If $P_{AVG} < 0$ and $P_{FLC} = 0$	$P_{GRID} = P_{AVG} \Rightarrow P_{GRID} < 0$	P_{FLC} conserves the energy used by the grid in accordance with P_{AVG}
If$P_{AVG} \geq 0$ and $P_{FLC} = 0$	$P_{GRID} = P_{AVG} \Rightarrow P_{GRID} \geq 0$	P_{FLC} keeps the electricity from the mains at a constant P_{AVG}
If $P_{AVG} < 0$ and $P_{FLC} < 0$	$\Rightarrow P_{GRID} < 0$	P_{FLC} increases the load on the utility grid
If $P_{AVG} < 0$ and $P_{FLC} > 0$	If $\lvert P_{AVG} \rvert > P_{FLC} \Rightarrow P_{GRID} < 0$ If $\lvert P_{AVG} \rvert < P_{FLC} \Rightarrow P_{GRID} > 0$ If $\lvert P_{AVG} \rvert = P_{FLC} \Rightarrow P_{GRID} = 0$	P_{FLC} reduces the amount of energy drawn from the mains P_{FLC} Boosts the output of the mains' electrical supply P_{FLC} demonstrates that supplemental electricity from the grid may be avoided
If $P_{AVG} \geq 0$ and $P_{FLC} < 0$	If $P_{AVG} > \lvert P_{AVG} \rvert \Rightarrow P_{GRID} > 0$ If $P_{AVG} < \lvert P_{AVG} \rvert \Rightarrow P_{GRID} < 0$ If $P_{AVG} = \lvert P_{AVG} \rvert \Rightarrow P_{GRID} = 0$	P_{FLC} cuts down on the mains' output P_{FLC} increases the load on the utility grid P_{FLC} demonstrates that supplementary mains electricity is not required
If $P_{AVG} \geq 0$ and $P_{FLC} > 0$	$\Rightarrow P_{GRID} > 0$	P_{FLC} Boosts the output of the mains' electrical supply



***Corresponding author**

Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

The training method of the system included many components, including input/output, type, mapping, and rulebase. The course was implemented using an offline learning methodology. The present study used actual data about the generation of electricity from renewable energy sources (RES) and the consumption of electrical load. This data was gathered over a span of one year, namely from February 2022 to February 2023. The main objective of this training approach was to decrease a pre-established set of quality requirements, as outlined in Section III. The methodology used is explicitly delineated and may be succinctly summarized as follows:

The first step involves establishing the initial design of the Fuzzy Logic Controller (FLC).

1- Establish the measurement framework (MF) for the variables pertaining to inputs and outputs, encompassing their numerical values, types, and corresponding mappings.

2- Establishing the foundational rule-base is a crucial step in the process.

In the subsequent phase, it becomes essential to undertake modifications to the membership functions (MFs) associated with the input and output variables. The adjustment of parameters associated with the inputs and outputs of the membership functions (MFs) should be carried out using authentic recorded data in order to minimize the quality standards outlined in Section III. In the third phase, optimization of the foundational rules is performed. It is suggested that the initial rule-base be finetuned. using recorded data from the actual world in order to optimize the quality standards described in Section III. The procedure results in the depiction of the construction of five triangular membership functions (MFs) for each input variable, as seen in Figure 10(a) and Figure 10(b). The linguistic variables in question are represented by the abbreviations NB, NS, ZE, PS, and PB, which correspond to five fuzzy sets denoting different degrees of membership. Specifically, the symbols B, S, N, P, and ZE represent "Big," "Small," "Negative," "Positive," and "Zero," respectively. Furthermore, these multifunctional entities effectively include the whole range of variance for each input, as shown by:

$$\dot{P}_{AVG,MIX} \leq \dot{P}_{AVG}\left(n\right) \leq \dot{P}_{AVG,MAX} \qquad (23)$$

$$SOC_{MIN} \leq SOC\left(n\right) \leq SOC_{MAX} \qquad (24)$$

The terms Ṗ (;#.1(2 and Ṗ (;#.1%* represent the upper and ower bounds of the derivative term's variation, respectively. n addition, we have estimated the average maximum power Ṗ (;#.1(2 and average minimum power Ṗ in watts per econd (W/s) using the well-established approximation method, as shown below.

$$\dot{P}_{AVG,MIN} = -\left(9/10\right)\cdot\left(P_{LOAD}/T_W\right) \qquad (25)$$

$$\dot{P}_{AVG,MAX} = \left(9/10\right)\cdot\left(P_{LOAD}/T_W\right) \qquad (26)$$

Given a time window of one day, denoted as TW.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

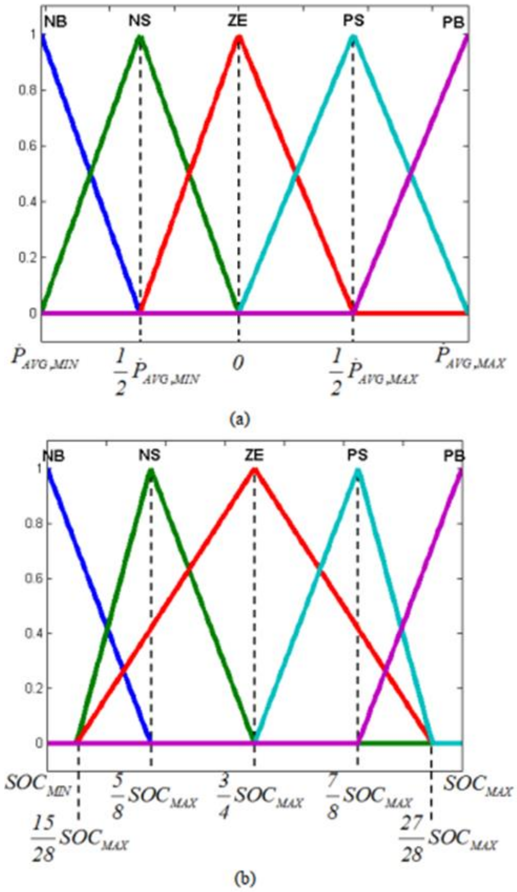


Figure 10: Ṗ (;# (n) and SOC(n) are two membership functions for the input variables.

Furthermore, the determination of the controller output is established by the use of PFLC(n), which encompasses a total of nine triangular membership functions, as seen in Figure 11. In a similar vein, the membership functions (MFs) acquired are linked to a total of nine fuzzy subsets, denoted as NB, NM, NS, NSS, ZE, PSS, PS, PM, and PB. Furthermore, to supplement the preexisting classifications B, S, N, P, and ZE, the subsets M and SS are designated with the signifiers of "Medium" and "Smallest," correspondingly. The range of variance is included by the distribution of output membership functions (MFs).

$$-k \le P_{FLC}\left(n\right) \le k \qquad (27)$$

The controller's output maximum power setting is denoted by the "k" variable.

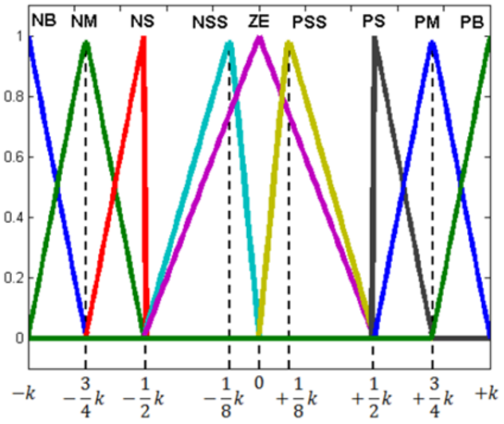
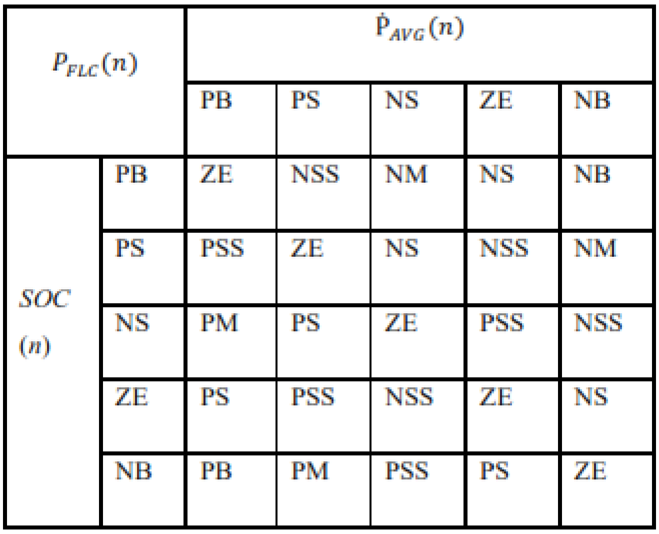


Figure 11: The membership functions for the output of the controller's PFLC(n) are determined.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

Furthermore, the construction of the first rule-base for the Fuzzy Logic Controller (FLC) was informed by linguistic knowledge pertaining to the attributes of the MG. An observed phenomenon is the presence of a notable rate of change in energy, which is represented as "Ṗ (n) IS PB." In instances where the balance between consumption and generation within the microgrid is disrupted and the battery's energy storage level is depleted (indicated by an insufficient state of charge, SOC(n), it becomes imperative to augment the power injection from the primary grid to replenish the battery's energy reserves. This is achieved by increasing (n), which can be denoted as PB. As a result, the control rule was established. It can be inferred that if the average power, denoted as Ṗ, is positively balanced (PB) and the state of charge, denoted as SOC, is negatively balanced (NB), then the power factor, denoted as , is also positively balanced (PB). On the contrary, it is recommended to reduce or cease the injection of power into the grid when the battery is approaching its maximum charge state, indicated as "SOC(n) is PB." This control rule is established as a result. In case both Ṗ (;# and SOC are PB therefore, . The extrapolation of this mode of reasoning to additional scenarios leads to the formulation of the initial set of rules, as depicted in Table II.

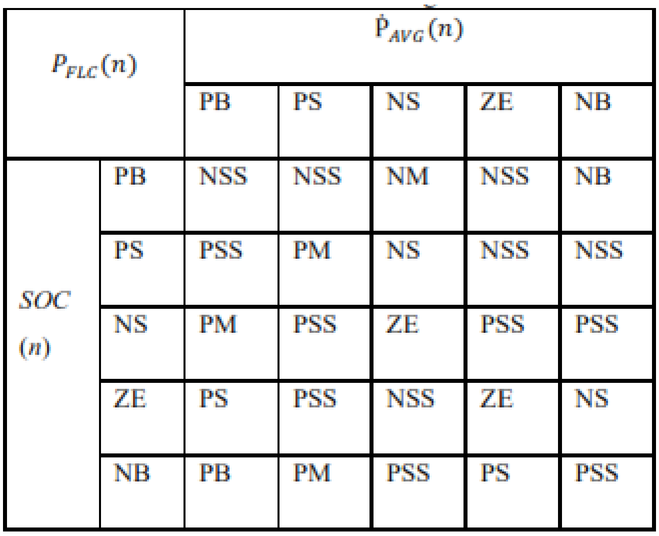
Table 2: Foundational FLC Rules



$P_{FLC}(n)$		$\dot{P}_{AVG}(n)$				
		PB	PS	NS	ZE	NB
SOC (n)	PB	ZE	NSS	NM	NS	NB
	PS	PSS	ZE	NS	NSS	NM
	NS	PM	PS	ZE	PSS	NSS
	ZE	PS	PSS	NSS	ZE	NS
	NB	PB	PM	PSS	PS	ZE

The optimization process mentioned earlier, as previously explained and expanded upon, leads to the presentation of the optimized fuzzy logic controller (FLC) rule-base, which is available in Table III. SOC (n)

Table 3: Modified FLC Regulations



$P_{FLC}(n)$		$\dot{P}_{AVG}(n)$				
		PB	PS	NS	ZE	NB
SOC (n)	PB	NSS	NSS	NM	NSS	NB
	PS	PSS	PM	NS	NSS	NSS
	NS	PM	PSS	ZE	PSS	PSS
	ZE	PS	PSS	NSS	ZE	NS
	NB	PB	PM	PSS	PS	PSS

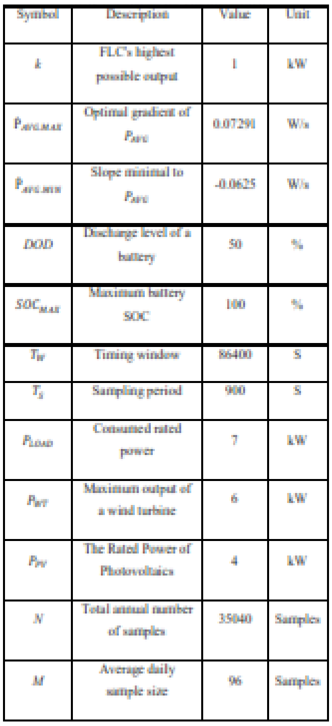
OUTCOMES OF A CASE STUDY

The ongoing simulation of the Emergency Medical Services (EMSs) is being carried out using genuine data gathered from February 2022 to February 2023. The numerical simulations were performed using Matlab® software, utilizing the parameters specified in Table IV, in order to obtain the results and make comparisons.

---

*Corresponding author
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

Table 4: Controls for The Simulation



Symbol	Description	Value	Unit
k	FLC's highest possible output	1	kW
$\dot{P}_{AVG,MAX}$	Optimal gradient of P_{AVG}	0.07291	W/s
$\dot{P}_{AVG,MIN}$	Slope minimal to P_{AVG}	-0.0625	W/s
DOD	Discharge level of a battery	50	%
SOC_{MAX}	Maximum battery SOC	100	%
T_W	Timing window	86400	S
T_S	Sampling period	900	S
P_{LOAD}	Consumed rated power	7	kW
P_{WT}	Maximum output of a wind turbine	6	kW
P_{PV}	The Rated Power of Photovoltaics	4	kW
N	Total annual number of samples	35040	Samples
M	Average daily sample size	96	Samples

The findings demonstrate a significant decrease in three quality indicators as indicated in the proposed fuzzy Environmental Management System (EMS). When comparing the simple moving average (SMA) approach to the current scenario, it is seen that the values of experience a drop of 63% and 17% respectively. On the other hand, there is a notable decrease of 58% and 5% in the values of the fuzzy expert management system (EMS) based on MG NPT experience, when a comparison is made. Moreover, a notable improvement of the proposed Energy Management System (EMS) lies in its capacity to substantially decrease the Maximum Power Demand (MPD) #.1%* need. The research demonstrates a significant reduction of 96% when comparing it to the SMA method, and a reduction of 95% when comparing it to the fuzzy EMS based on MG NPT. The primary factor contributing to the improved effectiveness of the fuzzy Energy Management System (EMS), which relies on the Maximum Generation Equivalent Reserve Capacity (MG ERoC), is the notable reduction in the Minimum Power Demand (MPD) requirement. However, it is crucial to recognize that the values of APD (Average Percentage Difference) and PPV (Positive Predictive Value) exhibit a little increase when compared to other methodologies.

VERIFICATION BY EXPERIMENT

THE MICROGRID ARCHITECTURE

Experimental validation of the proposed architecture for the fuzzy energy management system (EMS) is conducted inside a microgrid (MG). Microgrid (MG) infrastructure includes weather station, power converter, energy storage, programmable load, renewable generating, and supervisory and control station.

1- Generators powered by the sun and the wind make up the renewable energy grid. There is a maximum output of 4,080 watts from the solar panel array. The system is composed of a total of 52 BP585 solar panels, which are divided into four groups. Each group is comprised of 13 linked panels. The solar panels have been positioned in a southern direction, looking towards the equator, with an inclination of 30 degrees.

2- An electronic load device called an AMREL PLA7.5K-600-400 is used to mimic the load profile. A connection between the electronic load and the monitoring and control station may be quickly and easily set up with the help of the RS-485 communication bus.

3- 3- The 125 stationary lead-acid cells from FIAMM SMG300 form a series connection that makes up the energy storage system. Every individual cell is designed to operate at a voltage of 2 volts and has a discharge capacity of 300 ampere-hours over a period of 10 hours.

---

*Corresponding author
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

4- The power converter used by the MG incorporates a modified iteration of the MS30. The new iteration encompasses three distinct modules, including a module dedicated to the conversion of power derived from a wind turbine, another module designed for the purpose of charging batteries, and a third module specifically tailored to invert energy provided by solar panels.

5- A weather station has been erected along the MG's path so that its progress may be tracked, as well as the weather and any other circumstances that may be important. The system comprises of an irradiance calibrated cell, two anemometers positioned at the wind turbine and one at the solar array, an external temperature sensor, a temperature sensor for the photovoltaic (PV) panels, a temperature sensor for the batteries, and a temperature sensor located in the battery room.

6- The monitoring and controlling station consists of power analyzers, a personal computer (PC) with general-purpose capabilities, and the National Instruments PCI eXtensions for Instrumentation (NIPXI) platform.

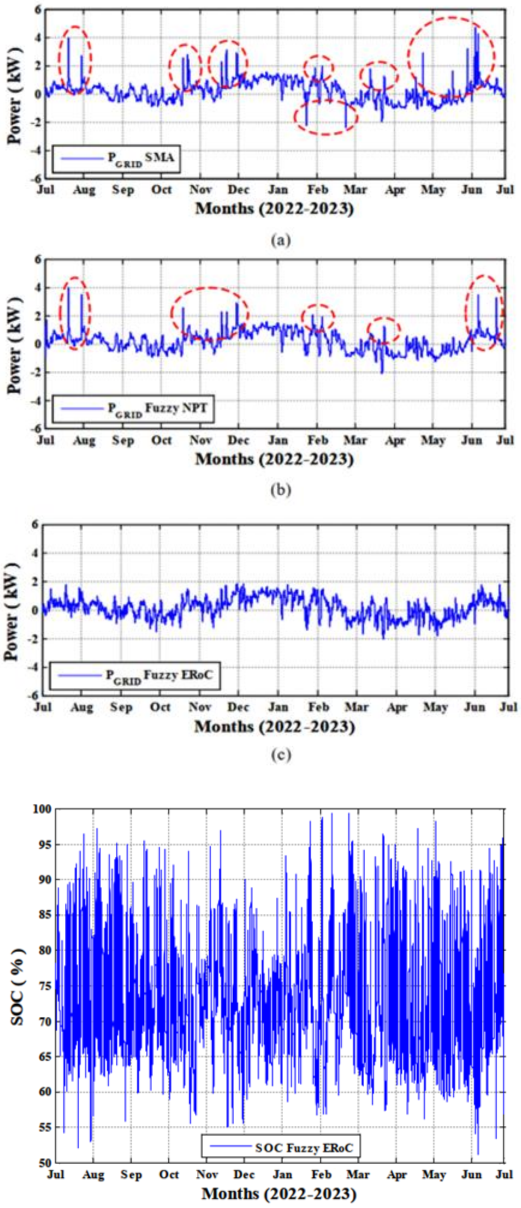
The power analyzers of each component collect data, which is acquired by the four modules of the NI-PXI system. These modules are used for real-time control of the various components within the microgrid. In this particular context, the following devices are utilized: the National Instruments PXI-8102 Embedded Controller, the National Instruments PXI-8433/4 Serial Interface designed for RS-485 connection, the National Instruments PXI-8231 Gigabit Ethernet Interface, and the National Instruments PXI-6238 Analog I/O data collecting board. The power analyzers, which assess the basic electrical characteristics of every microgrid component, are located inside the switch cabinet. The parameters given above include voltage, current, and frequency. The personal computer serves as the user interface for microgrids (MG), responsible for displaying the historical data of MG variables that have been gathered by the National Instruments (NI) PXI system.

ANALYSIS OF EXPERIMENTAL FINDINGS

The implementation of the fuzzy EMS system is carried out using the LabVIEW platform, followed by its execution on the NI-PXI hardware in real-time. It is important to acknowledge that the optimization procedure used in the development of the Fuzzy Logic Controller (FLC) determines the upper and lower bounds for every input variable. Hence, it is essential to include supplementary signal conditioning methodologies to standardize the recorded physical quantities within the specified limits. If the task is not accomplished, it would lead to the fuzzy logic controller (FLC) generating an uncertain output, thus resulting in a malfunction of the electronic management system (EMS). From March 3rd to March 30th, 2023, the system was put through rigorous testing in real-world scenarios to empirically evaluate the suggested fuzzy EMS architecture. Figure 14 displays the results of the experiment, including the net power (black dotted line), grid power (solid red line), and battery state of charge (solid green line). The power profile of the grid after the implementation of the proposed EMS is shown in Figure 16. The effectiveness of the EMS design is shown by the fact that considerable changes in the net power of the Microgrid (MG) create very modest power fluctuations inside the grid, mitigating the negative consequences caused by these variations. Figure 16 is a graphical depiction of the simulation results, giving further proof that the battery's State of Charge (SOC) does indeed follow the predicted pattern. Predicted results from the modeling research are corroborated by observations of the battery's state of charge (SOC) fluctuating around its nominal capacity of roughly 80%. Therefore, the proposed architecture of the fuzzy EMS ensures the state of charge (SOC) of the battery is always kept within the acceptable range. Furthermore, Figure 17 depicts the grid power profile obtained via simulation, labeled as PGRID Sim and visually represented by the gray dotted line. It also showcases the grid power profile obtained in real-world conditions, referred to as PGRID Exp and visually represented by the red solid line. These profiles were generated utilizing the fuzzy EMS design provided in the current work. The power profile of the experimental grid is consistent with the reported changes in simulations, therefore confirming the effectiveness of the suggested technique. This research does a detailed investigation to provide a full analysis of a specific day, with the objective of clarifying the patterns and features shown by the primary variables of the microgrid (MG). Power from the grid, the batteries, and the batteries' state of charge (SOC) are all considered in this analysis. Figure 19 shows that the microgrid (MG) has a consistent morning power consumption, as shown by the lack dashed line. As a result, the proposed energy management system (EMS) effectively controls the power flow inside the grid to maintain a consistent power absorption from the primary grid, shown by the red solid line. The electricity is used to fulfill the consumption needs of the MG while also recharging the battery, as seen by the green solid line. It is noteworthy to observe that the battery experiences a charging procedure that is defined by a steady power, as shown by the pink dashed line. Subsequently, the measurement gauge (MG) exhibits an abrupt fluctuation in its energy levels at around 6:00 AM. The effectiveness of the proposed fuzzy energy management system (EMS) is apparent in its capacity to substantially enhance the power generation of the grid, as originally anticipated. As a result, this improvement allows the storage system to effectively meet the requirements of the microgrid (MG). Following this, the magnetic generator (MG) undergoes a notable fluctuation in its energy levels throughout the noon period, namely around 12:00 PM. In the given context, the suggested fuzzy energy management system (EMS) aims to optimize the gridsupplied electricity in order to facilitate efficient battery recharge and prolong its operational longevity. This is especially important when the state of charge (SOC) of the battery has diminished during prior operations. After initiating the battery charging process, the recommended setup of the fuzzy Energy Management System (EMS) decreases the electricity supply from the electrical grid. The occurrence may be explained by the operating condition of the Microgrid (MG) during this particular time period, as shown by a negative power line generation (PLG < 0). The process of charging the battery continues until around 18:00, at which point the Energy Management System (EMS) maintains a pretty stable power output from the grid. The aforementioned activity is carried out with the intention of using the potential energy contained inside the battery in order to meet the demands of the load. The use of this technology allows for the efficient control of the power profile of the grid by the energy management system (EMS), while simultaneously reducing the occurrence of excessive battery charging. It is vital to acknowledge that this specific method is repeated for each energy adjustment inside the microgrid (MG).

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

The research used a one-year dataset to run simulations, spanning a wide variety of meteorological conditions that are represented in the net power profile. These variables include both daily and seasonal oscillations. It is important to highlight this aspect of the study. In addition, the research in question has been subjected to testing in a genuine environment for a period of one month, exhibiting a reasonable level of performance. Nevertheless, the relevance is in the possible instabilities that may occur in power production during short time periods, ranging from minutes to a few hours. However, the aforementioned oscillations may be efficiently controlled by using battery storage systems, which are specifically engineered to offset the daily swings in power supply.



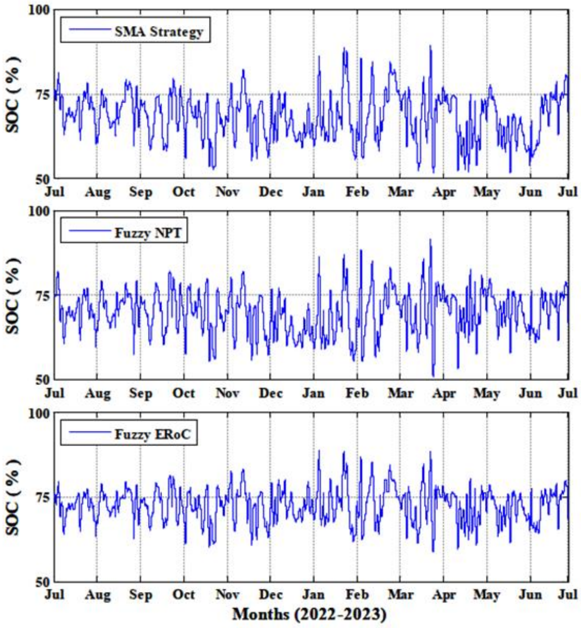
(a)

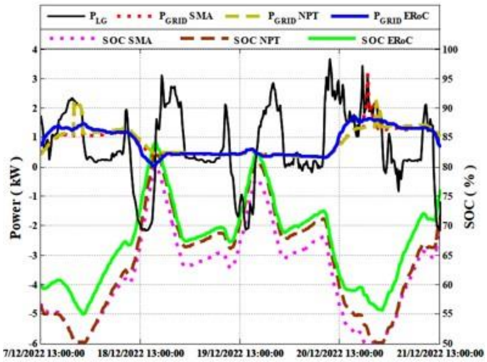
(b)

(c)

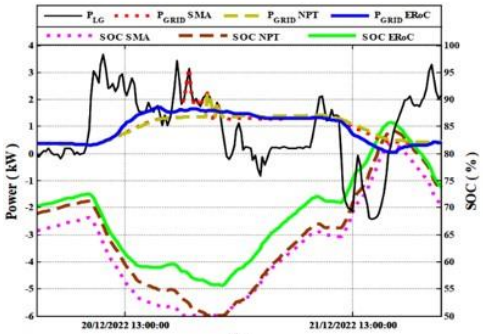
---

*Corresponding author
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

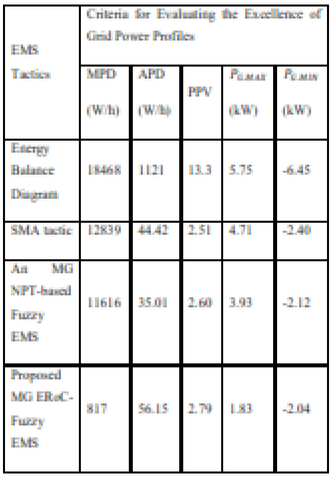




(a)



(b)



EMS Tactics	Criteria for Evaluating the Excellence of Grid Power Profiles				
	MPD (W/h)	APD (W/h)	PPV	$P_{G,MAX}$ (kW)	$P_{G,MIN}$ (kW)
Energy Balance Diagram	18468	1121	13.3	5.75	-6.45
SMA tactic	12839	44.42	2.51	4.71	-2.40
An MG NPT-based Fuzzy EMS	11616	35.01	2.60	3.93	-2.12
Proposed MG ERoC-Fuzzy EMS	817	56.15	2.79	1.83	-2.04

---

*Corresponding author
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

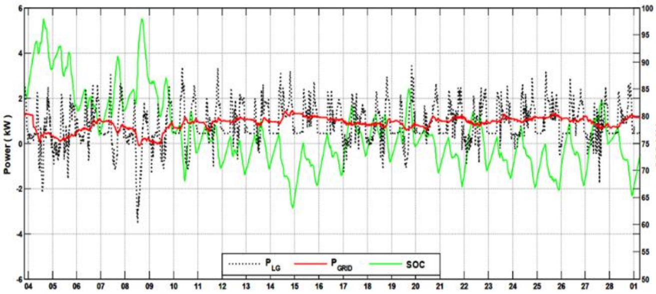


Figure 16: As part of the trials conducted for the proposed fuzzy Energy Management System (EMS), various data were gathered. This included information on the rate of change of energy, the net power profile of Microgrids (MGs), the power profile of the grid, and the state of charge (SOC) of the batteries.

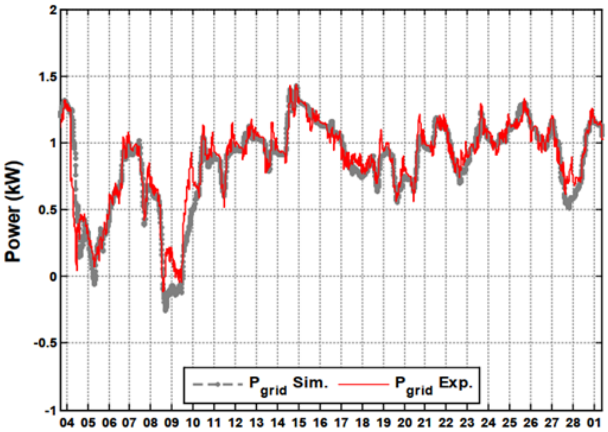


Figure 17: The accuracy of the grid profile presented for the design of the fuzzy EMS is confirmed by both simulation and experimental testing.

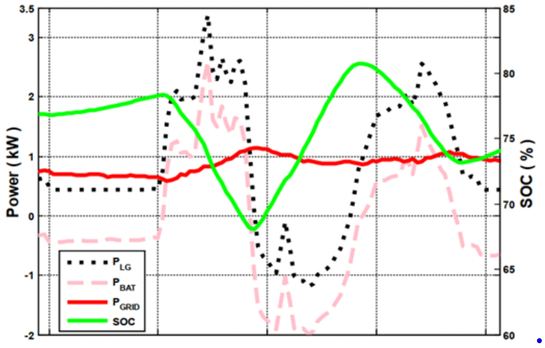


Figure 18: Variables in microgrid electricity and the changing state of charge of batteries on June 10th 2023

CONCLUSION

The current investigation has proposed a theoretical framework for an Energy Management System (EMS) that incorporates Fuzzy Logic Control (FLC). The principal objective of the Energy Management System (EMS) is to optimize the power stability of a home microgrid interconnected with the main grid. The microgrid is equipped with renewable energy generators and have the capacity to store energy in battery systems. The design of the Energy Management System (EMS) is predicated on the underlying premise that both the renewable energy sources and the load exhibit a limited degree of controllability. The execution of the fuzzy logic controller was carried out in two separate phases. In the first phase, the inputs used for the fuzzy controller were determined to be the rate of energy change inside the microgrid and the state of charge (SOC) of the battery. The selection of these inputs was made with the aim of effectively optimizing the power exchange between the microgrid and the main grid. The subsequent phase included the implementation of an offline optimization approach that relied on a predetermined set of criteria for evaluating the level of quality. The aforementioned procedure was used to ascertain the various parameters of the fuzzy logic controller (FLC), namely the membership functions and rule base. The architecture in question enables the Energy Management System (EMS) to promptly react and effectively mitigate variations in energy levels inside the Microgrid (MG). The primary objective is to keep the battery's State of Charge (SOC) at 80% of its rated capacity at all times. In this way, the battery's state of charge (SOC) may smooth out spikes and dips in the microgrid's net power, leading to a more uniform grid power profile, provided the SOC is kept

---

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

within reasonable parameters. Additionally, a fuzzy controller with a structure of 25 rules, two inputs, and one output was developed using the Fuzzy Logic Controller (FLC) architecture. This configuration suggests that the controller exhibits a comparatively modest degree of intricacy. In addition, a comprehensive evaluation has been conducted at the simulation level, using authentic data, to compare the proposed design with other techniques that aim to achieve the same objective. The present assessment has effectively shown the improvements brought about by the design that has been offered. The feasibility of the suggested energy management system (EMS) based on a fuzzy logic controller (FLC) is confirmed by experimental verification, which aligns with the conclusions obtained through simulation. The current study focuses largely on broadening the scope of the proposed technique to include controlled loads, namely an electric water heater.

REFERENCES

[1] A. Jaber, M. Ismael, T. Rashid, Mohammed Abdulhadi Sarhan, M. Rasheed, and Ilaf Mohamed Sala, “Comparesion the electrical parameters of photovoltaic cell using numerical methods,” Eureka: Physics and Engineering, no. 4, pp. 29–39, Jul. 2023, doi: https://doi.org/10.21303/2461-4262.2023.002770.

[2] A. Raghdi, Menad Heraiz, M. Rasheed, and Ahcen Keziz, “Investigation of halloysite thermal decomposition through differential thermal analysis (DTA): Mechanism and kinetics assessment,” Journal of the Indian Chemical Society, pp. 101413–101413, Oct. 2024, doi: https://doi.org/10.1016/j.jics.2024.101413.

[3] A. Shukur, Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, “Decomposing Method for Space-Time Fractional Order PDEs,” Al-Salam journal for engineering and technology, vol. 3, no. 2, pp. 1–11, May 2024, doi: https://doi.org/10.55145/ajest.2024.03.02.01.

[4] A. Zubaidi, Lamyaa Mahdi Asaad, Iqbal Alshalal, and M. Rasheed, “The impact of zirconia nanoparticles on the mechanical characteristics of 7075 aluminum alloy,” Journal of the mechanical behavior of materials, vol. 32, no. 1, Jan. 2023, doi: https://doi.org/10.1515/jmbm-2022-0302.

[5] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraji, and M. Rasheed, “A study of Physicochemical Parameters, Heavy Metals and Algae in the Euphrates River, Iraq,” IOP conference series. Earth and environmental science, vol. 1262, no. 2, pp. 022007–022007, Dec. 2023, doi: https://doi.org/10.1088/1755-1315/1262/2/022007.

[6] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraji, M. Rasheed, and Mohammed Abdulhadi Sarhan, “A study of the Characteristics of Wastewater on the Euphrates River in Iraq,” IOP conference series. Earth and environmental science, vol. 1262, no. 2, pp. 022005–022005, Dec. 2023, doi: https://doi.org/10.1088/1755-1315/1262/2/022005.

[7] Ahcen Keziz, M. Heraiz, F. Sahnoune, and M. Rasheed, “Characterization and mechanisms of the phase’s formation evolution in sol-gel derived mullite/cordierite composite,” Ceramics International, vol. 49, no. 20, pp. 32989–33003, Oct. 2023, doi: https://doi.org/10.1016/j.ceramint.2023.07.275.

[8] Ahcen Keziz, M. Rasheed, M. Heraiz, F. Sahnoune, and A. Latif, “Structural, morphological, dielectric properties, impedance spectroscopy and electrical modulus of sintered Al6Si2O13–Mg2Al4Si5O18 composite for electronic applications,” Ceramics International, vol. 49, no. 23, pp. 37423–37434, Dec. 2023, doi: https://doi.org/10.1016/j.ceramint.2023.09.068.

[9] Ahcen Keziz, Meand Heraiz, M. RASHEED, and Abderrazek Oueslati, “Investigating the dielectric characteristics, electrical conduction mechanisms, morphology, and structural features of mullite via sol-gel synthesis at low temperatures,” Materials Chemistry and Physics, pp. 129757–129757, Jul. 2024, doi: https://doi.org/10.1016/j.matchemphys.2024.129757.

[10] Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, “The conjugate gradient approach to solve two dimensions linear elliptic boundary value equations as a prototype of the reaction diffusion system,” Al-Salam journal for engineering and technology, vol. 3, no. 1, pp. 157–168, Jan. 2024, doi: https://doi.org/10.55145/ajest.2024.03.01.014.

[11] D. Bouras and M. Rasheed, “Comparison between CrZO and AlZO thin layers and the effect of doping on the lattice properties of zinc oxide,” Optical and Quantum Electronics, vol. 54, no. 12, Oct. 2022, doi: https://doi.org/10.1007/s11082-022-04161-1.

[12] D. Bouras, M. Fellah, A. Mecif, R. Barillé, A. Obrosov, and M. Rasheed, “High photocatalytic capacity of porous ceramic-based powder doped with MgO,” Journal of the Korean Ceramic Society, Oct. 2022, doi: https://doi.org/10.1007/s43207-022-00254-5.

[13] D. Bouras, M. Rasheed, R. Barille, and M. N. Aldaraji, “Efficiency of adding DD3+(Li/Mg) composite to plants and their fibers during the process of filtering solutions of toxic organic dyes,” Optical Materials, vol. 131, p. 112725, Sep. 2022, doi: https://doi.org/10.1016/j.optmat.2022.112725.

[14] D. Bouras, Mamoun Fellah, Régis Barille, Mohammed Abdul Samad, M. Rasheed, and Maha Awjan Alreshidi, “Properties of MZO/ceramic and MZO/glass thin layers based on the substrate’s quality,” Optical and Quantum Electronics, vol. 56, no. 1, Dec. 2023, doi: https://doi.org/10.1007/s11082-023-05778-6.

[15] Djelel Kherifi, Ahcen Keziz, M. Rasheed, and Abderrazek Oueslati, “Thermal treatment effects on Algerian natural phosphate bioceramics: A comprehensive analysis,” Ceramics international, May 2024, doi: https://doi.org/10.1016/j.ceramint.2024.05.317.

[16] E. Kadri, K. Dhahri, R. Barillé, and M. Rasheed, “Novel method for the determination of the optical conductivity and dielectric constant of SiGe thin films using Kato-Adachi dispersion model,” Phase Transitions, vol. 94, no. 2, pp. 65–76, Feb. 2021, doi: https://doi.org/10.1080/01411594.2020.1832224.

[17] E. Kadri, M. Krichen, R. Mohammed, A. Zouari, and K. Khirouni, “Electrical transport mechanisms in amorphous silicon/crystalline silicon germanium heterojunction solar cell: impact of passivation layer in conversion efficiency,” Optical and Quantum Electronics, vol. 48, no. 12, Nov. 2016, doi: https://doi.org/10.1007/s11082-016-0812-7.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

[18] Farouk BOUDOU, Abdelmadjid GUENDOUZI, A. BELKREDAR, and M. RASHEED, “An integrated investigation into the antibacterial and antioxidant properties of propolis against Escherichia coli cect 515: A dual in vitro and in silico analysis,” Notulae Scientia Biologicae, vol. 16, no. 2, pp. 13837–13837, May 2024, doi: https://doi.org/10.55779/nsb16211837.

[19] I. Alshalal, H. M. I. Al-Zuhairi, A. A. Abtan, M. Rasheed, and M. K. Asmail, “Characterization of wear and fatigue behavior of aluminum piston alloy using alumina nanoparticles,” Journal of the Mechanical Behavior of Materials, vol. 32, no. 1, Jan. 2023, doi: https://doi.org/10.1515/jmbm-2022-0280.

[20] M. A. Sarhan, S. Shihab, B. E. Kashem, and M. Rasheed, “New Exact Operational Shifted Pell Matrices and Their Application in Astrophysics,” Journal of Physics: Conference Series, vol. 1879, no. 2, p. 022122, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/2/022122.

[21] M. Al-Darraji, S. Jasim, O. Salah Aldeen, A. Ghasemian, and M. Rasheed, “The Effect of LL37 Antimicrobial Peptide on FOXE1 and lncRNA PTCSC 2 Genes Expression in Colorectal Cancer (CRC) and Normal Cells,” Asian Pacific Journal of Cancer Prevention, vol. 23, no. 10, pp. 3437–3442, Oct. 2022, doi: https://doi.org/10.31557/apjcp.2022.23.10.3437.

[22] M. Darraji, L. Saqban, T. Mutar, M. Rasheed, and A. Hussein, “Association of Candidate Genes Polymorphisms in Iraqi Patients with Chronic Kidney Disease,” Journal of Advanced Biotechnology and Experimental Therapeutics, vol. 6, no. 1, p. 687, 2022, doi: https://doi.org/10.5455/jabet.2022.d147.

[23] M. Enneffatia, M. Rasheed, B. Louatia, K. Guidaraa, S. Shihab, and R. Barillé, “Investigation of structural, morphology, optical properties and electrical transport conduction of Li0.25Na0.75CdVO4 compound,” Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012050, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012050.

[24] M. Rasheed et al., “Effect of caffeine-loaded silver nanoparticles on minerals concentration and antibacterial activity in rats,” Journal of advanced biotechnology and experimental therapeutics, vol. 6, no. 2, pp. 495–495, Jan. 2023, doi: https://doi.org/10.5455/jabet.2023.d144.

[25] M. Rasheed, M. N. Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, “Solar PV Modelling and Parameter Extraction Using Iterative Algorithms,” Journal of Physics: Conference Series, vol. 1963, no. 1, p. 012059, Jul. 2021, doi: https://doi.org/10.1088/1742-6596/1963/1/012059.

[26] M. Rasheed, M. N. Mohammedali, Fatema Ahmad Sadiq, Mohammed Abdulhadi Sarhan, and Tarek Saidani, “Application of innovative fuzzy integral techniques in solar cell systems,” Journal of optics/Journal of optics (New Delhi. Print), Jun. 2024, doi: https://doi.org/10.1007/s12596-024-01928-5.

[27] M. Rasheed, M. Nuhad Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, “The numerical Calculations of Single-Diode Solar Cell Modeling Parameters,” Journal of Physics: Conference Series, vol. 1963, no. 1, p. 012058, Jul. 2021, doi: https://doi.org/10.1088/1742-6596/1963/1/012058.

[28] M. Rasheed, O. Alabdali, S. Shihab, A. Rashid, and T. Rashid, “On the Solution of Nonlinear Equation for Photovoltaic Cell Using New Iterative Algorithms,” Journal of Physics: Conference Series, vol. 1999, no. 1, p. 012078, Sep. 2021, doi: https://doi.org/10.1088/1742-6596/1999/1/012078.

[29] M. Rasheed, O. Y. Mohammed, S. Shihab, and A. Al-Adili, “Explicit Numerical Model of Solar Cells to Determine Current and Voltage,” Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012043, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012043.

[30] M. Rasheed, S. Shihab, O. Alabdali, A. Rashid, and T. Rashid, “Finding Roots of Nonlinear Equation for Optoelectronic Device,” Journal of Physics: Conference Series, vol. 1999, no. 1, p. 012077, Sep. 2021, doi: https://doi.org/10.1088/1742-6596/1999/1/012077.

[31] M. Rasheed, S. Shihab, O. Y. Mohammed, and A. Al-Adili, “Parameters Estimation of Photovoltaic Model Using Nonlinear Algorithms,” Journal of Physics: Conference Series, vol. 1795, no. 1, p. 012058, Mar. 2021, doi: https://doi.org/10.1088/1742-6596/1795/1/012058.

[32] M. Rasheed, SuhaShihab, O. Alabdali, and H. H. Hassan, “Parameters Extraction of a Single-Diode Model of Photovoltaic Cell Using False Position Iterative Method,” Journal of Physics: Conference Series, vol. 1879, no. 3, p. 032113, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/3/032113.

[33] Manel Sellam, M. Rasheed, S. Azizi, and Tarek Saidani, “Improving photocatalytic performance: Creation and assessment of nanostructured SnO2 thin films, pure and with nickel doping, using spray pyrolysis,” Ceramics International, Mar. 2024, doi: https://doi.org/10.1016/j.ceramint.2024.03.094.

[34] N. Assoudi et al., “Comparative examination of the physical parameters of the sol gel produced compounds La0.5Ag0.1Ca0.4MnO3 and La0.6Ca0.3Ag0.1MnO3,” Optical and Quantum Electronics, vol. 54, no. 9, Jul. 2022, doi: https://doi.org/10.1007/s11082-022-03927-x.

[35] O. Alabdali, S. Shihab, M. Rasheed, and T. Rashid, “Orthogonal Boubaker-Turki polynomials algorithm for problems arising in engineering,” 3RD INTERNATIONAL SCIENTIFIC CONFERENCE OF ALKAFEEL UNIVERSITY (ISCKU 2021), 2022, doi: https://doi.org/10.1063/5.0066860.

[36] S. M. H. AL-Jawad, M. Rasheed, I. M. Ibrahim, A. S. Sabber, and A. K. Elttayf, “Impact of Copper Doping on Nanocrystalline SnO2 Thin Films Synthesized by Sol-Gel Coating and Chemical Bath Deposition for Gas Sensor Applications,” Journal of nano research, vol. 84, pp. 25–40, Sep. 2024, doi: https://doi.org/10.4028/p-4frfak.

[37] S. Shihab, M. Rasheed, O. Alabdali, and A. A. Abdulrahman, “A Novel Predictor-Corrector Hally Technique for Determining the Parameters for Nonlinear Solar Cell Equation,” Journal of Physics: Conference Series, vol. 1879, no. 2, p. 022120, May 2021, doi: https://doi.org/10.1088/1742-6596/1879/2/022120.

[38] Selma, M. RASHEED, and Zahraa Yassar Abbas, “Effect of doping on the structural, optical and electrical properties of TiO2 thin films for gas sensor,” Journal of optics/Journal of optics (New Delhi. Print), May 2024, doi: https://doi.org/10.1007/s12596-024-01913-y.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq

[39] T. Rashid, Musa Mohd Mokji, and M. Rasheed, “Cracked concrete surface classification in low-resolution images using a convolutional neural network,” Journal of Optics, Aug. 2024, doi: https://doi.org/10.1007/s12596-024-02080-w.

[40] W. Saidi, Nasreddine Hfaidh, M. Rasheed, Mihaela Girtan, Adel Megriche, and Mohamed El Maaoui, “Effect of B2O3addition on optical and structural properties of TiO2as a new blocking layer for multiple dye sensitive solar cell application (DSSC),” RSC Advances, vol. 6, no. 73, pp. 68819–68826, Jan. 2016, doi: https://doi.org/10.1039/c6ra15060h.

***Corresponding author**
Zuhair Shakor Mahmood,
Electronics Department, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq
e-mail: zuherkazanci@ntu.edu.iq