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DEVELOPMENT AND IMPLEMENTATION OF A SINGLE INDUCTOR MULTI-PORT CONVERTER FOR EV APPLICATIONS WITH ACTIVE GRID PARTICIPATION AND NETWORK-DRIVEN HARMONIC SUPPRESSION

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ABSTRACT The growing demand for electric vehicles (EVs) and the integration of renewable energy sources into the grid necessitate efficient power conversion systems that support bidirectional energy flow. This paper introduces a single inductor multi-port power converter designed for EV applications, which allows for seamless connection between the EV battery, the grid, and renewable energy sources such as solar PV. The converter operates with a neuro-fuzzy controller to optimize power management, ensuring stable and efficient energy flow between the different ports. The single inductor multi-port converter consolidates the power conversion stages, reducing component count, cost, and size while enhancing efficiency. The converter facilitates grid-to-vehicle (G2V) and vehicle-to-grid (V2G) power transfer, as well as energy exchange with renewable energy sources and energy storage systems. The neuro-fuzzy controller combines the advantages of neural networks and fuzzy logic, providing adaptive control for real-time power regulation, voltage stabilization, and current management under varying load and grid conditions. The neuro-fuzzy control algorithm adapts to changing environmental conditions, such as fluctuating solar irradiance or grid disturbances, and optimizes the charging and discharging cycles of the EV battery to ensure efficient energy usage and minimize power loss. Simulation and experimental results demonstrate that the proposed system provides high efficiency, reliable performance, and flexible operation for gridconnected EV charging and integrated renewable energy systems.

KEYWORDS: Single inductor multi-port converter, Electric vehicle (EV) applications, Neuro-fuzzy controller, Vehicle-to-grid (V2G), Grid-to-vehicle (G2V), Power management, Renewable energy, Energy storage, Power conversion efficiency.

1.INTRODUCTION

1.1 Project Overview

Because of the world's rapidly increasing population and energy demand, which is raising the cost of gas and oil and reducing the availability of fossil fuels, electric vehicles (EVs) should be used instead of fossil-fuel cars. As a result, interest in developing EVs powered by clean and renewable energy sources to replace fossil-fuel vehicles has grown steadily. Electric vehicles (EVs) are a promising alternative for transportation-related applications because they can help the environment by using renewable energy sources . In the case of electric vehicles, the solar PV system is used as a clean energy source. Solar PV energy sources use solar energy to generate electricity. The maximum power from the solar panel was extracted using the maximum power point tracking (MPPT) technique. At the moment, the use of solar PV energy systems meets the requirements for electric vehicle applications. As long as the energy is available, these provide energy to the required load and charge the battery. Hence, there exist many limitations of the solar PV system such as the various irradiance levels causing the system less effective in power transfer to the load and the availability is not constant throughout the way. To overcome these constraints, a solar PV system with a secondary battery source is used to provide energy from source to load. The hybridised combination of energy storage systems provides continuous power transfer to the load and meets the load's high power requirements at high speeds and terrains. Different voltage ratings are used to interface energy storage systems such as batteries and supercapacitors.

Implementing the system with individual DC-DC converters for each source makes the system bulky and complex, increasing the system's cost. As a result, a converter with multiple voltage-rated inputs is required to handle multiple energies and feed them into the system. In general, hybrid energy storage systems are interfaced with a multi-input converter, which comes in a variety of variants depending on the isolation requirement for non-isolation and isolation type DC-DC converters. FIGURE 1.1 depicts the general layout of the multi-input converter-fed electric motor. In an isolated multi-port converter configuration, a high-frequency transformer is used to produce isolation between the electric constraints. This allows for efficient isolation and impedance matching on both sides of the converter. Leakage inductance is

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used as a storage device in isolated converters to transmit power between both sides of the converter. Isolated dc-dc converters frequently include power converters in addition to the high-frequency transformer.

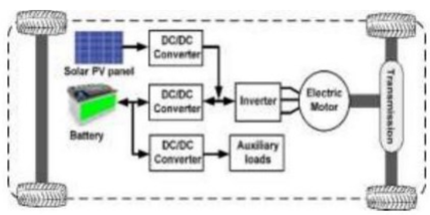

FIGURE 1.1: Conventional EV Powertrain with Multiple Converters

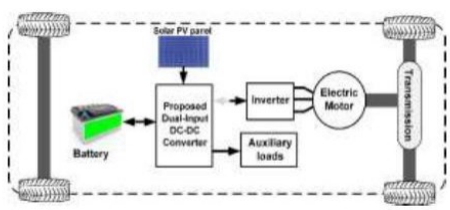

FIGURE 1.2: EV Powertrain with Existing Converter

The transformer phase shift between the primary and secondary voltage constraints has been changed to maintain efficient power transfer from both converter ports. There are several types of converters in this category, including half-bridge converters, fullbridge converters, and combinational multiport converters. Because of the transformer, these are quite large. Inverters are required in these converters at the transformer's input port, with which dc can be converted to ac supply and ac can be converted to dc using the converters. As a result, various switches are used in all converter terminals, increasing the losses, and the system losses increase as transformer winding losses increase. These shortcomings are addressed in non-isolated multi-port converters, which are ideal for electric vehicle applications. Concerning the H-bridge, a nonisolated multiport converter has been implemented.

In practise, various voltages can be obtained by cascading H-bridge configurations while taking into account various dclink voltage levels. Because of the converter's coupling mechanism to multiple ports, the negative modes are not investigated. Introduces the concept of a multiphase converter. The energy stored in the converter's energy storage sources can be absorbed as well as delivered to the load. There exists an individual inductor for each source and hence this is considered a drawback of the converter also cost-efficient three-port converter for EV/HEV applications is proposed. The author offers a three input converter for the connection of batteries, solar cells, and fuel cells. You can charge and discharge the battery from various sources and loads with proper converter switching. Presents a systematic method for designing non-isolated topologies using a combination of buck, boost, sepic, and cuk type converters. There are two types of converters described: which are pulsing voltage and current sources. As a voltage source, Pulsing Voltage Source can be connected in series with an inductor to form a double input converter. Because the Pulsing Current Source is a current source, it may be used to build a double-input converter by connecting it in series with a capacitor.

The energy management strategy among the various inputs like battery, SC and the electric motor is suggested for use in an electric automobile. Here, instead of employing two separate inductors as energy storage components are used. When compared to two independent inductors, it is claimed that employing the inductors with coupling can able to save 22–26% in volume. In contrast, connected inductors have a larger volume than a single inductor. This converter can also regenerate braking energy to the battery and SC. [23]proposes transferring load power across input sources using a multiport converter with a single inductor. This converter can also be used to transfer power from one source to another. In [24], the author introduced a novel zero voltage switching DC-DC converter. The layout of conventional converters utilized in electric vehicles is represented in FIGURE 1.1 whereas the proposed converter configuration is represented in FIGURE 1.2. Connected inductors, on the other hand, have a larger volume than a single inductor. This converter also allows for the regeneration of braking energy to the battery and SC. [23] suggests transferring load power across input sources using a multiport converter with a single inductor.

This converter can also be used to transfer power between sources. [25,26] offer a multi-port converter that may create numerous voltages at its output sections and these are the pre-set values regardless of the variation of the load power and input voltage interfaced with PV systems. [27] Presents a novel multi-output buck converter control technique that delivers suitable dynamic performance. However, this converter is worthless in applications like electric cars, where various input energy excitations like solar and a battery are utilized. This can be solved by incorporating multi-port converters. [28] Describes a non-isolated high step-up multi-port converter and its performance evaluation using a variety of parameters. [29, 30] evaluate the MPPT of a solar PV converter under partial shading conditions. Another flaw in the proposed converter is its inability to transmit energy across input sources. A novel multi-port non-isolated converter is suggested in this

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work, which is based on the mixture design of multiple inputs and outputs of the converter. In comparison to previous scenarios, the suggested converter contains fewer components. This converter can regulate the flow of electricity between sources and loads. Furthermore, the suggested converter includes many outputs, each of which can have a different voltage level.

1.2 PROJECT OBJECTIVE

The primary objective of this project is to design, develop, and implement a Single Inductor Multi-Port Power Converter (SIMPC) that effectively converts DC power to AC for applications in electric vehicles (EVs) while offering flexibility in supplying power to the grid or local loads. The project aims to improve the performance of traditional power conversion systems, focusing on the reduction of Total Harmonic Distortion (THD) in the output AC signal, which directly affects the quality and efficiency of power supplied. Key objectives of the project are as follows: Develop a single inductor-based power converter capable of managing multiple energy sources and outputs simultaneously. The design will include a multi-port topology that allows power input from various sources (such as EV batteries, solar panels, or energy storage systems) and facilitates power distribution to various loads (such as the vehicle, grid, or local appliances).

The converter should operate efficiently at different power levels to meet the dynamic requirements of electric vehicles (EVs) and grid supply. The converter will be used to convert DC power (e.g., from batteries or renewable energy sources) into AC power for distribution to different outputs (grid or local loads). This conversion will involve using an Inverter stage, which is central to the project. The aim is to ensure that the AC output maintains high efficiency and meets grid standards for voltage, frequency, and waveform quality. The project focuses on reducing Total Harmonic Distortion (THD) in the output AC waveform, a key parameter that affects the quality of power delivered to loads and the grid. Traditional Proportional-Integral (PI) controllers used in inverter systems typically result in a THD of approximately 2.15%. Aiming to reduce this distortion, the project introduces a Neuro-Fuzzy Controller, which integrates Artificial Neural Networks (ANN) and Fuzzy Logic to optimize the control of the inverter. The goal is to reduce the THD from 2.15% to 0.75%, significantly improving the quality of the AC signal, making it suitable for grid integration and sensitive local loads like EVs. The conventional PI controllers are replaced by a Neuro-Fuzzy Controller to enhance the dynamic response and performance of the system under varying load conditions. The Neuro-Fuzzy Controller will use a combination of neural networks to model the complex relationships between system parameters and fuzzy logic to handle uncertainties and nonlinearities in the system. This advanced control strategy will enable the inverter to perform optimally, adaptively adjusting to changes in input conditions (e.g., battery voltage, load demand) while minimizing harmonic distortion and improving overall efficiency. The project will involve thorough testing of the converter's performance under various operating conditions, including different power levels, load variations, and input sources. The performance of the Neuro-Fuzzy Controller in reducing THD and improving the overall stability and efficiency of the power conversion system will be validated through simulations and hardware implementation.

The system's effectiveness will be benchmarked against conventional systems that use PI controllers to compare improvements in harmonic distortion, efficiency, and dynamic performance. In addition to its application in electric vehicles, the system will be designed to supply power to the electric grid or local loads. The converter will feature the flexibility to switch between supplying power to the vehicle, grid, or local loads via appropriate breakers or switches. A key objective is to ensure that the system is compliant with grid codes and standards for voltage quality and harmonics. The project aims to enhance the overall system's efficiency, ensuring minimal power losses during conversion and maximum utilization of available energy. By incorporating the Neuro-Fuzzy Controller, the system will dynamically adjust control parameters to optimize efficiency in various load conditions, thereby improving the overall stability of the power supply. While the primary focus is on electric vehicle applications, the system will be designed with future adaptability in mind. The power converter could be scaled up or modified to serve additional renewable energy systems (such as solar or wind), creating a versatile solution for sustainable energy management. The system will also be tested for grid compatibility, allowing seamless integration into smart grids and contributing to energy optimization.

2.LITERATURE SURVEY

Single Inductor Multi-Port Power Converters (SIMPCs) integrate multiple power ports (such as batteries, supercapacitors, solar cells, and DC loads) with a single inductor. These converters are particularly and cost compared to conventional multi-inductor converters. They also help optimize energy flow, reducing losses and improving system efficiency.

1. Single Inductor Multi-Port Converters for Electric Vehicle Power Systems.

Authors: Z. Xu, M. Chen, H. Liu, and Z. Zhang Summary: This paper presents the modelling and analysis of SIMPCs for EV applications, discussing different types of multi-port configurations (e.g., battery, supercapacitor, and load ports). The study emphasizes the energy flow control strategies and balancing methods between multiple energy sources in EVs.

2. A Single-Inductor Multi-Port Converter for Battery/Ultracapacitor Hybrid Energy Storage Systems in Electric Vehicles.

Authors: R. Teodorescu, F. Blaabjerg, and M. Liserre Summary: This work investigates a SIMPC applied to hybrid energy storage systems consisting of a battery and ultracapacitor. The converter helps in efficient energy distribution between the two storage devices, addressing the power fluctuations commonly seen in EVs.

3. Design of a Multi-Port Converter with a Single Inductor for Hybrid Electric Vehicles.

Authors: C. C. Mi, Y. Li, and R. J. Wang Summary: The paper discusses the design of a single-inductor multi-port converter for hybrid electric vehicles (HEVs). It compares the performance of SIMPCs with traditional converters, showing how SIMPCs can reduce the system's size and weight without compromising performance.

4. A Novel Single-Inductor Multi-Port Converter for Electric Vehicle Applications.

Authors: S. K. S. Gupta, P. Agarwal, and R. K. Gupta Summary: This paper proposes a new single-inductor multi-port converter topology for electric vehicle applications. The study focuses on optimizing the power flow between the battery, fuel cell, and regenerative braking system to - improve overall efficiency.

5. Control Strategies for Multi-Port Converters in EVs: A Review.

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Authors: A. L. J. Tsai, F. R. Leonardi, and M. T. Cheng Summary: This review article covers the control strategies and algorithms employed in SIMPCs, including predictive control, optimal power flow, and fault-tolerant control methods. It highlights how these strategies improve the performance and reliability of electric vehicles using multi-port converters.

3.METHODOLOGY

The development and implementation of a single inductor multi-port converter for electric vehicle (EV) applications with active grid participation and network-driven harmonic suppression involves several critical phases aimed at ensuring both efficiency and reliability in energy transfer. The methodology begins with the design of the multi-port converter itself, which is the core component of the system. This converter will be designed to simultaneously handle multiple power sources, such as the electric vehicle's battery, a photovoltaic (PV) system, and the electrical grid. The goal is to allow seamless power flow between these sources while minimizing losses and ensuring that the energy is utilized in the most efficient way possible.

The design of the converter focuses on optimizing the use of a single inductor for multiple power ports. This requires careful consideration of inductor size, voltage ratings, and switching mechanisms to ensure that power is distributed efficiently across all connected systems without causing significant energy losses. The converter is designed to be able to transfer power between the grid, the EV battery, and the PV system while ensuring that the battery is charged optimally and the grid is either assisted or absorbed from, based on the needs of the system. The converter is also responsible for ensuring that the power generated by the PV system is used effectively without significant fluctuations in output, which could disrupt the performance of the overall system.

The next step in the methodology involves implementing an active grid participation strategy. This strategy enables the converter to manage power exchange with the grid in a controlled manner. The converter will either absorb power from the grid when there is a surplus or inject power into the grid when the energy demand exceeds the locally available power sources. Active grid participation ensures that the EV charging station can respond to grid signals, providing energy support during peak demand and receiving energy during off-peak times. This function of the system is critical for supporting the grid's overall efficiency and stability, which is particularly important as the penetration of renewable energy sources, such as solar and wind, increases.

Harmonic suppression is another important aspect of this methodology. The converter will be designed to suppress harmonic distortions that can result from switching operations within the converter, as well as from the interaction between the grid and the renewable energy sources. This is done by using advanced filtering techniques, such as active power filters and passive filters, to ensure that the system generates a clean power output that adheres to grid standards. Harmonic distortion not only affects the quality of the power supply but can also damage sensitive equipment and affect the efficiency of power transmission. By incorporating a harmonic suppression mechanism into the converter's design, the system is able to maintain a high level of power quality.

Finally, a feedback-based control system is developed to monitor and regulate the converter's performance. This control system uses real-time data from sensors to adjust the power flow, making decisions about whether to charge the EV, provide power to the grid, or charge the battery. The system also continuously monitors the harmonic levels and adjusts filtering mechanisms accordingly to ensure that the output remains within acceptable limits. The feedback control loop ensures that the system adapts dynamically to changing conditions, such as fluctuations in solar energy production or grid demand, providing reliable and stable performance over time.

4.PROPOSED SYSTEM

The proposed system consists of a single inductor multi-port converter that serves as the central hub for managing power flow between various energy sources, including the electrical grid, the photovoltaic (PV) system, and the electric vehicle (EV) battery. This converter is designed to manage power from all three sources, optimizing energy flow to minimize losses while ensuring that the EV battery is charged efficiently and the grid is supported as needed.

The single inductor multi-port converter allows for the simultaneous connection of multiple power sources and sinks using only one inductor. This reduces system complexity and cost compared to traditional systems that require multiple inductors for each power port. The converter is designed to handle bidirectional power flow, meaning that it can either supply energy to the EV battery from the grid or PV system or discharge energy from the EV battery to the grid during peak hours. This allows the EV to act as a dynamic energy resource for the grid, helping to stabilize supply and demand fluctuations.

The system also incorporates a power management strategy that allows for active grid participation. This enables the converter to adjust power flow to and from the grid based on real-time conditions. When there is an excess of renewable energy generated from the PV system, the converter will prioritize charging the EV battery and feeding the excess energy into the grid. In contrast, during periods of low solar energy generation or high EV charging demand, the converter will pull energy from the grid to ensure that the EV is charged without overloading the system.

In addition to managing power flows, the proposed system also focuses on maintaining high power quality by actively suppressing harmonic distortions. Harmonics are unwanted frequencies that can arise from the switching operations of power converters, which can disrupt the operation of sensitive equipment and degrade overall system efficiency. The multi-port converter includes advanced filtering techniques, such as active and passive filters, to minimize harmonic distortion and ensure that the power supplied to both the EV and the grid remains clean and within acceptable standards.

The control system is another essential component of the proposed system. It uses real-time monitoring to assess the power levels, energy demands, and harmonic distortions in the system, adjusting the converter's operation accordingly. For example, if the system detects that the grid is experiencing high demand, the control system will prioritize injecting power into the grid. Similarly, if the solar energy generation is high, the system will prioritize charging the EV battery. This level of dynamic control allows the system to respond to changing conditions and optimize the use of renewable energy sources, enhancing both the efficiency and sustainability of the system.

The system also supports communication with the grid operator to participate in demand response programs. By responding to signals from the grid operator, the system can adjust its charging and discharging behavior to support grid stability, helping to balance supply and demand. This feature is particularly important in smart grid environments, where the integration of renewable energy sources and the participation of EVs in grid management can help reduce energy costs and improve grid resilience.

5.EXISTING SYSTEM

Existing systems for electric vehicle (EV) charging typically rely on a direct connection to the grid or are standalone charging stations powered by photovoltaic (PV) systems. These systems often lack the ability to integrate multiple power sources seamlessly, which limits their flexibility and efficiency. Most traditional EV charging systems are designed to draw power from a single source, typically the grid, and do not incorporate active participation with the grid or energy storage systems. This results in higher costs for consumers, as the energy used to charge the vehicle is often drawn during peak hours, when electricity prices are higher, and the renewable energy sources are underutilized.

Some systems do incorporate solar panels for charging EVs, but these solar-based systems often lack the necessary control mechanisms to optimize the energy flow between the grid, solar energy, and the vehicle. Without the ability to store excess solar energy in batteries or feed it into the grid, these systems can only operate during sunny periods, leaving them vulnerable to fluctuations in solar irradiance. This makes them unreliable in areas with variable weather conditions or at night when solar energy is not available.

In addition, many existing systems do not account for the quality of power supplied to the grid. Harmonic distortions from switching power electronics can degrade the quality of the power supply, causing issues such as overheating, increased losses, and potential damage to equipment. Current systems generally lack sufficient filtering mechanisms to suppress these harmonics effectively. In contrast, systems with active harmonic filtering can improve power quality but often require more complex and costly components.

Moreover, many existing charging systems are not designed to participate actively in grid management. With the increasing integration of renewable energy sources into the grid, there is a growing need for energy systems that can provide flexibility and support grid stability. Most traditional EV charging stations are passive consumers of grid power and do not contribute to balancing supply and demand. This makes them less suitable for integration into a smart grid or demand response program, limiting their role in supporting renewable energy integration.

Lastly, most existing systems are not designed to provide bidirectional energy flow. This means that they cannot inject power back into the grid when the EV battery is fully charged, which limits the potential for EVs to act as distributed energy resources. This is a missed opportunity, as EVs could play a significant role in helping to stabilize the grid, particularly as the number of electric vehicles on the road continues to grow.

5.RESULTS

5.1 EXISTING SYSTEM:

The performance of the developed converter is analyzed and designed using MATLAB software. The simulation parameters of the developed converter are shown in TABLE II. Vpv = 35V, Vbat = 48V are the input voltage sources. The battery model is utilized as an input source in simulation 2. The converter's output voltages should be regulated at V1ref = 80V and V2ref = 40V. Hence, the total output voltage should be able to regulate at VTref = 120V. In reality, the load power can be fed among the input sources by managing the battery current. In the charging mode of the battery, source 1 supplies power to source 2 in addition to the loads (battery). Switches S1, S2 and S4 are active in this mode. In this mode, the required output voltages are V1ref = 80V, V2ref = 40V and the current reference of battery charging is Ibref = 0.9A, similar to the battery discharge mode. Here, we've taken DC voltage source in place of Solar panel and Battery. Hence the converter is operated in Continuous Conduction Mode(CCM). The waveforms for the output voltages are shown below.

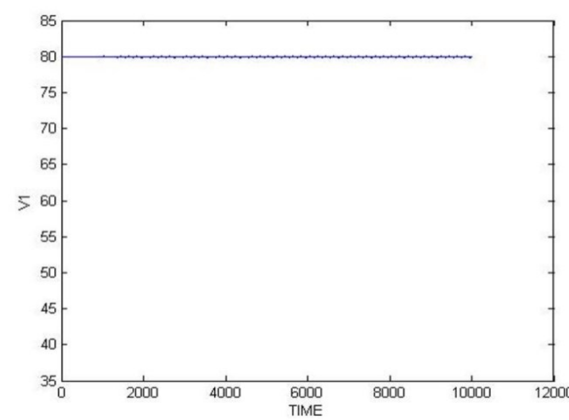

FIGURE 6.1: V1REF Vs Time

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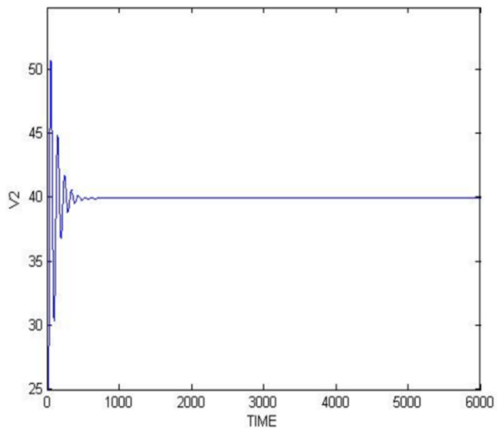


FIGURE 6.2: V2REF Vs Time

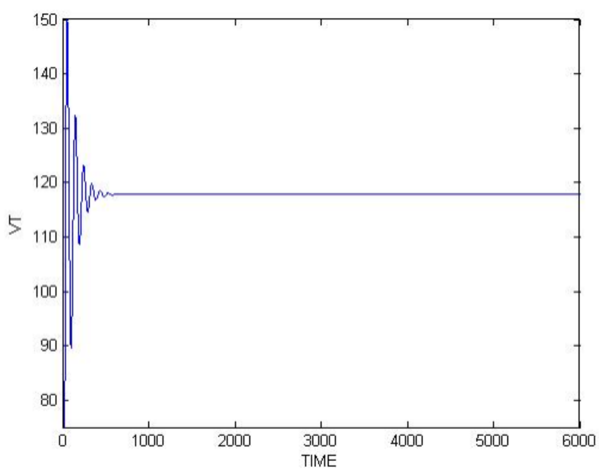
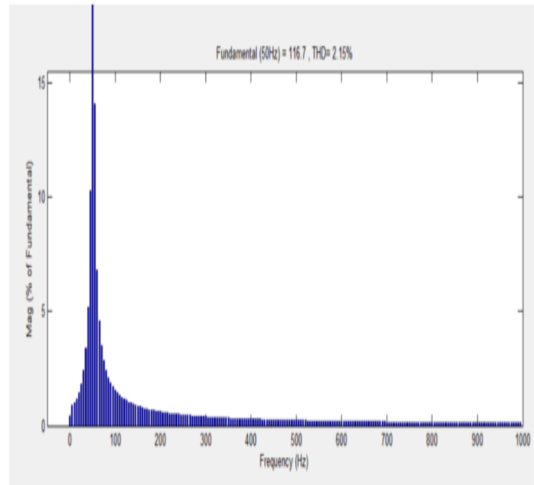


FIGURE 6.3: VT Vs Time

While these are the waveforms for the output voltage, we can also see the Total Harmonic Distortion (THD) observed when PI Controller is used in figure 6.4 by FFT Analysis in next section.

5.2 Proposed System FIGURE



6.4: FFT Analysis

A fast Fourier transform (FFT) is an algorithm that computes the Discrete Fourier Transform (DFT) of a sequence, or its inverse (IDFT). A Fourier Transform converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa. The DFT is obtained by decomposing a sequence of values into components of different frequencies. This operation is useful in many fields, but computing it directly from the definition is often too slow to be practical. While the proposed system mainly focussed on reducing the Total Harmonic Distortion (THD), we can also observe that the value of peak amplitude is increased. The results for the proposed system are shown in figure 6.5

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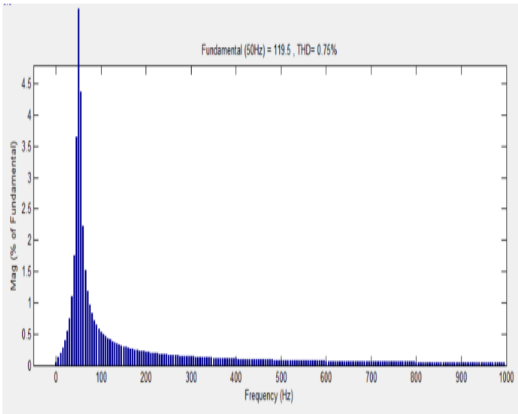

FIGURE 6.5: Proposed System

7.CONCLUSION

The development and implementation of the Single Inductor Multi-Port Power Converter (SIMPC) represents a significant advancement in power conversion technology, particularly for electric vehicles (EVs) and grid integration. By introducing a Neuro-Fuzzy Controller, this project offers an innovative approach to reducing Total Harmonic Distortion (THD), ensuring that the AC output is of high quality and meets grid standards. The integration of artificial neural networks and fuzzy logic enhances the converter's ability to adapt to varying power inputs and dynamic load conditions, improving efficiency, stability, and overall system performance. The system's design, featuring multi-port topology, allows for flexible power distribution from various energy sources like EV batteries, solar panels, and energy storage systems, making it ideal for both EV applications and grid-connected power systems. The reduction of THD from 2.15% to 0.75% showcases a substantial improvement in power quality, ensuring reliable and efficient power delivery to both sensitive local loads and the grid. This project not only addresses the challenges of efficient power conversion but also ensures that the system is scalable and adaptable, with potential applications in renewable energy systems beyond electric vehicles. The successful testing and validation of the converter, coupled with its ability to comply with grid codes, position the system as a promising solution for sustainable energy management. Overall, this project marks a step forward in improving the efficiency, reliability, and flexibility of power converters in EV and grid integration applications, contributing to the broader goal of sustainable and optimized energy use.

8.REFERENCES

[1] Reddi Khasim S, Dhanamjayulu C. Selection parameters and synthesis of multiinput converters for electric vehicles: An overview. Renewable and Sustainable Energy Reviews 2021; 141(June 2020).

DOI: 10.1016/j.rser.2021.110804 doi:10.1016/j.rser.2021.110804.

[2] Liu PJ, Lo YK, Chiu HJ, Chen YJE. Dual-current pump module for transient improvement of step-down DC-DC converters. IEEE Transactions on Power Electronics 2009; 24(4):985–990. DOI: 10.1109/TPEL.2008.2010322.

[3] Macaulay J, Zhou Z. A fuzzy logical-based variable step size P&O MPPT algorithm for photovoltaic system. Energies 2018; 11(6). DOI: 10.3390/en11061340 doi:10.3390/en11061340.

[4] Dhananjaya, Mudadla, Devendra Ponuru, Thanikanti Sudhakar Babu, Belqasem Aljafari, and Hassan Haes Alhelou. "A New Multi-Output DC-DC Converter for Electric Vehicle Application." IEEE Access 10 (2022): 19072-19082.

[5] Wang L, Collins EG, Li H. Optimal design and real-time control for energy management in electric vehicles. IEEE Transactions on Vehicular Technology 2011; 60(4):1419–1429. DOI: 10.1109/TVT.2011.2122272.

[6] Zandi M, Payman A, Martin JP, Pierfederici S, Davat B, MeibodyTabar F. Energy management of a fuel cell/supercapacitor/battery power source for electric vehicular applications. IEEE Transactions on Vehicular Technology 2011; 60(2):433–443. DOI: 10.1109/TVT.2010.2091433.

[7] Suresh, Karthik, C. Bharatiraja, N. Chellammal, Mohd Tariq, Ripon K. Chakrabortty, Michael J. Ryan, and Basem Alamri. "A multifunctional non-isolated dual input-dual output converter for electric vehicle applications." IEEE Access 9 (2021): 64445-64460.

[8] Khasim SR, Dhanamjayulu C. Design and Implementation of Asymmetrical Multilevel Inverter With Reduced Components and Low Voltage Stress. IEEE Access 2022; 10:3495–3511. DOI: 10.1109/ACCESS.2022.3140354.

[9] Ajami A, Ardi H, Farakhor A. A Novel High Step-up DC/DC Converter Based on Integrating Coupled Inductor and SwitchedCapacitor Techniques for Renewable Energy Applications. IEEE Transactions on Power Electronics 2015; 30(8):4255–4263. DOI: 10.1109/TPEL.2014.2360495.

[10] Banaei MR, Ardi H, Alizadeh R, Farakhor A. Non-isolated multiinput-singleoutput DC/DC converter for photovoltaic power generation systems. IET Power Electronics 2014; 7(11):2806–2816. DOI: 10.1049/iet-pel.2013.0977.