Solar/Wind Hybrid Power System based Charging Electric Vehicles Applications using fuzzy logic controller

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Abstract:

This paper explores the design and implementation of a hybrid power system for charging electric vehicles (EVs) using solar and wind energy, managed by a Fuzzy Logic Controller (FLC). The hybrid system integrates photovoltaic (PV) panels and wind turbines to harness renewable energy sources, addressing the growing demand for sustainable and efficient EV charging solutions. The FLC optimizes the power flow from the hybrid system to the EVs, ensuring maximum utilization of the available renewable energy while maintaining stable and efficient charging.The proposed system features a comprehensive architecture that includes power converters, energy storage, and an intelligent control unit. The FLC is designed to manage the variability and intermittency of solar and wind energy, dynamically adjusting the charging process based on real-time data such as energy generation, battery state of charge (SOC), and grid conditions.This study presents the concept of using a local hybrid solar/wind power system in Lubbock to charge electric vehicles. Power converters are used to connect the wind and photovoltaic farms to the EV stations. Moreover, the suggested system can be linked to the grid to balance load demand during periods of peak demand. The suggested system's viability and potential are demonstrated by the simulation results.

Keywords: Wind turbine, Solar photovoltaic system, Electric vehicles

I.INTRODUCTION

1.1 Background on Renewable Energy and Electric Vehicles (EVs)

The global shift towards sustainable energy solutions has intensified interest in renewable energy sources such as solar and wind power. Concurrently, electric vehicles (EVs) are gaining popularity as a cleaner alternative to traditional internal combustion engine vehicles, driven by advances in battery technology, government incentives, and increasing environmental awareness. However, the widespread adoption of EVs poses significant challenges to the electrical grid, particularly in terms of managing the increased demand for electricity and ensuring the stability and reliability of power supply.

1.2 Importance of Hybrid Renewable Energy Systems

Hybrid renewable energy systems, which combine multiple energy sources such as solar and wind, offer a promising solution to the challenges associated with renewable energy variability and intermittency. By harnessing energy from both the sun and wind, these systems can provide a more reliable and continuous power supply. This is particularly beneficial for EV charging, as it reduces dependency on the grid and maximizes the utilization of locally available renewable energy resources. Hybrid systems also enhance energy security and reduce greenhouse gas emissions, contributing to environmental sustainability.

1.3 Overview of Fuzzy Logic Controllers in Power Management

Fuzzy Logic Controllers (FLCs) are an effective tool for managing complex systems with inherent uncertainties and nonlinearities, such as hybrid renewable energy systems.

Unlike traditional controllers that rely on precise mathematical models, FLCs use a rule- based approach to make decisions based on fuzzy sets and linguistic variables. This allows FLCs to handle imprecise and fluctuating input data, making them well-suited for optimizing power flow in systems where energy generation and demand can vary significantly.

Using an electric vehicle can minimize the damages that the transportation section has on the environment. The cost, charging structure, power electrical system, and battery capacity are all factors that affect how well EVs work [1]. The utilization of ecologically friendly energy sources like solar and wind energy is inevitable in light of global warming and the potential for fossil fuel shortages. Utilizing solar and wind energy has the benefit of being cheap, plentiful, pollution-free, and available everywhere. The battery has to be charged in order for the car to operate. No need to mention that the car requires more charge while traveling over long distances. As a result, charging facilities for EVs are situated along the sides of the highway. These automobiles are charged with the help of power produced by renewable energy sources, which are close to the charging station [2]. Furthermore, the energy from various input sources had to be transferred via power converters, including isolated and nonisolated types. Isolated converters are more sophisticated than non-isolated converters due to the use of transformers. As a result, transformers are not required in the circuits of the majority of applications, which instead require a multiport dc-dc converter [3]. In addition, in order to extract maximum power from the solar part of the system, there is a need for a tracking technique. In this paper, the P&O MPPT technique is used to extract the most power possible from the PV component [4]. The main contribution of this paper is to charge EVs with renewable energies both in the daytime and nighttime.

II. LITERATURE SURVEY

2.1 Renewable Energy Systems for Electric Vehicle Charging

The integration of renewable energy sources, particularly solar and wind, for charging electric vehicles (EVs) has gained considerable attention in recent years. Numerous studies have explored the potential of solar and wind energy to provide clean, sustainable power for EV charging, reducing reliance on fossil fuels and mitigating greenhouse gas emissions. Hybrid systems combining both solar and wind energy offer enhanced reliability and efficiency by balancing the intermittent nature of these renewable sources. Research has demonstrated that hybrid renewable energy systems can effectively meet the energy demands of EV charging stations, especially when coupled with energy storage solutions.

2.2 Solar and Wind Energy Integration

Solar and wind energy integration involves harnessing energy from photovoltaic (PV) panels and wind turbines to create a hybrid system that can provide continuous and reliable power. Various configurations and control strategies have been proposed to optimize the performance of these systems. Studies have shown that the complementary nature of solar and wind energy—where solar power is typically available during the day and wind power can be harnessed both day and night—makes hybrid systems particularly effective. Research has also focused on optimizing the size and placement of PV panels and wind turbines to maximize energy generation and efficiency.

2.3 Fuzzy Logic Controllers in Renewable Energy Systems

Fuzzy Logic Controllers (FLCs) are increasingly used in renewable energy systems to manage the uncertainties and nonlinearities associated with energy generation and consumption. FLCs employ a rule-based approach that uses fuzzy sets and linguistic variables to make control decisions, allowing them to handle imprecise and fluctuating input data. In the context of hybrid renewable energy systems, FLCs have been applied to optimize power flow, improve system stability, and enhance energy efficiency. Research has shown that FLCs can effectively manage the charging and discharging processes in energy storage systems, balance the power supply from solar and wind sources, and ensure efficient energy use in EV charging applications.

2.4 Hybrid Power Systems for EV Charging

Hybrid power systems combining solar and wind energy have been studied extensively for their potential to support EV charging infrastructure. Key research areas include system design, energy management strategies, and the integration of energy storage. Studies have highlighted the benefits of hybrid systems in providing a stable and reliable power supply for EV charging, reducing grid dependency, and enhancing the sustainability of EV charging stations. Research has also explored the use of advanced control algorithms, including FLCs, to optimize the performance of hybrid systems and ensure efficient energy utilization.

III. PHOTOVOLTAIC INVERTER SOLAR/WIND SYSTEM CHARACTERISTICS

In order to explain and build the hybrid system presented in this paper, solar PV panels and wind turbines combine to create a highly reliable hybrid energy system that can harvest renewable energy under various weather situations [5, 6]. When the sun is shining and the wind isn't too strong, solar panels will generate energy; nevertheless, when severe weather strikes and the sky is cloudy, wind turbines become crucial. To maximize the utilization of renewable energy resources, the suggested solar/wind hybrid power systems combine both sources of electricity with a bank of batteries to store the energy. In the case of extra energy, by using an inverter, the extra energy from the solar part can feed the power grid [7, 8]. In addition, to design a power plant, a machine learning model is required to predict future energy [9-11].

1) Solar PV subsystem

Solar PV systems use the photovoltaic effect to turn sun radiation into power. Semiconductor materials with P-N junctions employ this method to generate energy when exposed to light [12]. Fig 1 shows a solar cell's equivalent circuit.

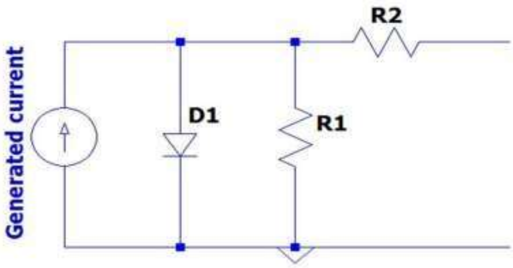

Fig. 1. solar cell's equivalent circuit

The generated current in the secondary side of each solar panel is obtained as follow:

$$I_o = I_{sh} - I_s\left(\exp\left(\frac{V+IR_2}{nV_t}\right)-1\right) - \frac{V_o+IR_2}{R_1} \qquad (1)$$

Where Vo and Io are the generated voltage and current. I-V curves for solar cells show how current changes with voltage in a photovoltaic device. Characteristics of Solar Cells I-V Curves are essentially a visual summary of a module's operation that shows how current, and voltage relate to each other under the different irradiance and temperature circumstances [13]. Fig. 2 depicts the I-V, P-V curves of the proposed solar module.

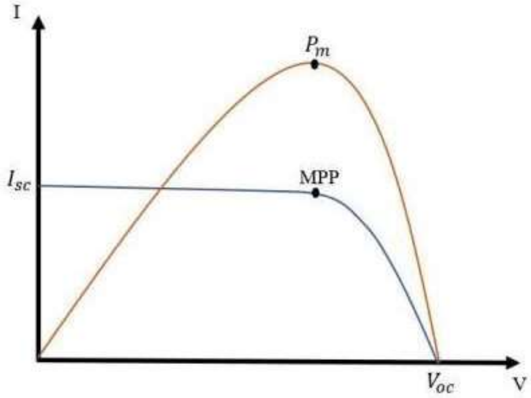

Fig. 2. Solar module I-V and P-V characteristic

An MPPT approach with a buck-boost converter is required in order to obtain the highest amount of energy from the sun. The P&O approach is used in this paper to track the maximum power points at a different time of the day. If the output power of the system is more than the needed energy for the charging station, as a demand side management with utilizing a multilevel inverter, the extra power can feed the power grid.

IV. DESIGN OF THE FUZZY LOGIC CONTROLLER

The FLC is designed to handle the variability and intermittency of solar and wind energy while ensuring efficient and stable charging of EVs. The design process involves several key steps:

Input Variables

The FLC uses several input variables to make decisions about power distribution and charging:

- **Solar Power Generation (P_solar):** The current power output from the PV panels.
- **Wind Power Generation (P_wind):** The current power output from the wind turbines.
- **Battery State of Charge (SOC):** The current state of charge of the energy storage units.
- **EV Battery State of Charge (SOC_EV):** The current state of charge of the EV batteries.
- **Grid Demand (D_grid):** The current power demand from the grid.

Fuzzy Sets and Membership Functions

Each input variable is divided into fuzzy sets with corresponding membership functions. For example:

- **P_solar and P_wind:** Low, Medium, High.
- **SOC and SOC_EV:** Empty, Low, Medium, High, Full.
- **D_grid:** Low, Medium, High.

Fuzzy Rules

A set of fuzzy rules is created to determine the optimal charging strategy based on the input variables. Examples of fuzzy rules include:

- If PsolarP_{solar}Psolar is High and SOCSOCSOC is Medium and SOCEVSOC_{EV}SOCEV is Low, then Charge EV.
- If PwindP_{wind}Pwind is Low and SOCSOCSOC is High and DgridD_{grid}Dgrid is High, then Discharge Battery to Grid.

Inference Engine

The inference engine processes the fuzzy rules and determines the output actions. It evaluates the degree to which each rule applies and combines the results to form a final decision.

Defuzzification

The fuzzy output is converted into a precise control action using a defuzzification method, typically the centroid method. This control action is then applied to manage the power converters and ensure optimal power distribution.

V. PROPOSED EV CHARGING STATION

The proposed EV charging station in this paper contains two renewable energy sources including wind and solar system. The wind system contains 10 wind turbines and the nameplate capacity for the whole wind system is 600kW. Deimos DT2160 is utilized in this paper with three blades and the rotor diameter is 21 meters, the hub height of 50 meters, with the cut-in wind speed of 3 meter per second and cut-out wind speed of 25 meter per second. Fig. 4, shows the power curve of a turbine.

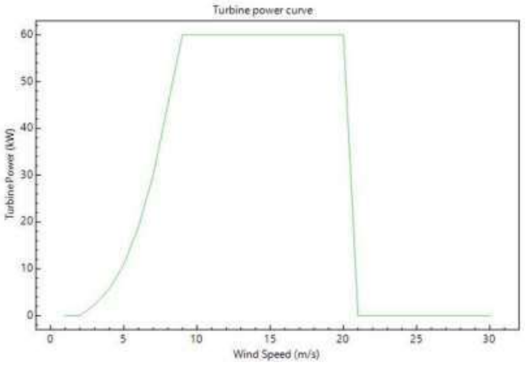

Fig. 4. Turbine power curve

As it can be seen, the output power of each turbine is 60 kW. In addition, the swept area by the blades is 362 square meters. Furthermore, table 1 shows the solar system used in this paper which has the nameplate capacity of 500kW.

TABLE 1. Presented solar system

Cells numbers per module	72	Efficiency	21.08 %
Module Size	1.6*1.14 m	Weight	18.5 kg
Rated power	339.3 W	Tilt	33.5 °
I (SC)	6.54 A	V(OC)	74.6 V
I (MPP)	6.14 A	V (MPP)	62.2 V

According to table 1, each module has 72 cells in series, and the weight of each module is 18.5 kg. the rated power is 339W and the tilt angle for the solar panels is 33.5 degrees which is equal to Lubbock latitude angle. Using solar and wind at the same time increase the reliability of the system. The proposed charging station block diagram is seen in Fig. 5.

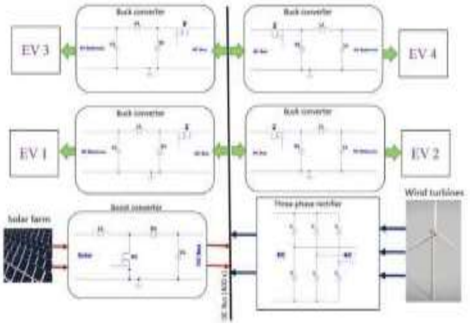

Fig. 5. Charging station block diagram

During the day, solar and wind energy are used to recharge the battery. By stepping up the voltage to 400V using a boost converter, the solar panel's output is managed. Since wind is present at night, it partially charges the DC bus. Then the EVs are charged by battery via utilizing a buck converter. Solar energy is widely available and cost-free, but power stability is challenging. However, it may be effectively made up for by fusing with another energy source. As a result, in this study, solar and wind energy are combined. When there is wind, the battery is charged. When it is hot, a PV module may be used to charge the battery. This research proposes a hybrid system that is unusual in that it generates power from two separate renewable sources. When the hybrid solar/wind system is unable to absorb enough energy, the extra energy stored in the battery is utilized to charge EVs [20, 21].

V. SIMULATION RESULTS

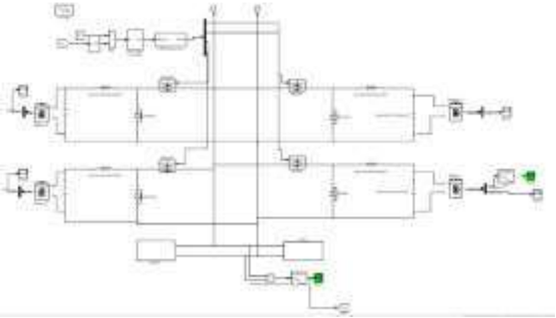

Fig6: Proposed Simulation Diagram using fuzzy

The proposed system is simulated via MATLAB software. The two significant factors in order to utilize the solar/wind hybrid system is the weather temperature and wind speed. According to the data from Lubbock, the number of sunny days is high and also the wind speed is quite suitable for wind turbines.

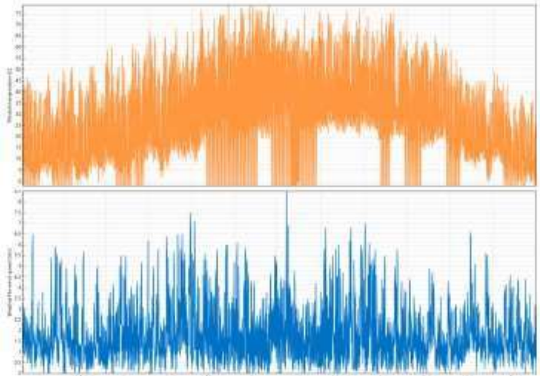

Fig. 7 Ambient temperature and wind speed

After producing the power from solar system, a boost converter is required to step up the voltage to 400V for the DC bus. Fig. 7 shows the voltage of the solar system and the output voltage of the utilized boost converter.

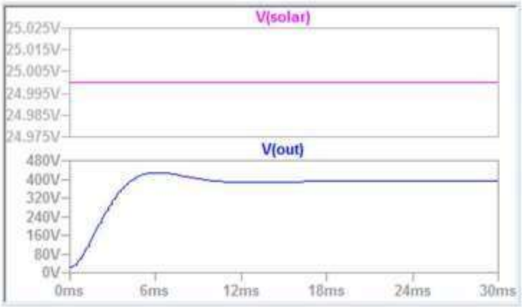

Fig. 8. Output voltage of the utilized boost converter.

Based on Fig. 8, the employed boost converter step up the voltage from 25V to 400V in the proposed DC fast charging station. No need to state that in order to charge the EV batteries a buck converter is required to step down the voltage for the batteries. Fig. 9 shows the output voltage of the buck converter which should be equal to the needed voltage of the EV batteries.

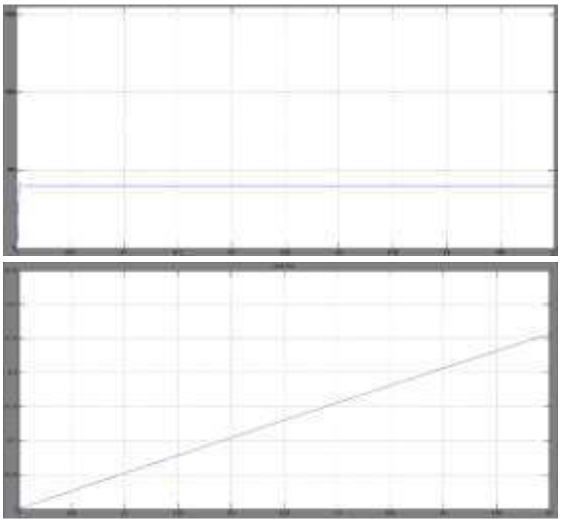

Fig. 9. Output voltage of the utilized buck converter

According to the figure above, by using a buck converter, the voltage of the DC bus will be changed to the desirable voltage for the EV bank of batteries. Finally, the extracted power for each of the renewable system as well as the whole system is illustrated in Table 2.

TABLE 2. Comparison table for the proposed system

	Wind system	Solar system	Hybrid system
Nameplate capacity	600kW	500kW	1.1MW
Extracted power	2,904,420 kWh	1,057,599 kWh	3,962,019 kWh

Table 2 shows that the total system's extracted power is around 4 GW annually. If each EV takes 30 kWh for charging, then 133000 cars may be charged annually, which is a very huge number.

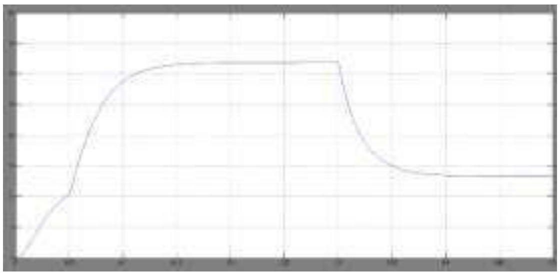

Fig10: wind active and reactive power

VII. CONCLUSION

The rise in EV utilization creates a demand for energy that the infrastructure of the present power system cannot provide. In this work, a hybrid renewable energy charging station that requires no external electrical source and has no maintenance costs is presented. The storage batteries are charged by the use of renewable energy sources, and from them, the cars are charged. In these charging stations, the cost of power is lower, and simple to use power is obtained. According to the simulation result, by using just a 600kW wind system consisting of 10 turbines, and the 500kW solar system, the yearly 4 GW power can be achieved in Lubbock which can charge around 133000 EVs which is very remarkable. Furthermore, a very huge amount of CO2 and SO2 will be removed from the air.

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