Efficient Energy Management of Hybrid Renewable Power Generation Based on Charging Station Demand

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Abstract. Resources for energy are very important for the existence of mankind. The choice of power generation methods and their economic feasibility vary depending on the demand and geographical region. However, the scarcity of charging stations is one of the most major obstacles that stands in the way of the broad adoption of electric vehicles. In order to address the issue of charging stations, this research suggests the implementation of a hybrid charging station that is powered by both solar and wind energy, in addition to an algorithm that optimizes energy management. The development of a proposed charging station that utilizes a hybrid renewable energy source has been enhanced by the implementation of simulation done on MATLAB based on a fuzzy logic inference controller system. The ultimate aim focus on reducing the need for charging and optimize the use of hybrid renewable energy sources through effective management of power generation, power utilization, distribution, charging timelines, demand and electric vehicle power consumption. When compared to the demand, the results demonstrate that the suggested algorithm leads to a reduction in energy demand and management. Additionally, the proposed framework of the energy management optimization system was executed and the results reflect that peak demand of a charging station is reduced significantly during peak hours.

Keywords: Hybrid Renewable Energy, IEVCS, Fuzzy logic, Load forecasting, EV scheduling, Demand analysis.

1. Introduction

A growth in worldwide power demand has resulted in the extraction of fossil fuels, which has caused environmental damage and accelerated global warming [1]. Electric vehicles are not widely used as a more cost-effective means of transportation because there are not enough charging stations, particularly in less developed countries. EV users charge their batteries at home, which results in a loss of system capacity in the power industry and a reduction in profitability [2,3]. Due to their non-linear operation, the linkage of multiple electric car chargers to the distribution system often leads to power quality issues. Possible occurrences include power dissipation, harmonic distortions, and voltage fluctuations [4]. Problems with the power quality of distribution networks are caused by charging procedures for electric vehicles that are disorganized and inefficient [5]. To close the demand-supply gap in the electrical industry, researchers all over the world are working to develop renewable resources that are both cost-effective renewable resources and environmentally beneficial, responsible [6]. The charging of batteries, the performance of converters, the usage of renewable energy, and the management of energy are all areas that can be improved in order to find solutions to these issues [7]. From both a technological and an economic point of view, the usage of renewable resources results in the most advantageous method. Additionally, it lessens the load on the power supply, which results in an increase in power. These resources are vital because they are inexpensive, kind to the environment, and require little maintenance.

Despite the fact that the infrastructure for the generation of renewable energy source is expensive and occasionally breaks, by incorporating hybrid renewable energy sources into charging stations for electric vehicles, it is possible to overcome these challenges [8]. Renewable energy sources such as solar and wind offer a tremendous amount for the alternative of fossil fuels. Integrated Electric Vehicle Charging Stations (IEVCS) are reliable based upon an optimization technique for an efficient charging management outcome [9]. An efficient resulting algorithm is based on fuzzy logic. As a result of their higher ability to imitate decision-making, Fuzzy Logic Inference

Controller systems are ideal for use to operate electric vehicle charging stations and have the ability to model nonlinear functions [10,11]. Methods that are based on fuzzy logic inference controller system are beneficial and have the ability to make decisions, recognize patterns, identify, optimize, and control [12]. An optimization strategy for energy management is required in order to make the most of the utilization of hybrid renewable energy when charging electric cars. To enhance the IEVCS, optimization looks at factors such as power generated, EMS (Energy management system), energy demand, and transmission loss [13]. Proposed research focuses on enhancing fuzzy logic inference controller system for scheduling and segregating resourceful energy management methods for charging electric vehicles and upgrading IEVCS [14]. Therefore, in order to make hybrid renewable energy sources like solar and wind energy function well for charging electric vehicles, the research concentrated on developing a fuzzy logic inference controller system. This was done in order to make these sources productive. [15].

This research focus on the understanding of hybrid renewable energy source to be concentrated for the alternate of fossil fuels and focus on the next level as maximum utilization of energy and proper allocation of electric vehicles to the charging station based on the fuzzy logic techniques and checking the demand analysis and load forecasting thus scheduling to manage the energy efficiently.

The section of the paper is structured as described below. The conceptual proposed Integrated Electric Vehicle Charging Stations and Sugeno-type fuzzy logic inference controller system model are presented in Section II. Section III discussed the Mathematical model of FUZZY LOGIC INFERENCE CONTROLLER SYSTEM for IEVCS. In Session IV, are the results and discussion of the proposed IEVCS. Presented in Section V are the conclusion and the implications for future research.

2. Proposed work

Every day, there is eight hours of sunshine, beginning at eight in the morning and finalize at four in the afternoon. Solar energy cannot be generated when it is cloudy or raining outside. As a result of this, wind turbines are utilized in order to generate electricity because the sun is not shining. In this particular scenario, a fuzzy logic processor is utilized in order to determine the most demand effective charging for each electric vehicle at each and every charging station. Input variables include the amount of power that is generated by the output, the amount of power that the electric vehicles require and demand.

In this proposed work, it is necessary to utilize a combination of renewable energy sources as the power generation unit in order to fulfill the demand for electric vehicles. Additionally, energy management is accomplished through the utilization of fuzzy logic in conjunction with the interconnection of charging stations.

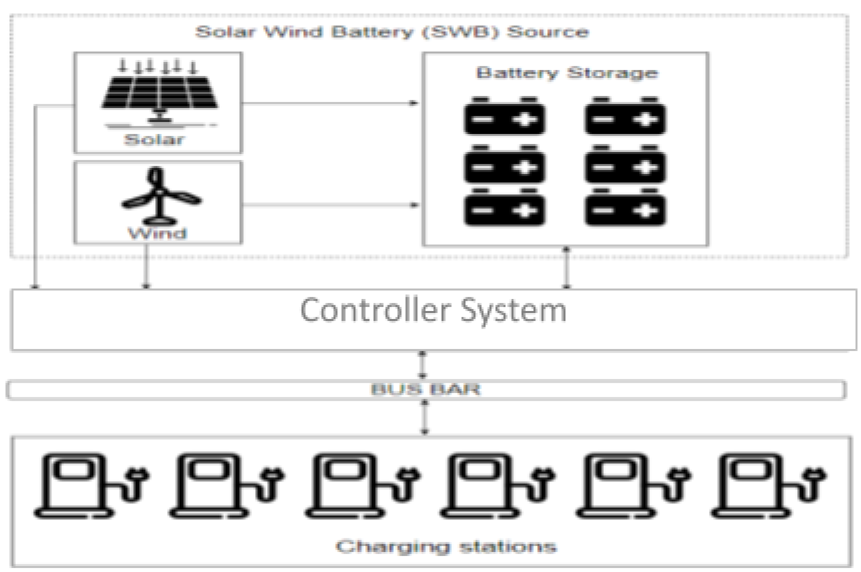


FIGURE 1: *Block diagram of the Proposed System*

This work is carried out in three stages as shown in fig 1. Stage 1 is of Combined energy source named as SWB (Solar, Wind, Backup Battery) source, Stage 2 is completely of FLICS (Fuzzy Logic Inference Controller system), Stage 3 consists of IECV (Integrated charging stations).

Stage1:

The hybrid renewable energy sources (solar and wind) are used as the energy generation part. The solar Power obtained will be directly driven to the next stage as part of generation along with the wind Energy achieved. In addition to this an additional Battery back is maintained for storing the excess energy or the surplus power which is received during the off-peak hours where there is no demand by the electric vehicles to the charging station and the transmission of energy is not required. During peak hours when the demand is very high and if the solar & wind can't deliver the energy needed, then the stored energy has to be directed towards the charging station.

This will be applicable for three conditions.

1. Demand is high (peak hour)
2. Solar power is not available (nighttime / during rainy days)
3. Wind energy is not received due to climatic conditions.

The above conditions can be used to determine whether the battery pack has to store the energy / transmit the stored energy.

Stage 2:

The optimization is done with Fuzzy Logic Inference Controller System (FLICS) which will control the amount of energy generated, level of battery backup storage and the decision made for the battery action status (receive / transmit). This will collect the data from the input (Generation side) and the output (distribution side). With this collected data FIS will act as intermediate part to serve the needs of the proposed system to monitor and take decisions. Another set of output data is received from the charging station about the status of the available power, demand of the Electric vehicle waiting to get charged. This information will be accessed for the better energy management of the whole system.

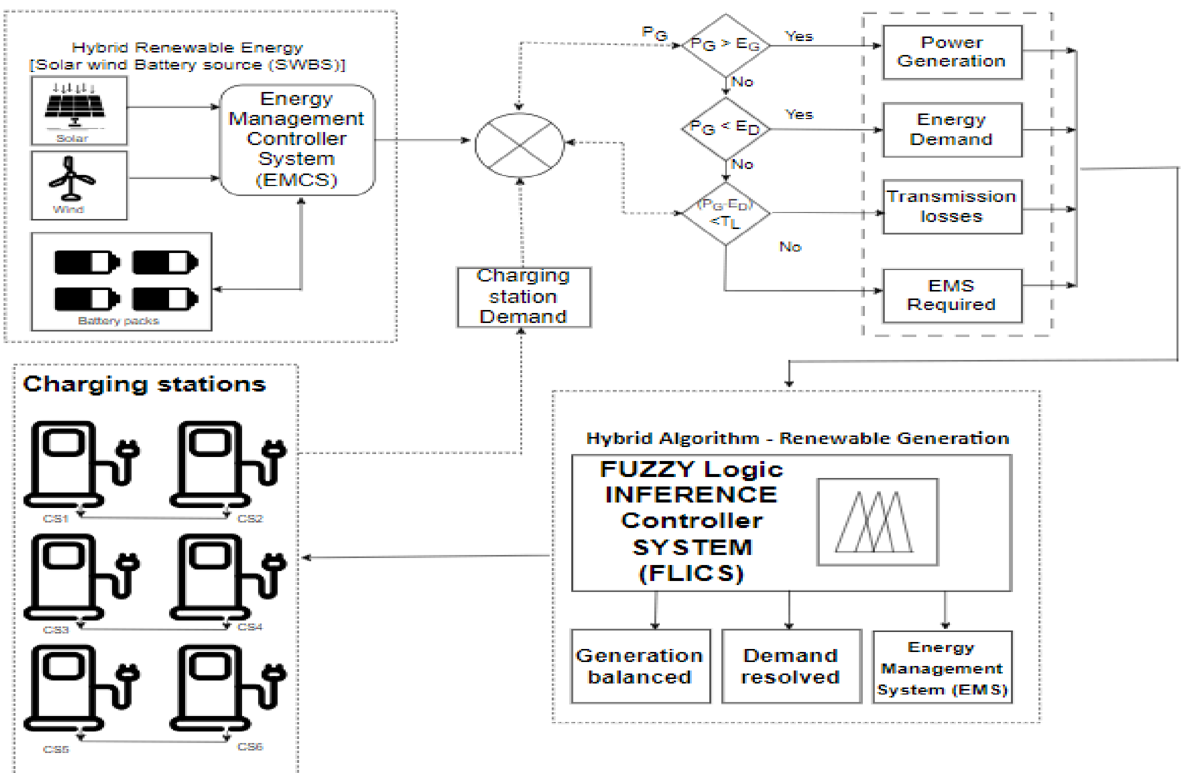


FIGURE 2: *A flowchart of the work that is being suggested.*

Stage 3:

The individual charging stations are interconnected with one another to form a (IEVCS) Integrated Electric Vehicle Charging station and will be used for the bi-directional transfer of energy when required. All the data from the charging stations are given to the FIS which will check for the individual demand as well as the whole IEVCS demand also.

This system will ensure that the power generated is utilized properly based on the requirement of the charging stations. The operational flow chart shown in Fig 2 provides an explanation of how the FLICS operates as well as the major features of the system.:

3. Mathematical model for FLICS in IEVCS

The model suggests the IEVCS with hybrid (solar & wind) renewable resources for the efficient management of energy by using the optimization done by fuzzy logic. An illustration of the proposed IEVCS with a capacity of power coming from solar and wind sources, respectively. The power that is generated by the IEVCS that has been suggested can be described as follows:

Power Generated from hybrid renewable source

$$P_{swg} = f(i_s, i_w) \tag{1}$$

Where, 'i_s' and 'i_w' denote solar energy and wind energy, respectively.

3.1 Energy Management System Of IEVCS

This part deals with the efficient system to manage the energy with the fuzzy for the IEVCS. The two major objectives of the system are the first is to maximize the exploitation of renewable resources and the second is to minimize the charging station battery energy wastage.

Each of these objectives can be described as follows:

$$Max\left(EV_{Utilization}\right) and\ Min(CSB_{charging}) \tag{2}$$

$$Max_{soc} \geq In_{soc} \geq Min_{soc} \tag{3}$$

$$B_{dc} = \frac{\left(CSBmax_{soc} - CSBmin_{soc}\right)}{Bc \times \eta} \tag{4}$$

$$P_{swg} \geq P_{IEVCS} \tag{5}$$

Where, B_{dc} stands for Battery charging duration, P_{swg} denotes the amount of power that is generated by renewable resources (solar and wind), B_c is the Battery capacity, P_{IEVCS} is the Overall Power maintained in the Integrated Charging stations, η is the efficiency and CSB is the Charging station battery.

Whereas the state of charge (SOC) restrictions are considered in order to prevent electric vehicle batteries from failing. On top of that, it is primarily the responsibility of the battery to fulfill the high/low ramp rate that is most compatible with the SOC restrictions in order to make charging an electric vehicle efficient. The size of the battery and SOC of the electric vehicle both have a role in determining the amount of electricity that the vehicle requires.

It is necessary for the IEVCS to produce power that is either greater than or equal to the power that it demands in order for it to operate well. "Charge duration" (T_C) refers to the amount of time that must pass before the cells can be charged once more. The duration of the vehicle to charge is

$$T_C = T_e - T_i - T_h \tag{6}$$

where Ti, Te, and Th are the starting time, departure time and holding time.

3.2 Sugeno Model

For this IEVCS, the Sugeno-type fuzzy logic inference controller system model is applied for a range of input situations in order to identify the desirable charging rate that utilizes a hybrid renewable energy source. This is done in order to maximize efficiency. Within the context of this particular modeling technique, the defuzzification strategy that is based on the centroid is applied. The amount of power that is generated, as well as the obtainable amount of output power, EMS, energy demand, and transmission loss are the input factors that the fuzzy model takes into consideration. It is generally accepted that the output factors include the demand resolved, EMS, generation balance, electric vehicle scheduling.

Within the framework of this fuzzy logic inference controller system as shown in fig 3, the various phases of the input and output variables are characterized by membership functions that are triangular, trapezoidal, and Gaussian accordingly as illustrated in fig 4.

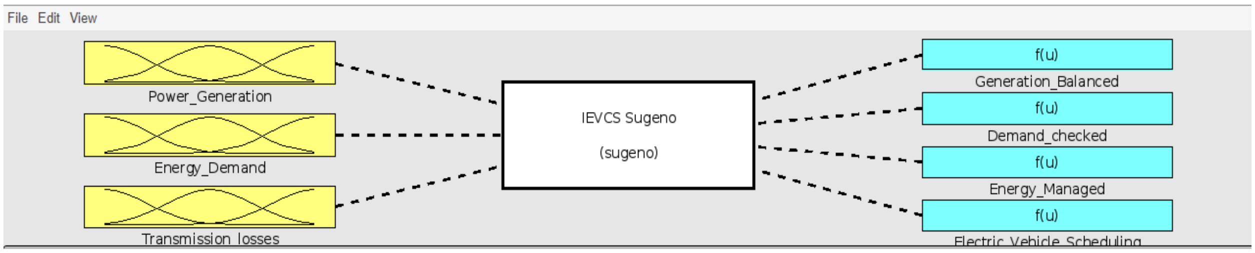


FIGURE 3: *Sugeno Fuzzy Logic Implementation of IEVCS system*

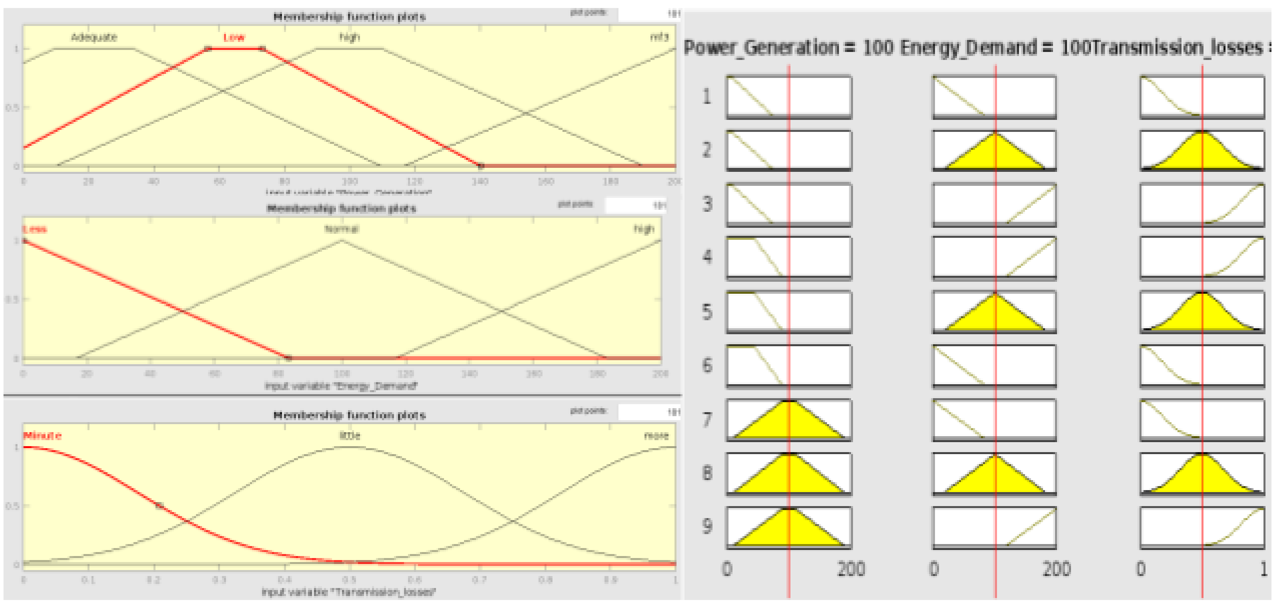


FIGURE 4: *Membership functions of the input variables and execution*

In the event that solar and wind resources are sufficient, there is the potential for an increase in power generation. On the other hand, when there is no sun energy present, there is a low generation of power. The input “power generation” is split into three MF’s. The categories are "Low", "Adequate" and "High". The amount of energy used by the vehicle is determined by the capacity and soc of the battery.

Fuzzy rule viewer makes use of numerical representations, how the output variables change in response to changes in the input variables. This optimization strategy can also be demonstrated to you by a fuzzy logic inference controller system, which will show you how the rules are organized. The membership functions for "EV-Power-Demand" in this model are: " High", "normal" and “Less". In the optimization system that has been suggested, a rule-based method that is based on fuzzy "if-then" is utilized.

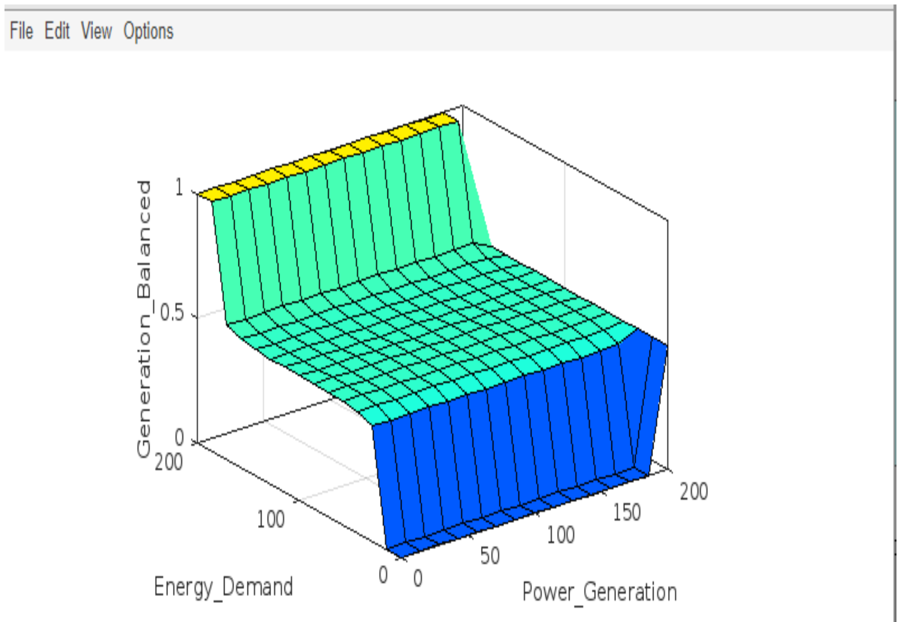


FIGURE 5: *Surface plot of the Sugeno system*

For the purpose of establishing the membership duties, information regarding the Battery EVs that are already present is utilized. The output variables will execute the Sugeno logic and the surface plot as in figure 5 suggests the improvement of energy balance is done with response to the energy demand.

Hybrid algorithm:

The optimization techniques use hybrid algorithms such as Particle Swarn Optimization (PSO) and Ant Colony Optimization (ACO) for the better utilization of the energy generated and transmitted to the charging stations.

The first Technique (PSO) is used to identify the availability of enormous or adequate charge in the particular charging station so that the electric vehicle movement can be diverted for the maximum utilization of energy without waiting time of the vehicle in the stations.

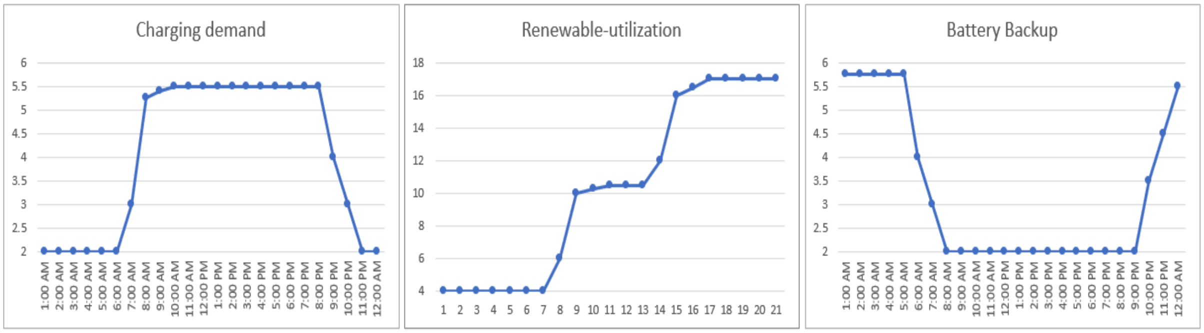
The second technique (ACO) is used to check the properties of the integration of charging stations to yield the maximum and most efficient method of power transfer within the charging stations based on the findings of the previous technique handled.

Thus, the mathematical modelling of IEVCS with the Generated power and the battery SOC's of the charging stations will prove that the handling of energy can be done in an efficient way and the additional support will be given by the optimization techniques. This will help in maintaining the sufficient energy in the charging stations during the off-peak period and supply required energy during the on-peak period and finally store the surplus or available energy to the storage battery and even supply the grid as future scope.

4. Results & Findings

For the purpose of reducing the demand of charging electric vehicles, the fuzzy-based optimization that has been presented takes into consideration the amount of solar and wind resources. On the other side, the IEVCS is proposed and optimized using a hybrid renewable resource for varied charging times, electricity demand, temperature and battery capacity. The charging is significantly greater during peak hours, when solar panels are not functioning well and wind resources are the only ones that are capable of charging electric vehicles. If there is not enough power generated to satisfy the requirements of electric vehicles, then power will be drawn from the backup battery. Even though the majority of electric vehicles are plugged in during off-peak hours, the demand of charging an electric vehicle is high.

The elements (A), (B), and (C) of Figure 6 illustrate how the demand of charging and the use of renewable energy shift in response to changes in electric vehicle power demand, renewable utilization and battery backup. When there is sufficient electricity, the demand decreases, but when there is not sufficient power, the demand increases.



(a) (b) (c)

FIGURE 6: *Graphical representations of demand, utilization and backup*

The demand varies based on the amount of power that the electric vehicle requires, as shown in fig (6a). As the demand for electric vehicles increases and decreases, charging electric vehicle also fluctuates. The majority of the time, electric vehicles consume more power during peak hours, which causes the distribution network to move more slowly.

Where, fig (6b) illustrates this situation of increased amount of generation from solar and wind sources. Because there is a greater availability of power, electric vehicle drivers are more likely to recharge their batteries regularly.

Compared to the amount of electricity that is produced, fig (6c) illustrates how the utilization of Battery backup shifts over time. Due to the fact that the intended IEVCS generates power through the utilization of solar and wind resources, and the quantity of electricity obtained and efficient depend upon energy management of fuzzy logic inference controller system.

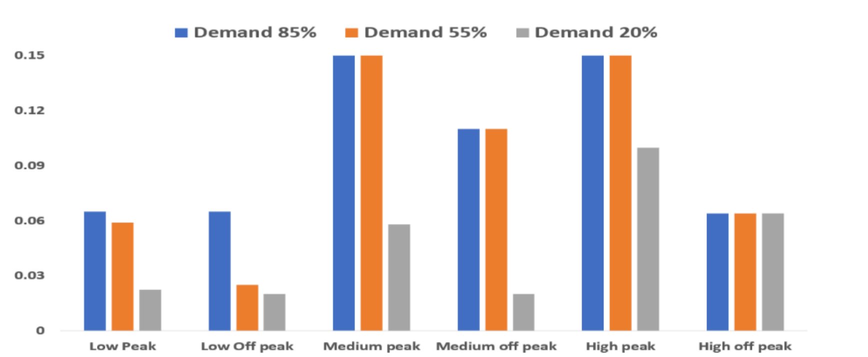
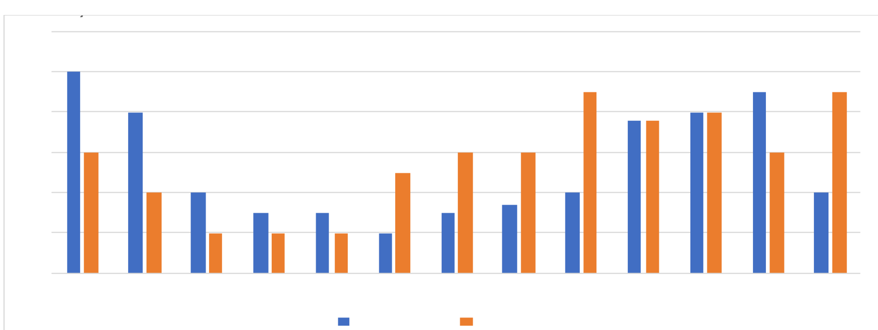


FIGURE 7: *Charging Demand in various peak positions.*

Fig 7 illustrates how the demand varies depending on the amount of renewable energy that is utilized in comparison to the demand that is already in place. When this kind of optimization is implemented, it encourages users which is extremely beneficial for the environment. As a result, demand during peak hours may be reduced



even further.

FIGURE 8: *Charging demand during weekdays and weekend.*

Through the implementation of the proposed fuzzy logic inference controller system, charging stations for electric vehicles are stimulated to make use of hybrid renewable energy sources. This results in a reduction in the need for electric vehicle load during peak hours, which in turn strengthens the distribution network and a leveled demand check for this concept for an electric vehicle charging station.

The distribution network is impacted by the fact that charging electric vehicles consumes a significant amount of energy. When there is a significant demand for electricity, the distribution network is altered by electric vehicle charging, which results in voltage drops and power loss. The demand is further analyzed for weekdays and weekend as represented in fig 8.

When more renewable energy sources are utilized, the amount of power that is drawn from the utility grid is reduced. As a result, there will be a reduction in the amount of indirect greenhouse gas emissions discharged into the atmosphere. In addition to reducing emissions of greenhouse gases, solar-wind-based energy conversion and storage (SWB) reduces the system's dependence on the power grid by utilizing a variety of renewable energy sources.

5. Conclusion and Future work

The fuzzy algorithm predicts the appropriate charging demand by taking into consideration the amount of power that is available. This allows for the most efficient utilization of hybrid renewable energy sources, the amount of power that is utilized, the amount of power that is generated, the energy management system, the amount of energy that is required, and the transmission loss. This illustrates that the hybrid renewable energy-based integrated energy delivery and control system (IEVCS) has a lower energy consumption than grid energy systems, particularly during off-peak hours. In light of this, it is possible that drivers of electric vehicles will be more likely to charge their batteries during particular times of the day. Additionally, because there is less demand during times of high demand, it increases the quality of the power production that is produced at those periods. There is a decrease in the demand for battery charging, and the establishment of an efficient energy management system for the proposed IEVCS is dependable. Significantly, the hybrid renewable energy based IEVCS was appropriate and possible to employ some more advanced algorithms. When it comes to IEVCS optimization, there is a significant amount of research potential in comparing the effectiveness of different algorithms. A charging network that is capable of lasting for an extended period of time can be constructed using the way that has been recommended for improving things. Subsequently, future research work focuses on study based on real-time performance verification. An additional aspect that will be thoroughly investigated is the impact that the implementation of the proposed IEVCS. Consequently, a new strategy known as V2G technology, which stands for vehicle to grid, can be developed in order to establish a two-way energy sharing system that functions similarly to a smart grid for electric vehicle charging stations (IEVCS). By utilizing this system, electric vehicles are able to send power to the electric grid during times of high demand. The findings of this study have a significant impact on the expansion of power system networks and transportation systems over the long run, and the plan that has been proposed has a number of beneficial consequences on the economy, the environment, and technology.

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