Grid Interfaced Hybrid System Performance Improvement with Distributed Power Flow Controller using Impedance Source Inverter

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Abstract: *The main aim of this paper is to introduce a framework for the design and modelling of a photovoltaic (PV)-wind hybrid system and its control strategies. The purpose of these control techniques is to regulate continuous changes in the operational requirements of the hybrid system;currently, in power system networks, the distribution of energy plays a major role in maintaining power reliability in distribution systems. In this study, the proposed hybrid system was incorporated with a combined PV and wind energy system. Maximum power point tracking (MPPT) methods have been proposed to achieve maximum efficiency from the designed system. In addition, this study focused on improving the stability of the hybrid system. To improve the power quality and transient stability of the proposed system, we introduce a novel control strategy called the distributed power flow controller (DPFC) implementation with an optimization technique called the Perturb and observe(P&O)technique. This P&O control technique was developed for the first time in the application of a DPFC controller in a grid-connected system. The control technique was developed using signals from the system parameters, that is, voltage and current.To tune these parameters, this study used Impedance Source Inverter and Perturb and Observe techniques. The proposed system with controllers was tested in MATLAB/Simulink and the results were compared.*

Keywords: *Distributed power flow controller, Impedance Source Inverter, grid interconnected, MPPT (P&O) technique, Boost Converter, PV system and wind energy system*

I. INTRODUCTION

In the present scenario, the demand for electrical energy has surged rapidly, necessitating the exploration of alternative power generation methods. Conventional power generation systems, such as those based on gas, coal, and nuclear power plants, significantly contribute to pollution and greenhouse gas emissions [1]. To mitigate these environmental impacts and meet increasing electrical demands, the integration of non-conventional energy sources has become imperative. Renewable energy sources, such as wind and solar, offer distinct advantages, including being pollution-free, having low maintenance costs, and being economically viable [2].

Among the various renewable energy systems available, photovoltaic (PV) and wind energy systems stand out due to their simple structure, abundant availability, and high efficiency [3]. These systems play a pivotal role in the development of hybrid energy systems [4]. Photovoltaic systems are highly favored due to their convenience and effectiveness compared to other renewable energy sources [5]. However, PV systems face challenges related to stability, as their output is influenced by factors such as time, location, season, and weather. Additionally, the installation costs for solar systems remain relatively high.

Weather conditions significantly affect the output generated by solar systems [6]. To maximize output and enhance the efficiency of solar panels, various Maximum Power Point Tracking (MPPT) techniques are implemented [7]. Similarly, wind energy systems are crucial complementary sources for PV systems, with their electrical energy generation dependent on natural wind availability. Like solar systems, wind systems also experience output variability due to changing weather conditions, necessitating the implementation of MPPT techniques to optimize performance [8].

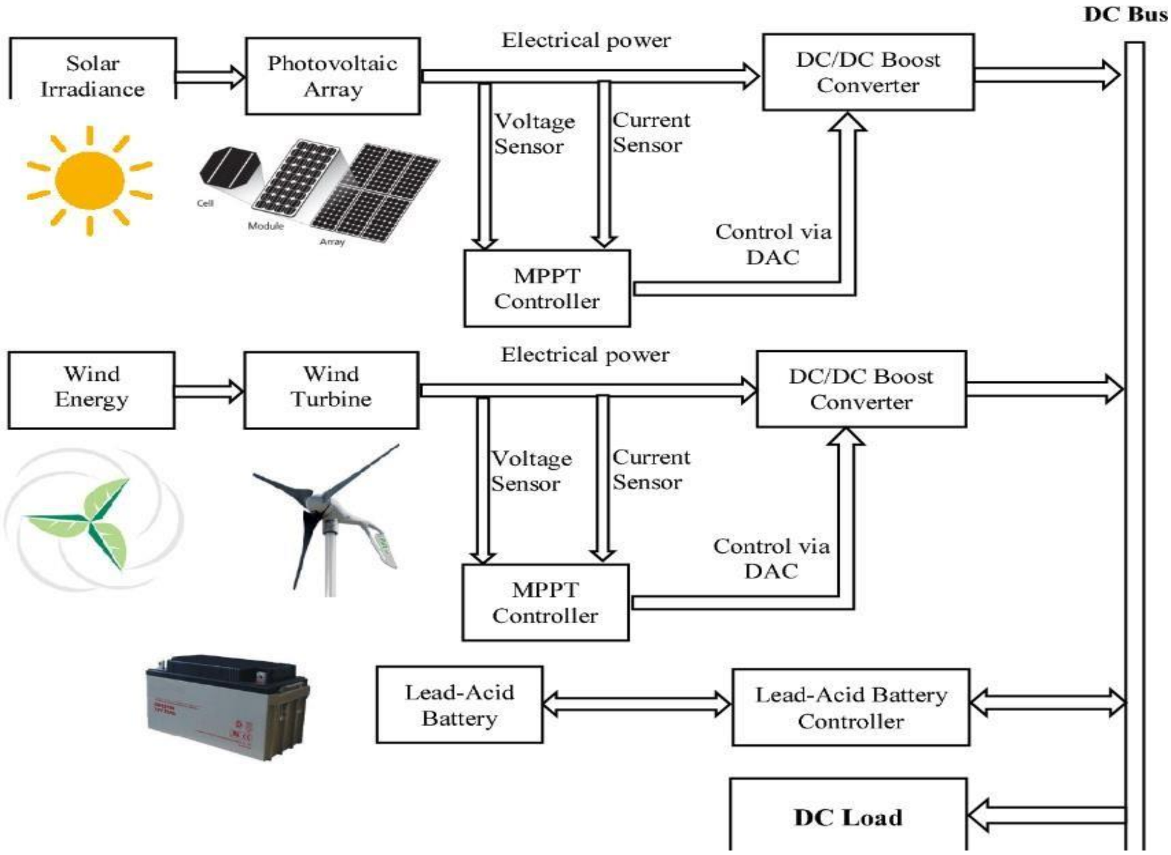

Fig. 1: Hybrid Micro Grid

To ensure seamless integration with the grid, the solar system is connected to a voltage source inverter, which matches the frequency levels and system rates [9]. The control diagram for the inverter is designed using a general Pulse Width Modulation (PWM) technique, with reference signals derived from grid parameters [10]. Modern electric power systems are characterized by their large scale and complexity. In an interconnected power framework, power load demand fluctuates arbitrarily, impacting both area frequency and tie-line power exchange. Maintaining a balance between generation and load without effective control is challenging.

A robust control system is essential to mitigate the effects of random load changes and to maintain frequency at standard levels. This study introduces a novel framework for designing and modeling a PV- wind hybrid system, emphasizing advanced control strategies to enhance system efficiency and stability. The proposed hybrid system leverages the strengths of both PV and wind energy sources, utilizing sophisticated MPPT methods and integrating a Distributed Power Flow Controller (DPFC) to improve power quality and transient stability. Additionally, the system incorporates Z-source inverters (ZSI) for efficient DC to AC power conversion, ensuring optimal performance and grid synchronization.

The hybrid system and its control mechanisms were rigorously tested using MATLAB/Simulink simulations, with results analyzed to validate the effectiveness of the proposed design. This comprehensive approach addresses the contemporary challenges of energy generation and distribution, providing a sustainable and efficient solution for modern power systems.

II. TOPOLOGY AND DESIGN OF INVERTER

This project investigates a detailed dynamic modeling, design and control strategy of a grid- connected PV and wind hybrid power system. The hybrid power system consists of PV station of 1MW rating and a wind farm of 9 MW rating that are integrated through main AC-bus to inject the generated power and enhance the system performance. The MPPT technique is applied for both PV station and wind farm to extract the maximum power from hybrid power system during variation of the environmental conditions. The effectiveness of the MPPT technique and control strategy for the hybrid power system is evaluated during different environmental conditions such as the variations of solar irradiance and wind speed. The simulation results have proven the effectiveness of the MPPT technique in extraction the maximum power from hybrid power system during variation of the environmental conditions. Moreover, the hybrid power system successfully operates at unity power factor since the injected reactive power from hybrid power system is equal to zero. Furthermore, the control strategy successfully maintains the grid voltage constant regardless of the variation of environmental conditions and the injected power from the hybrid power system [11].

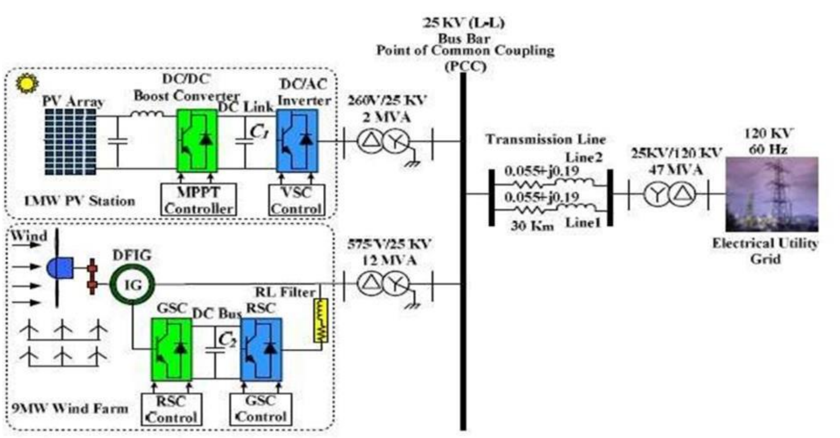

Fig. 2: The system configuration of PV and wind hybrid power system

The system configuration of the studied PV and wind hybrid power system is depicted in Fig. 2. The hybrid power system consisting of PV station of 1MW rating and wind farm of 9 MW rating placed at different locations. The PV station and wind farm are integrated through main PCC-bus to inject the generated power and enhance the system performance. The PV station consists of many PV modules electrically connected in parallel-series combinations to achieve the desired power capacity. Moreover, the PV station is equipped with the DC-DC boost converter to step up array output voltage, and aggregated DC-AC inverter to convert the generated DC power to AC power. The incremental conductance MPPT technique is implemented to extract maximum power from PV station under variation of the solar irradiance. Also, the PV station is interconnected with the PCC-bus through 260 V/25 KV Δ/Y transformer. On the other hand, the wind farm is considered to contain one equivalent aggregated DFIG that driven by a large aggregated wind turbine. Furthermore, the wind farm includes the grid side converter (GSC) for maintaining the DC-bus voltage constant and the rotor side converter (RSC) for extraction the maximum power from wind turbines. Moreover, a modified MPPT technique based on mechanical power measurement is implemented to capture the maximum power from wind farm.

Solar cells convert sun light into electricity, but have the major drawbacks of high initial cost, low photo-conversion efficiency and intermittency. The current-voltage characteristics of the solar cells depend on solar insolation level and temperature, which lead to the variation of the maximum power point (MPP). Herein, to improve photovoltaic (PV) system efficiency, and increase the lifetime of the battery, a microcontroller-based battery charge controller with maximum power point tracker (MPPT) is designed for harvesting the maximum power available from the PV system under given insolation and temperature conditions [12]. Among different MPPT techniques, perturb and observe (P&O) technique gives excellent results and thus is used. This work involves the design of MPPT charge controller using DC/DC buck converter and microcontroller.

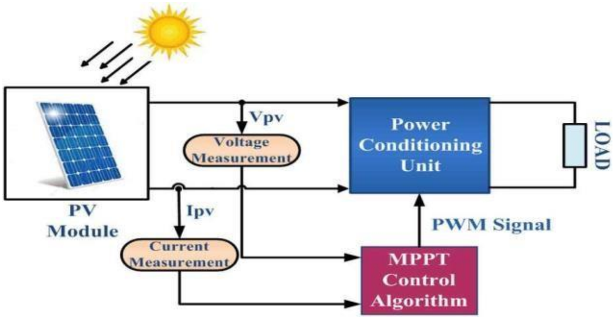

Fig. 3: MPPT Controller, Solar PV Block Diagram

A prototype MPPT charge controller is tested with a 200 W PV panel and lead acid battery. The results show that the designed MPPT controller improves the efficiency of the PV panel when compared to conventional charge controllers.

The growing demand and aging of networks make it desirable to control the power flow in power transmission system fast and reliability. Flexible AC transmission system (FACTS) technology is the application of power electronics in transmission system. The main purpose of this technology is to control and regulate the electric variables in the power system and hence therefore increases the power transfer capability and can be utilized for power flow control [13].

Currently unified power flow controller (UPFC) is the most powerful device which can simultaneously control all the parameters of the system. Ex. line impedance, the transmission angle and bus voltage etc. the main reason behind the wide spread of the UPFC are its ability to pass the real power flow bidirectionally, maintaining well regulated DC voltage, work ability in the wide range of operating condition etc. Simplified representation of UPFC as shown in Fig. 4.

UPFC is the combination of static compensator (STATCOM) and static synchronous series compensator (SSSC) coupled via a common DC link to allow bidirectional flow active power between the series output terminal of the SSSC and shunt output terminal of the STATCOM. The two converters operated from a DC link provided by a DC storage capacitor. The UPFC is not widely applied in practice due to their high cost and the redundancy to failure. Since the components of the UPFC handle the voltages and current with high rating, therefore the total cost of the system is high. To achieve the required reliability for power systems, bypass circuit or redundant back ups are needed which leads to increase the cost [14].

The same as the UPFC, The Distributed Power Flow Controller (DPFC) recently presented in is a power flow device within the FACTS family, which provides much lower cost and higher reliability than the conventional FACTS devices [15].

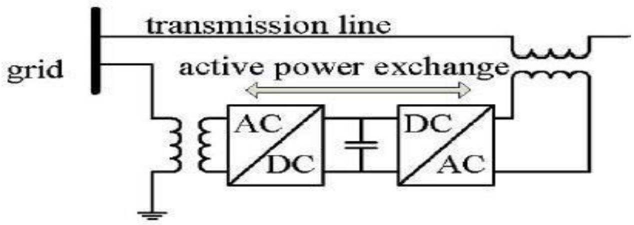

Fig. 4: Simplified representation of a UPFC

It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of power system like line impedances, transmission angle and bus voltage magnitude [16]. The DPFC Flow chart shown in Fig.5.

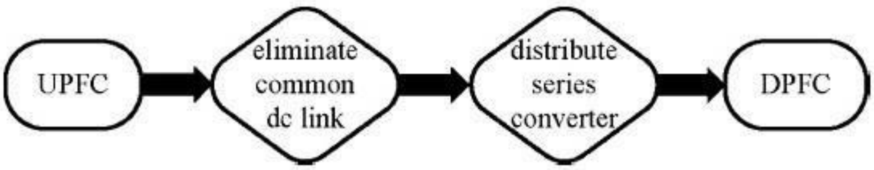

Fig. 5: Flowchart from UPFC to DPFC

Voltage Source Inverters (VSI) and Current Source Inverters (CSI) have a wide range of industrial applications, including special power supplies, hybrid electric vehicles, and distributed power systems. However, they have several limitations, such as reliability issues and a narrow voltage range, and they can function as either buck or boost inverters, but not both simultaneously [17].

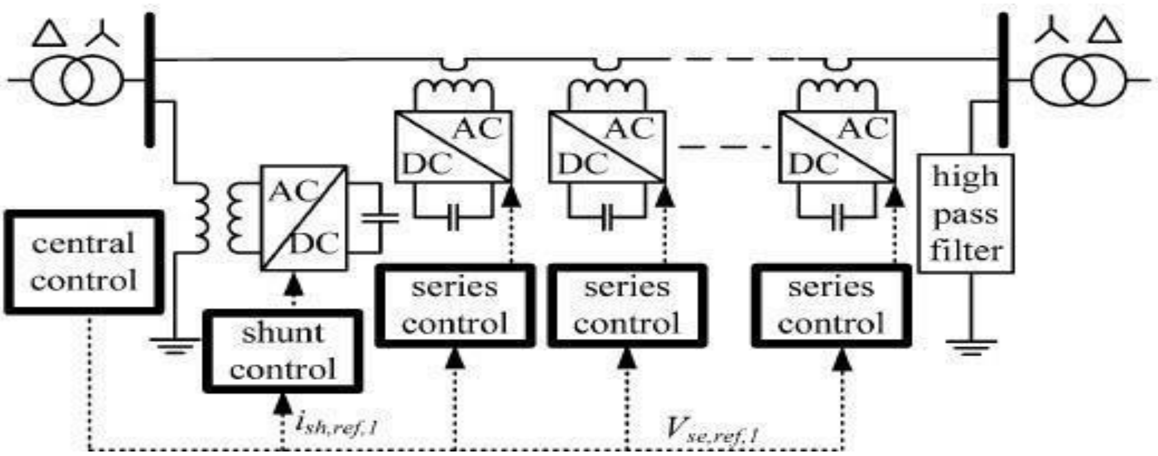

Fig. 6: DPFC control block diagram

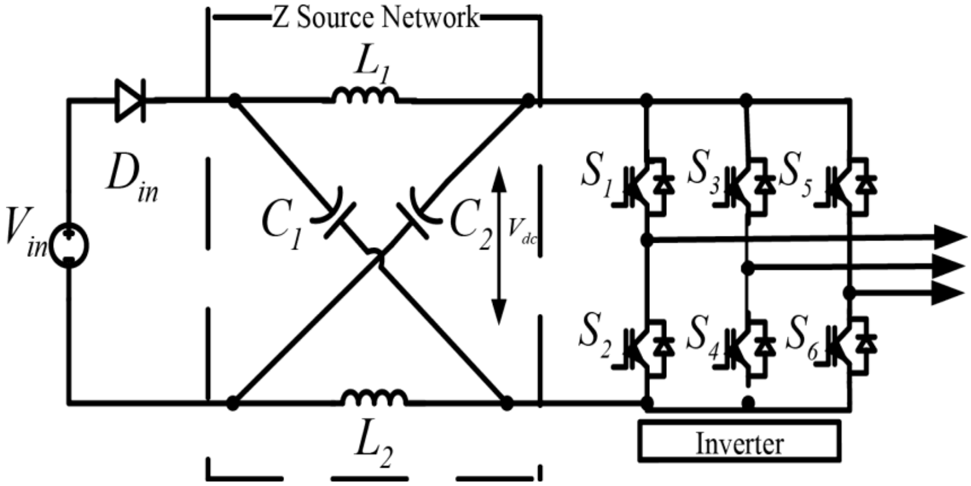

Fig. 7: Basic Topology of Z - Source Inverter

The ZSI features a unique impedance network, consisting of capacitors C1 and C2 and inductors L1 and L2, connected in an X-shape to couple the power source with the main circuit of the inverter, as shown in Figure 3. This basic impedance source network combines two linear energy storage elements L and C. To enhance the circuit's performance, different network configurations can be achieved by adding nonlinear elements such as diodes or switches to the impedance network.

III. SIMULATION RESULTS

The Distributed Power Flow Controller (DPFC) is an advanced type of flexible AC transmission system (FACTS) device designed to enhance the control and stability of power systems. The DPFC is derived from the Unified Power Flow Controller (UPFC), but it incorporates a decentralized approach to its components, which improves reliability and reduces costs. It consists of multiple series controllers distributed along the transmission line and a single shunt controller connected to the transmission network. These series controllers are single-phase voltage source converters (VSCs) that inject controlled series voltages to manage power flow.

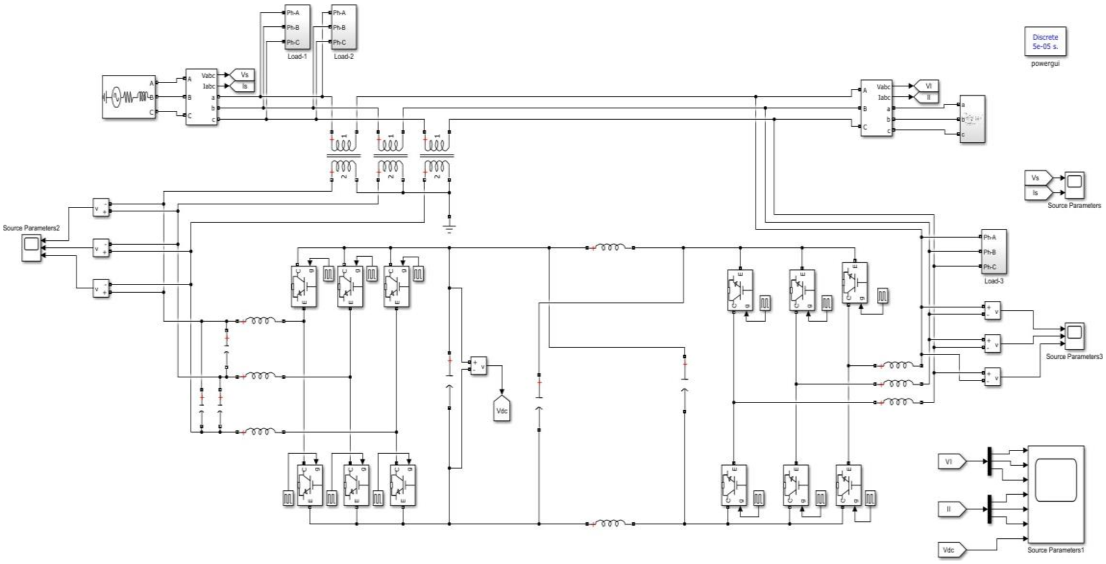

Fig. 8: Circuit of Distributed Power Flow Controller

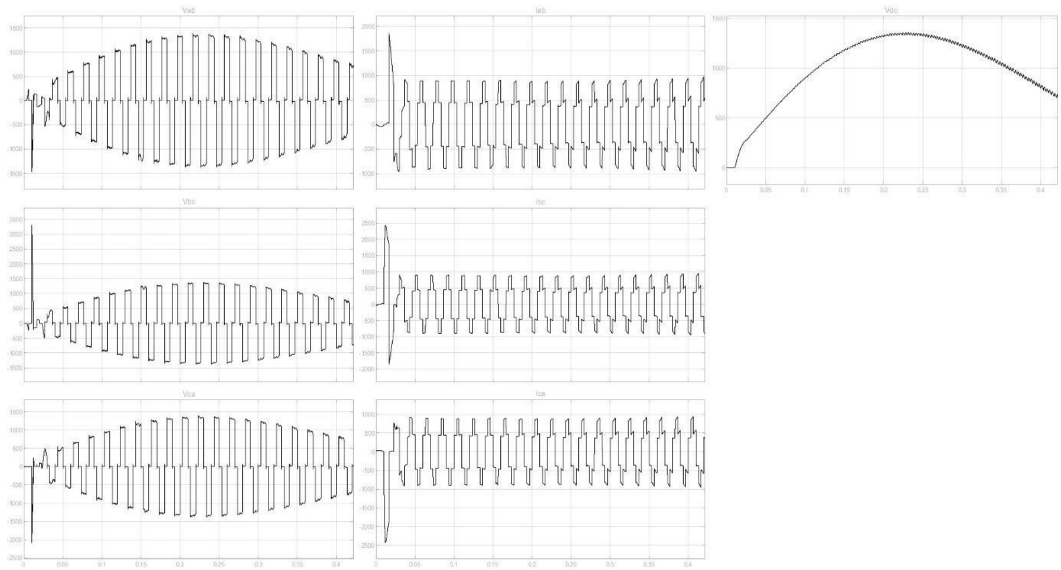

Fig. 9: V_{ac}, I_{ac}, and V_{dc} through ZSI

IV.CONCLUSION

In this project, a detailed dynamic modeling, design and control strategy of a grid- connected PV and wind hybrid power system has been successfully investigated. The hybrid power system consists of PV station of 1MW rating and a wind farm of 9 MW rating that are integrated through main AC-bus to inject the generated power and enhance the system performance. The incremental conductance MPPT technique is applied for the PV station to extract the maximum power during variation of the solar irradiance. On the other hand, modified MPPT technique based on mechanical power measurement is implemented to capture the maximum power from wind farm during variation of the wind speed. The effectiveness of the MPPT techniques and control strategy for the hybrid power system is evaluated during different environmental conditions such as the variations of solar irradiance and wind speed. The simulation results have proven the validity of the MPPT techniques in extraction the maximum power from hybrid power system during variation of the environmental conditions.

It proposed an optimization-based control strategy for a distributed power flow controller to improve the reliability, power quality, and transient stability of a hybrid system. In addition, an MPPT controller in that perturb and observe technique was implemented for both the PV and wind energy systems to improve the performance of the hybrid system. In the literature, different control techniques have been applied to tune the parameters of DPFC series and shunt controllers. However, this study proposes a novel optimization technique for tuning the parameters of the DPFC. The DPFC were tuned using ZSI and a solar pv -wind hybrid system to improve the power quality and the transient stability of the voltage, reactive power, rotor speed, and angle. These cases were successfully tested and verified in the MATLAB/Simulink environment. Based on these results, improvements in stability and power quality were achieved with the Impedance source inverter as compared to the voltage and current source inverter.

VI. REFERENCES

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