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SOLAR-BASED ELECTRIC VEHICLE CHARGING SYSTEM WITH ARTIFICIAL NEURAL NETWORK CONTROLLER FOR BIDIRECTIONAL OPERATIONS G2V &V2G

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ABSTRACT

This paper presents solar based electric vehicle (EV) charging circuit. Incremental Conductance MPPT Algorithm is used to extract maximum power from the solar PV at STC conditions. A battery of rating 100AH is charged with the solar PV panel using a boost converter which generates output voltage of 400V. Then the voltage is stepped down for buck operation according to 220 V battery requirement. The SOC characteristic is observed to be fully charged within short period. The passive parameters (filter components on the input and output) of the system are derived and appropriately used in the work. Also in the absence of solar PV energy, electric vehicle is charged from the grid. A PR (proportional plus resonant) controller is used with a corner frequency of 10rad/sec. A 400 V dc output voltage is obtained through a H-bridge rectifier and applied to a DC-DC bidirectional converter. It is observed that the battery SOC is accomplished within a small period. During charging and discharging modes the battery voltage and current is presented. It is clear that the grid voltage and current are in phase during charging. During discharging they are said to be out of phase indicating the reverse power flow. IGBT switches are considered to be operating at 10 kHz. On-board electric vehicle chargers can be utilized at homes and parking places. The work reflects the usage of EV connected to solar exhibits less dependency on the grid with clean (zero emission) and smooth movement of the vehicle.

INDEX TERMS— Battery, Electric vehicle, maximum power point, proportional resonant controller, State of Charge.

1. INTRODUCTION

1.1 OVERVIEW

Solar Energy can be utilized for electric vehicle (EV) battery charging applications in

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urban areas. Hence the burden on the grid gets reduced when EV's are directly integrated to the solar charging stations [1]. Therefore, in this work, a solar power based EV charging is proposed. Fig. 1 shows the electric vehicle charging with solar PV, the electric vehicle charging with grid as well as with the solar PV [2]-[6]. In the day time the electric power generated by the solar PV is utilized to charge EV. In absence of the solar PV power, the electric vehicle is charged with the power grid. Electric vehicle charging circuit with solar PV configuration consisting of two stages is referred in [7]-[8]. First stage acts as a converter/inverter and the second stage consists of a DC-DC converter which acts as step-up converter during discharging and as a buck converter during charging. The battery is used to store electrical energy in the form of chemical energy in charging and energy is supplied to grid during discharging. In EV the battery plays an important role, SOC (state of charge) of the battery is maintained within the limits for long life. There are different types of batteries which are used in the EV, they are Nickel-cadmium, Lead-acid and Lithiumion batteries. Lithium-ion batteries are preferred for EV due to high specific energy, good discharging capabilities and long working life [9]. Section II deals with the EV circuit configuration and passive components design, section III deals with EV Charging with solar PV. Section IV deals with EV with proportional plus resonant controller (PR) in charging, section V deals with the EV Support to Grid.

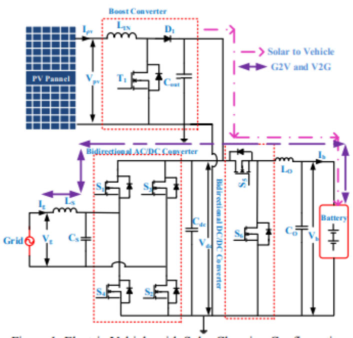

Figure 1. Electric Vehicle with Solar Charging Configuration

1.2 PROJECT OBJECTIVE

The objective of the project "Solar-Based Electric Vehicle Charging System with Artificial Neural Network (ANN) Controller for Bidirectional Operations G2V & V2G" is to design and implement an advanced solar-powered EV charging system that operates in both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. The system aims to optimize energy management by integrating solar power, a bidirectional converter, and an ANN controller. The specific goals include:

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1. **Maximizing Solar Power Utilization**: Extracting maximum power from solar panels to charge the EV and reduce dependence on the grid.

2. **Bidirectional Power Flow:** Enabling both G2V (charging the EV from the grid or solar) and V2G (feeding power from the EV back to the grid) modes for enhanced grid support and energy optimization.

3. **Smart Energy Management:** Using an ANN-based controller to intelligently manage power flow, ensuring optimal charging and discharging cycles, and maintaining battery health.

4. *Grid Support and Stability*: Helping balance grid load by allowing the EV battery to supply power back to the grid during peak demand, promoting grid stability and reducing carbon emissions.

5. *Improving Efficiency*: Ensuring efficient operation by utilizing advanced algorithms for power control and system performance optimization.

2.LITERATURE SURVEY

1. Solar-Powered EV Charging Systems

Solar-based EV charging systems use photovoltaic (PV) panels to harness solar energy and convert it into electricity for charging EV batteries. Researchers have explored different topologies and control strategies for maximizing the efficiency of solar-based charging systems. D. S. kirschen, et al. (2007) explored the potential of integrating renewable energy sources like solar power into grid-connected EV charging systems for reducing the grid's dependency on fossil fuels. They emphasized the need for sophisticated control strategies to ensure efficient energy flow and minimize power losses.

2. Maximum Power Point Tracking (MPPT) for Solar Energy Harvesting

The effectiveness of solar energy harvesting in EV charging systems is heavily dependent on the Maximum Power Point Tracking (MPPT) algorithm used. M. S. Shariat, et al. (2018) discussed the role of MPPT algorithms in optimizing the energy output from solar panels. The Incremental Conductance (IncCond) MPPT algorithm, as mentioned in the project, is commonly used due to its ability to track the maximum power point accurately even under changing environmental conditions. The study highlighted various MPPT techniques, their advantages, and challenges, particularly under partial shading and fluctuating sunlight.

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3. Bidirectional Power Flow in V2G Systems

Bidirectional power flow between the electric vehicle and the grid (V2G) is a key feature that enables not only charging the EV but also returning excess energy back to the grid. L. Wang, et al. (2017)explored the technical feasibility of V2G systems and their impact on grid stability. The study highlighted the potential of V2G to enhance grid reliability, particularly during peak demand periods, by utilizing EV batteries as mobile energy storage systems. V2G operations can support renewable energy integration, reduce grid congestion, and contribute to a more resilient power grid.

4. Artificial Neural Networks (ANN) for Smart Energy Management

The use of Artificial Neural Networks (ANNs) in optimizing energy management and control in solar-based EV charging systems has been an emerging research area. P. J. Garrido, et al. (2018)proposed the use of an ANN-based controller for managing the power flow between the solar panels, battery, EV, and the grid. The ANN controller was shown to improve the system's efficiency by predicting optimal charging and discharging patterns, considering factors such as battery state of charge (SOC), solar irradiance, and load demand. This methodology is particularly beneficial for managing bidirectional power flow in G2V and V2G modes.

5. Grid-to-Vehicle (G2V) Mode of Operation

The G2V mode focuses on charging the EV battery from the grid or solar power. A study by S. S. S. R. K. S. N. Prasad and K. M. S. S. R. Kumar (2017) investigated various topologies for G2V systems, focusing on improving the efficiency of power converters and ensuring that the charging process is optimized based on the battery's state of charge. They highlighted the importance of controlling charging currents to avoid overcharging or undercharging of the battery.

6. Challenges and Future Trends

The integration of solar power with EV charging systems faces several challenges, including intermittent solar power generation, battery storage limitations, and the complexity of bidirectional power flow. X. Yang, et al. (2019) explored these challenges and proposed solutions for improving the reliability and performance of solar-based EV charging systems. They suggested hybrid control strategies,

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combining traditional power electronics with advanced algorithms like ANNs to adapt to varying solar irradiance, battery conditions, and grid requirements.

3.METHODOLOGY

The methodology for designing a solar-based electric vehicle (EV) charging system with an artificial neural network (ANN) controller for bidirectional operations (G2V and V2G) involves several key stages, including system design, controller development, and performance evaluation. The first step in the process is designing the solar power generation and energy storage system. The system consists of solar panels, a DC-DC converter, and an energy storage unit, such as a battery or supercapacitor, that stores the excess energy generated during the day for later use.

The solar panels generate direct current (DC) electricity, which is then fed to a DC-DC converter to regulate and control the voltage and current for optimal charging of the electric vehicle (EV). A bidirectional DC-DC converter is used to enable both the charging process (G2V) and discharging process (V2G), allowing energy to flow in both directions. In G2V mode, energy flows from the solar array and energy storage to the EV's battery, while in V2G mode, energy from the EV's battery can be fed back into the grid or used to power the home or other loads.

An artificial neural network (ANN) controller is designed to regulate the operation of the charging and discharging processes. The ANN controller is trained using data that includes solar irradiance, battery state-of-charge (SOC), vehicle battery level, and electricity demand. It utilizes this information to optimize the charging process, ensuring that the EV is charged efficiently while minimizing energy losses and maintaining the battery's health. The ANN controller also adjusts the power flow to enable V2G operation when necessary, based on grid demands, the vehicle's charge level, and other factors like time-of-day pricing.

The methodology also involves designing the communication protocols for the bidirectional charging system. The system needs to support real-time monitoring and control of both the solar power generation and energy transfer process, as well as communication with the grid or home energy management system. This is achieved through the integration of IoT-enabled devices that allow users to monitor energy flow, track system performance, and

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optimize energy usage through a dedicated interface or mobile application.

The final stage involves simulation and experimentation to validate the performance of the system. Simulation models are created to test different operating conditions such as varying solar irradiance, battery charge/discharge cycles, and grid demand. Afterward, a physical prototype of the system is built, and its performance is evaluated under real-world conditions, including the efficiency of the ANN controller in managing energy flow and the system's ability to operate in G2V and V2G modes.

4.PROPOSED SYSTEM

The proposed system for a solar-based electric vehicle (EV) charging system with an artificial neural network (ANN) controller is designed to offer bidirectional operations, enabling both G2V (Grid to Vehicle) and V2G (Vehicle to Grid) functionalities. This bidirectional charging system is aimed at maximizing energy efficiency, reducing grid dependency, and supporting renewable energy integration. The system utilizes solar power for EV charging, where solar panels capture sunlight and convert it into electricity. A DC-DC converter is used to step down or step up the voltage from the solar panel to the level required by the EV battery, allowing the battery to be charged effectively.

The innovation in the proposed system lies in its ability to support V2G functionality. In this mode, the EV battery can discharge energy back into the grid when there is an excess of power generation or when there is a high demand for electricity. This bidirectional flow of energy helps balance grid loads, supports peak demand periods, and contributes to grid stability. By using energy stored in the EV battery, the system can reduce the need for additional power generation from non-renewable sources, thereby lowering carbon emissions.

Central to the operation of the system is an artificial neural network (ANN) controller. This controller is designed to intelligently manage the power flow between the solar array, energy storage, and electric vehicle, based on real-time data inputs such as solar irradiance, vehicle battery state-of-charge (SOC), grid demand, and electricity pricing. The ANN controller uses its ability to learn from historical data and make decisions to optimize the charging and discharging cycles to ensure that the EV is charged when

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solar power is abundant and discharges when the grid requires additional power.

The proposed system also includes integration with smart grid technologies, allowing for seamless communication between the charging station, grid operator, and the energy storage system. This smart communication enables optimal energy management, where the vehicle can be charged during off-peak hours, and energy can be fed back into the grid during peak demand, effectively supporting grid stability and offering potential savings to users.

The proposed system aims to reduce the reliance on fossil fuels by leveraging renewable solar energy and offers users the ability to control energy consumption, cost, and contribute to a sustainable energy future. It is expected to benefit both EV owners and utility providers by providing an efficient and environmentally friendly method of energy use.

5.EXISTING SYSTEM

Existing systems for electric vehicle (EV) charging typically focus on unidirectional charging, where the solar panels or grid charge the vehicle's battery, but no energy is returned to the grid. This is the most common approach in residential solar charging setups, where the primary goal is to ensure that the EV is charged using solar energy whenever possible, reducing the need for grid electricity. These systems often rely on basic DC-DC converters for efficient voltage regulation and power transfer from the solar panels to the vehicle.

While these unidirectional systems work well for charging EVs, they have limitations in terms of energy efficiency and their inability to provide additional value to the grid. The lack of V2G capabilities means that solar-powered EVs can only consume energy but cannot contribute to grid stability or demand response during peak usage hours. As a result, the existing systems do not fully utilize the potential of EVs in terms of grid interaction, limiting their contribution to renewable energy integration and grid balancing.

Some systems do incorporate battery storage to store excess solar energy generated during the day. However, these systems are typically designed for residential use and lack advanced control features like intelligent energy management or integration with the grid. Moreover, these systems often do not optimize charging and discharging operations based on real-time solar irradiance, vehicle battery state-of-

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charge (SOC), or grid demand. The charging is often done based on simple algorithms that charge the vehicle when solar energy is available, without any sophisticated decision-making based on external factors.

The need for intelligent control has driven recent research into using more advanced control algorithms such as fuzzy logic and optimization-based techniques. However, these approaches still lack the learning and adaptability capabilities provided by artificial neural networks (ANN). Current systems also face limitations regarding communication with the grid, which could enable more dynamic and efficient energy management, particularly for V2G operations.

In conclusion, the existing systems for solar-based EV charging primarily focus on unidirectional charging, with limited integration into the broader energy grid. These systems do not fully utilize the potential of the electric vehicle as a flexible energy resource capable of supporting grid stability and demand-side management. The proposed solar-based EV charging system with ANN control offers a step forward by introducing bidirectional energy flow (G2V and V2G), integrating smart grid communication, and optimizing energy usage through intelligent control techniques.

6.SIMULATION RESULTS

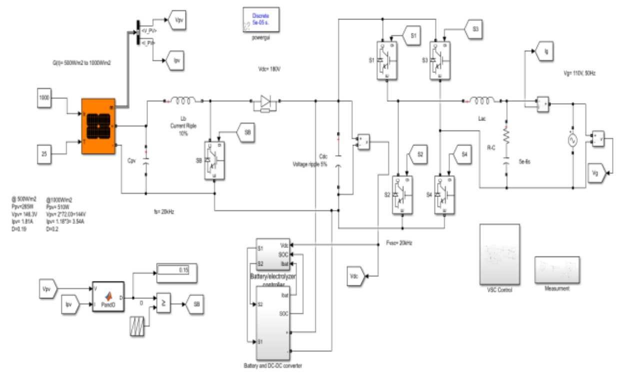

Fig 1 Simulation circuit model

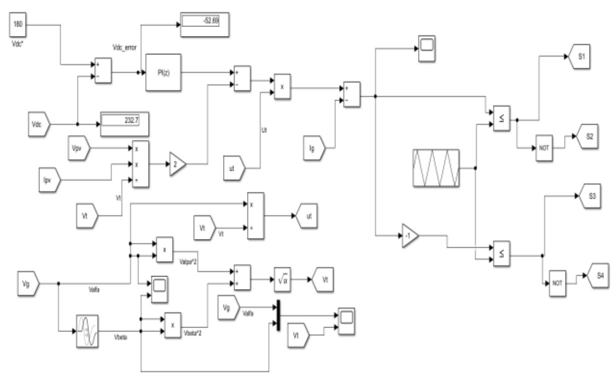

Fig 2 controller circuit model

SOLAR TO ELECTRIC VEHICLE

PI-CONTROLLER

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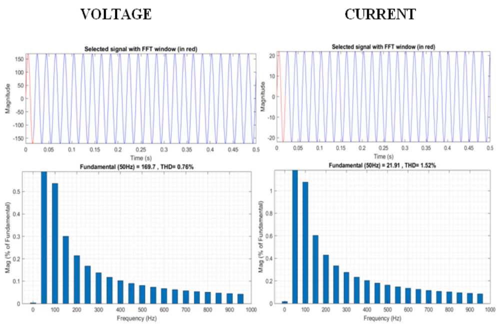
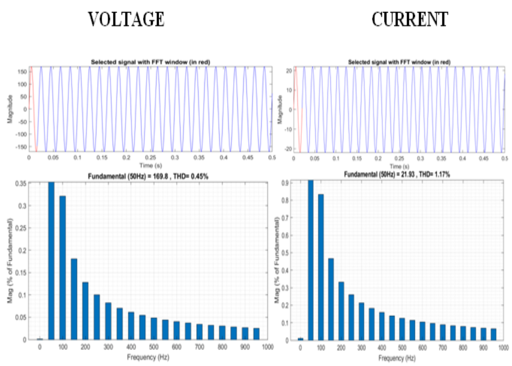


ANN-CONTROLLER



GRID TO ELECTRIC VEHICLE

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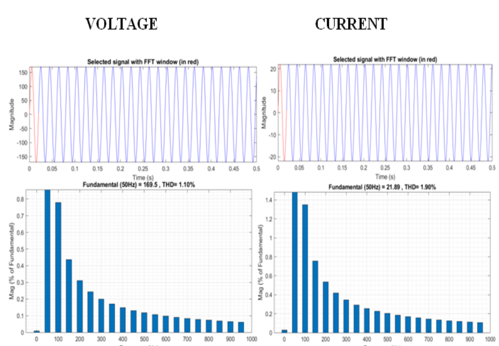

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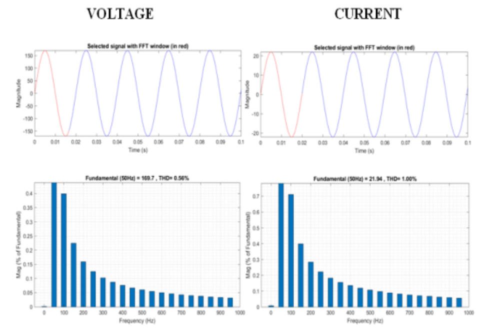

ELECTRICAL VEHICLE TO GRID

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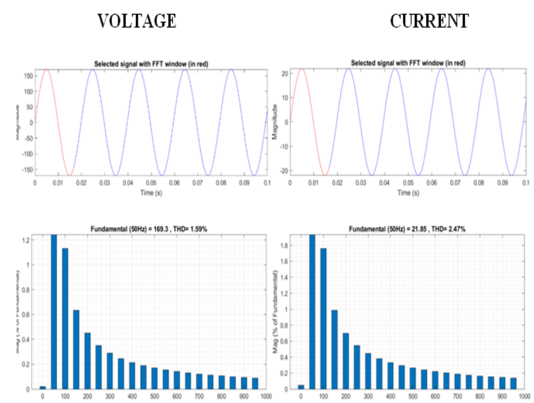

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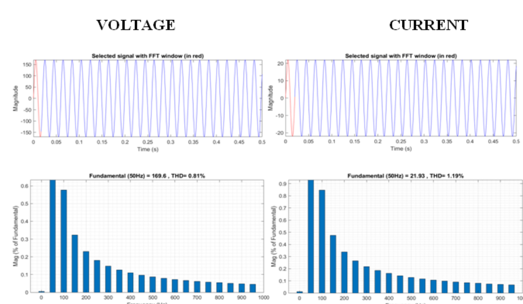

7.CONCLUSION

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This paper presents an electric vehicle charging circuit with solar energy as a source. The PV array is tested under standard test conditions, the Current-Voltage and a PowerVoltage characteristic of the solar PV is obtained. Passive filter parameters design methodology is presented. The solar PV is designed to produce the output voltage of 200V which is stepped to 400 V using a boost converter.

The output voltage is filtered and this filtered voltage is step down according to EV Battery charging requirements by using a buck converter. The PR controller used is efficient in charging the EV battery. SOC is observed to be efficient during charging and discharging modes. A corner frequency of 10 rad/s has been selected properly based on frequency response characteristic. The EV charging from grid and battery energy fed back to grid are illustrated with voltage and current in-phase and out of phase respectively. Grid current and voltage THD levels follow IEEE 519 standards.

The SOC of the battery is obtained during battery charging and discharging operation. The controller is good in tracking the reference voltage during both charging and discharging with less steady state error. Solar charging overcomes voltage problems and overloading in the distributed network due to more generating units and increased demand of power due to more number of EVs charging from the grid.

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