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Enhancing Power Quality and Fault Ride-Through Capabilities in Hybrid Solar-Wind Systems Using Dynamic Voltage Restorers

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Abstract: *The increasing prevalence of sensitive loads in various sectors has heightened concerns about power quality. Poor power quality can lead to economic losses, equipment outages, and data loss. Custom Power Devices (CPDs) like Distribution Static Synchronous Compensators (DSTATCOMs), Dynamic Voltage Restorers (DVRs), and Unified Power Quality Conditioners (UPQCs) are effective solutions for mitigating voltage disturbances. Among these, DVRs are the most cost-effective for addressing voltage sags, providing dual functionality by injecting required voltage during disturbances and protecting sensitive loads. The integration of renewable energy sources into power systems presents challenges due to their variable nature, necessitating dynamic voltage support. This research focuses on designing a comprehensive SIMULINK model for hybrid solar-wind systems with DVR integration to enhance fault ride-through (FRT) capabilities. Advanced control strategies using computational intelligence will be developed to optimize DVR performance. The findings will contribute to improved power quality and system reliability in hybrid renewable energy systems.*

Keywords-: *Power Quality, Sensitive Loads, Custom Power Devices, Dynamic Voltage Restorer, Voltage Sags, Renewable Energy Integration, Fault Ride-Through, Hybrid Solar-Wind Systems, SIMULINK Model, Computational Intelligence, Control Strategies..*

I. INTRODUCTION

The rise in sensitive loads, such as medical equipment in hospitals, schools, correctional facilities, and other settings, has led to growing concerns regarding power quality. Poor power quality can result in significant economic and production losses, outages of sensitive equipment, and data loss [1]. Excellent power quality is crucial for customers, utilities, and electrical device manufacturers. Critical power quality concerns include voltage sags, voltage swells, transients, harmonics, fluctuations, flickers, and interruptions, which will be discussed in more detail later [2]. To address power quality concerns and voltage disruptions for sensitive and critical loads, a variety of solutions have been proposed. “Custom Power Devices (CPDs)” based on power electronics are considered the most effective and cost-efficient solution for correcting and minimizing voltage disturbances [3]. CPDs can be connected in parallel, like the “Distribution Static Synchronous Compensator (DSTATCOM)”, in series, like the “Dynamic Voltage Restorer (DVR)”, or in parallel-series, like the “Unified Power Quality Conditioner (UPQC”) [4]. Each CPD acts as a compensation system with its unique control technique and application DSTATCOM is primarily used for power factor correction [5]. UPQC has the capability to inject both voltage in series and current in parallel simultaneously. However, UPQC and DSTATCOM are larger and more costly compared to DVR. DVR is considered the most cost-effective solution for mitigating voltage sags, which are among the most severe power quality concerns in modern power systems [6].

- During a voltage disturbance on the supply side, the DVR, being a power electronic-based device, injects the required voltage to the load side [8]. Additionally, the DVR can protect sensitive and critical loads from disruptions on the supply side. This dual functionality highlights the DVR's crucial role in voltage sag compensation and sensitive load protection. The DVR stands out as the most effective CPD due to its affordability, compact size, and rapid response to voltage perturbations [7].
- For instance, the installation cost of a DVR in the 2-10 MVA power range is approximately USD 300/kVA, whereas the installation cost of an “Uninterruptible Power Supply (UPS)” is around ‘USD 500/kVA’ [9].

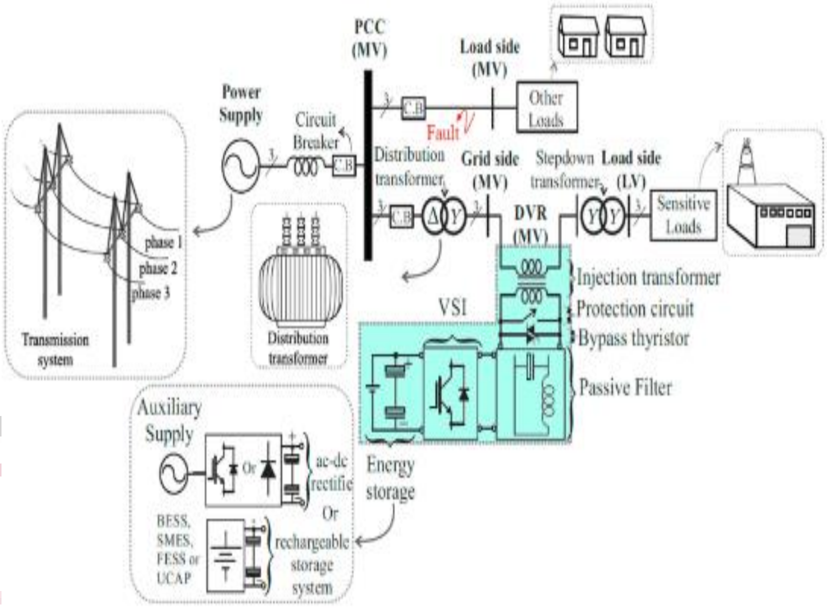

Figure 1: Schematic diagram of the “Dynamic Voltage Restorer (DVR)” system in the medium voltage distribution network.

- The maintenance and operating costs of a “Dynamic Voltage Restorer (DVR)” are typically around 5% of its initial cost, which is considerably lower than the estimated 15% for other devices [10].
- The “Unified Power Quality Conditioner (UPQC)”, a “hybrid of DSTATCOM and DVR”, employs two power converters. Structurally, the DVR is smaller than the UPQC. While DVR and DSTATCOM are comparable, DVR protects sensitive loads from supply disruptions, whereas DSTATCOM shields them from load-side disturbances. Moreover, DVRs often respond quickly to voltage perturbations (less than 1/4 cycle), unlike other Custom Power Devices (CPDs) such as the Static VAR Compensator (SVC), which takes 2-3 cycles [2].
- Numerous studies have examined DVR topologies, focusing on energy storage, power converters, and control systems, to enhance power quality, reduce costs, and improve DVR performance [11].
- There is a growing trend of modifying DVR architecture and integrating renewable energy resources, which has gained popularity [12]. While some general studies on DVRs exist, there is a lack of in-depth investigation into modified DVR designs and their integration with renewable energy systems [13].

A. Renewable Energy

Renewable energy, often called clean energy, originates from natural sources or processes that are continually replenished. For instance, sunlight and wind are consistent sources of energy, although their availability can vary based on time and weather conditions. The concept of renewable energy is not new.

- Historically, humans have utilized natural energy for various purposes such as heating, transportation, and lighting. For centuries, wind powered sailing ships and windmills used for grinding grain, while the sun provided daytime warmth and was essential in lighting fires for night time use.
- However, in the last 500 years, there has been a shift towards more affordable but environmentally harmful energy sources like coal and natural gas obtained through fracking.
- The advent of advanced and cost-effective technologies for harnessing wind and solar energy, renewable sources are becoming increasingly significant.
- This growth spans across various scales, from large offshore wind farms to residential solar panels that can even supply excess power back to the grid. Entire rural communities in places like Alaska, Kansas, and Missouri are now utilizing renewable energy for their heating and lighting needs.
- As the use of renewable energy continues to rise, an important objective will be to upgrade the U.S. electricity grid. This modernization aims to create a smarter, more secure, and regionally integrated grid system.

B. Types Of Renewable Energy Sources:

Solar energy : Humans have been utilizing solar energy for millennia, employing it for agricultural purposes, staying warm, and preserving food. The National Renewable Energy Laboratory notes that “more energy from the sun falls on the earth in one hour than is used by everyone in the world in one year.” Today, solar energy is used in various applications, including heating homes and businesses, warming water, and powering electronic devices. ‘Solar’, or ‘photovoltaic (PV)’, cells are crafted from silicon or other materials that convert sunlight directly in electricity. These “distributed solar systems” provide local electricity for homes and businesses through “rooftop panels” or community projects that power entire.

Wind energy : We've gone a long way from old-fashioned windmills. Today, turbines as tall as buildings and nearly as big in diameter command attention across the world. Wind energy propels a turbine's blades, which feed an electric generator, producing electricity. California, Iowa, Kansas, Oklahoma, and Texas are the leading wind power states, however turbines may be installed anywhere with strong wind speeds, including hilltops and broad plains, as well as offshore in open sea [14].

Hydroelectric power : Hydropower is the greatest renewable energy source for electricity in the United States, but wind energy is quickly predicted to take the lead. Hydropower uses fast-moving water in a huge river or swiftly descending water from a high point to transform its force into energy by rotating a generator's turbine blades. Large hydroelectric projects, sometimes known as megadams, are frequently seen as nonrenewable energy both domestically and globally. Megadams redirect and diminish natural flows, limiting access to animal and human populations that rely on these rivers. Small hydroelectric facilities (with an installed capacity of less than 40 megawatts) cause less environmental impact since they redirect just a portion of the flow.

Biomass energy : Biomass is sometimes misrepresented as a clean, renewable fuel and a cleaner alternative to coal and other fossil fuels for generating power. However, current research indicates that many types of biomass, particularly those derived from forests, emit more carbon than fossil fuels. There are also detrimental impacts on biodiversity. However, given the correct conditions, some kinds of biomass energy might be a low-carbon alternative. Sawdust and chips from sawmills, which would ordinarily degrade fast and emit carbon, may be used as a low-carbon energy source.Crops, waste wood, and trees are all examples of organic material derived from plants and animals known as biomass. Whenbiomass is burned, chemical energy is released as heat, which may be used to create electricity via a steam turbine.

Geothermal energy : If you've ever rested in a hot spring, you've experienced geothermal energy. The gradual disintegration of radioactive particles in rocks at the planet's interior causes the earth's core to be roughly as hot as the sun's surface. Drilling deep wells brings very hot subsurface water to the surface as a hydrothermal resource, which is then pushed via a turbine to generate energy.

FRT in Hybrid System : As conventional fossil fuels become increasingly depleted, the demand for hybrid power solutions has grown. When these hybrid systems are connected to the grid, it becomes crucial to protect the sources and power converters in the event of a grid fault. Several protective circuits are available for this purpose, including crowbar protection, DC copper protection, and dynamic resistance protection. Crowbar protection is often considered the simplest and most efficient method [15]. Since the focus of the suggested system is primarily on voltage compensation, a basic crowbar protection method is suggested to enable Fault Ride Through (FRT) during a malfunction.

Various approaches have been proposed in the literature to achieve fault ride through by providing additional voltage support. These auxiliary devices are categorized into three types: series, shunt, and hybrid linked [16]. This classification depends on how the auxiliary devices are connected between the generator and the grid.

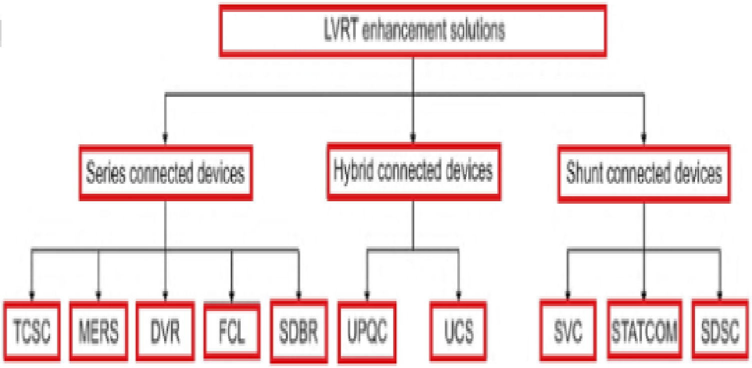

Figure 2 Micro-grid topology of hybrid renewable energy systems Source (MICROREN, 2015)

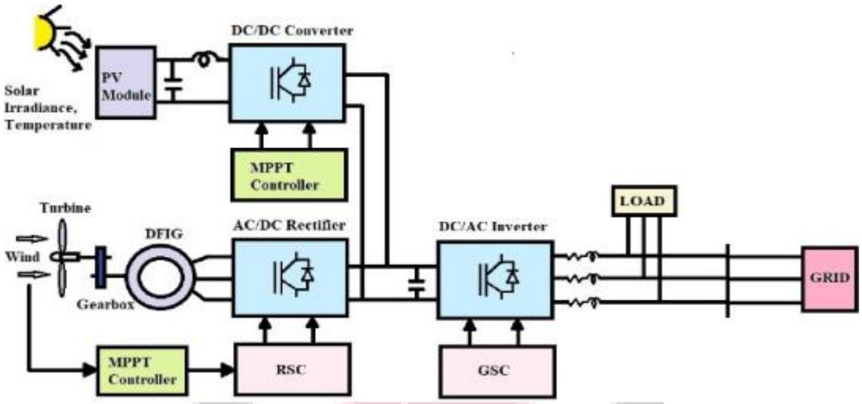

Figure 3: Wind/PV hybrid System

Depicts the hybrid system, which combines wind and PV on the grid. When solar and wind installations are connected into the grid, it improves the dependability of renewable power output to meet the demand [17]. The wind system consists primarily of a wind turbine and a doubly fed induction generator that produces output voltage.

Classification of FRT Methods for DFIG-WT :

RSC controls the speed of DFIG and the reactive power. The GSC regulates the dc voltage and maintains it at its regulated value to guarantee that active power is transferred between RSC and GSC and delivered to the grid. DFIG is very vulnerable to grid faults since its stator is directly connected to the grid [18].

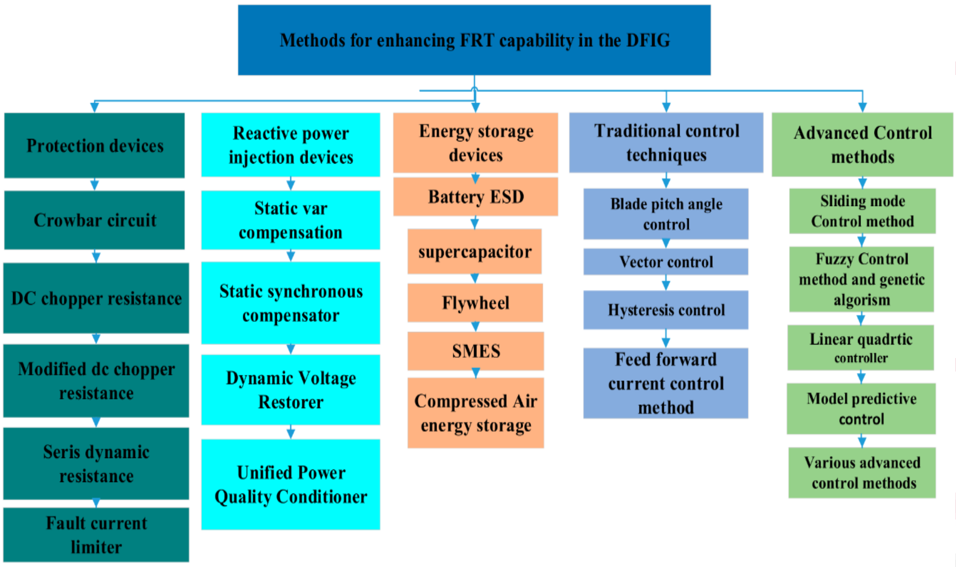

Figure 4 Classifications of FRT hardware methods for DFIG.

As a result, many ways are offered to improve the FRT capacity of DFIG, including protection devices, reactive power injection devices, ESDs, classic control methods, and sophisticated control methods. Figure 4 [19] depicts the categories of FRT capability approaches.

“Fault Ride-Through (FRT)” capacity in hybrid energy systems, particularly those that use renewable energy sources like solar and wind, is crucial for a variety of compelling reasons. This capacity means that the system can continue to operate during transient grid disruptions without disconnecting, considerably adding to overall grid stability and dependability [20].

II. LITERATURE REVIEW

1. Uthra R et al. (2021) [1] they explored voltage compensation in grid-integrated hybrid systems using either an “Electric Vehicle (EV)” charging station or a “Flexible AC Transmission System (FACTS)” device, depending on the severity of faults occurring at the Point of Common Coupling (PCC). When a fault is detected at the PCC, the system selects either the EV charging station or a FACTS device, specifically a “Dynamic Voltage Restorer (DVR)”, to provide the necessary voltage compensation. the effectiveness of this system was demonstrated through simulations conducted using MATLAB Simulink, which verified the proposed method's results.

2. Hassanein et al. (2020) [2] They investigated the control of "Dynamic Voltage Restorers (DVRs)" by regulating the load voltage under various abnormal operating conditions, such as three-phase faults, voltage sags/swells, and unbalanced loading. The control strategy involves two "Artificial Neural Networks (ANNs)" to adjust the "Insulated Gate Bipolar Transistor (IGBT)" pulses of the "voltage source inverter (VSI)" that governs the DVR. The ANNs regulate the D-Q axes voltage signals, which serve as inputs to the ANNs under any loading condition. There by enhancing the "low voltage ride through (LVRT) "capability. Additionally, the "total harmonic distortion" in the system is reduced, further improving power quality.
3. Kanagaraj et al. (2021) [3] proposed a "Dynamic Voltage Restorer (DVR)" integrated with a "photovoltaic-thermoelectric generator (PV-TEG)" system to address voltage disturbances in three-phase four-wire distribution systems. The hybrid PV-TEG energy source enhances the DVR's ability to compensate for deep and prolonged power quality disturbances. When the PV-TEG module generates sufficient power, the DVR can also reduce grid energy consumption by meeting load demands independently.The effectiveness of the proposed hybrid PV-TEG integrated DVR system was confirmed through simulations using MATLAB software, which tested four different operational modes.
4. Sundarabalan et al. (2019) [4] introduced a novel approach combining a "dynamic voltage restorer (DVR)" with "compressed air energy storage (CAES)" for improving the power quality. The main objective was to replace 'conventional battery-powered DVRs' with those powered by CAES, which offers zero greenhouse gas emissions and high response times. The paper presents the design and modeling of a third-generation CAES system. It also models a CAES-powered DVR connected to a distribution system supplying a sensitive load, analyzing voltage variations during various faults. The study investigates the system's performance with and without the CAES-powered DVR using MATLAB/Simulink and SimulationX software.
5. Rani et al. (2022) [5] proposed a system comprising a wind turbine, a "permanent magnet synchronous generator (PMSG)", a 'filter', and 'several switching devices'. The "Permanent Magnet Synchronous Generator (PMSG)" is advantageous for its high efficiency and low maintenance requirements, attributed to its use of permanent magnets. Nonetheless, the variable nature of wind energy can lead to power quality challenges during different three-phase fault scenarios.
6. Farooqi et al. (2022) [6] examined the impact of weather conditions, such as the thunderstorms and high winds, on the 'stability of transmission networks'. These conditions can cause faults like 'double line-to-ground' 'single line-to-ground', 'lightning strikes', 'impulse transients', and 'power outages'. The proposed technique targets the improvement of transient stability in microgrids while ensuring symmetrical operating conditions for the load. The control mechanism focuses on extracting fault signals and stabilizing the error signal. In this setup, a hysteresis-band "Pulse Width Modulation (PWM)" generator drives the inverter, which is connected to a PV-based battery storage system at the DC-Link. Simulation results, validated against IEEE 519 standards, illustrate the efficacy of the proposed system in addressing power quality concerns by injecting compensating voltage to safeguard the load and facilitate microgrid operation during power disruptions.
7. Moghassemi et al. (2020) [7] presented a comprehensive review of the DVR topologies, 'covering their operations', 'power converters', 'control methods', and applications. The research also compares state-of-the-art literature and offers a comparative analysis of 'power quality issues', 'DVR principles', 'operation modes', components, and topologies based on energy storage, single-/three-phase power converters, and control units with different processing stages. The paper also discusses configurations of the modified and improved DVR and their integration with distributed generation systems, serving as a valuable reference for researchers interested in DVR technology.
8. Benali et al. (2018) [8] proposed the integration of a "Dynamic Voltage Restorer (DVR)" to enhance power quality and bolster the low "voltage ride-through (LVRT)" capability of a three-phase medium-voltage network linked to a hybrid distribution generation system. This system comprises a "photovoltaic (PV)" plant and a "wind turbine generator (WTG)" interconnected at the same "point of common coupling (PCC)" alongside a sensitive load. The WTG employs a doubly-fed induction generator (DFIG) connected to the network via a step-up transformer, while the PV system is linked to the PCC through a two-stage energy conversion process involving a dc-dc converter and a dc-ac inverter.
9. Prasad et al. (2022) [9] focused on power quality (PQ) issues, which are crucial, especially for technologically advanced equipment reliant on high-quality power supply. Voltage swells/sags, interruptions, and harmonics can damage or disrupt end-user equipment. Custom power devices (CPDs), particularly dynamic voltage restorers (DVRs), are recommended to improve PQ. Using a multilevel inverter (MLI) in the DVR is suggested as a promising method to enhance PQ.
10. Molla et al. (2020) [10] researched renewable energy sources, noting their abundance and environmental benefits. However, the intermittent nature of sources like wind and solar PV can lead to fluctuations of the power. To mitigate these fluctuations and protect the sensitive loads, dynamic voltage restorers (DVRs) are commonly employed. This study focused on using a battery and "super magnetic energy storage (SMES)"-based DVR for compensating voltage sag conditions in a grid-connected hybrid PV-wind power system, using a pre-sag compensation method.

III. OBJECTIVES

This research work aims to achieve the following key objectives:

1. Developing a SIMULINK Model of Grid-Integrated Hybrid Solar-Wind Systems: The primaryobjective is to design a comprehensive SIMULINK model for hybrid solar-wind (HS_W) systems integrated with the grid. This model will incorporate various loads and a dynamic voltage restorer (DVR) circuit to evaluate and enhance fault ride-through (FRT) capabilities.
2. Investigating Hybrid System Behavior During Voltage Disturbances: The research will focus on examining the behavior of the hybrid system under different voltage conditions. Special attention will be given to understanding how the DVR can improve the system's FRT capabilities, ensuring stability and reliability during voltage sags, swells, and other disturbances.
3 .Designing and Implementing Advanced Control Strategies for DVR: A significant objective is to develop and implement advanced control strategies for the DVR. These strategies aim to enhance the FRT capabilities and overall power quality of the hybrid system. By utilizing cutting-edge computational techniques, the research seeks to optimize DVR performance, providing both theoretical insights and practical benefits.

IV. METHODOLOGY

The rising concern for environmental sustainability, coupled with advancements in technology for integrating renewable energy sources into the grid and the liberalization of the energy market, has resulted in an increased adoption of grid-connected Distributed Generation (DG). The deployment of Dynamic Voltage Restorers (DVRs) in hybrid solar-wind energy systems is crucial for addressing challenges related to voltage stability and power quality, which are essential for the efficient functioning of modern electrical grids.

- Renewable energy sources such as solar and wind continues to rise, their inherent variability and intermittency can cause significant voltage fluctuations. These fluctuations can compromise the stability of the power grid, thereby affecting the reliability and efficiency of energy distribution.

- Integrating DVRs helps mitigate these issues by providing dynamic voltage support, enhancing the stability and resilience of the grid.

- It helps prevent disruptions, equipment damage, and operational inefficiencies, thus ensuring that power is delivered consistently and efficiently to meet various electrical needs.

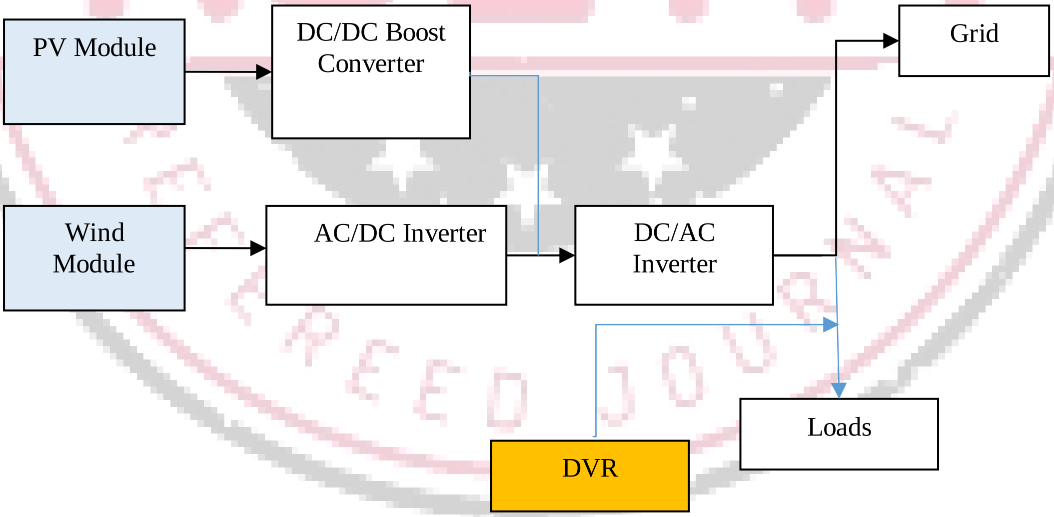

Figure 5 : Hybrid energy system topology

‘Dynamic Voltage Restorers (DVRs)’ play a crucial role in addressing these challenges by swiftly correcting voltage deviations during disturbances. They ensure that the voltage supplied to end-users remains stable within acceptable limits, thereby protecting sensitive equipment and ensuring uninterrupted service. Furthermore, DVRs improve the system's response to faults, enhancing the resilience of the grid infrastructure to accommodate the integration of multiple renewable sources.

A, Solar Energy System Designing in MATLAB :

A solar PV array, or photovoltaic array, is a system of interconnected solar panels that convert sunlight into electricity through the photovoltaic effect. Solar panels are made up of solar cells, typically composed of semiconductor materials like silicon that absorb sunlight and generate an electric current. This current is direct current (DC) and is produced when photons from sunlight knock electrons free from atoms in the semiconductor material, creating a flow of electricity.

- Solar panels can use various solar cell technologies, such as monocrystalline, polycrystalline, or thin-film cells.
- Monocrystalline cells are made from a single crystal structure, providing higher efficiency. Polycrystalline cells consist of multiple crystals and are slightly less efficient but more cost-effective. Thin-film cells are lightweight and flexible but generally less efficient than crystalline cells.

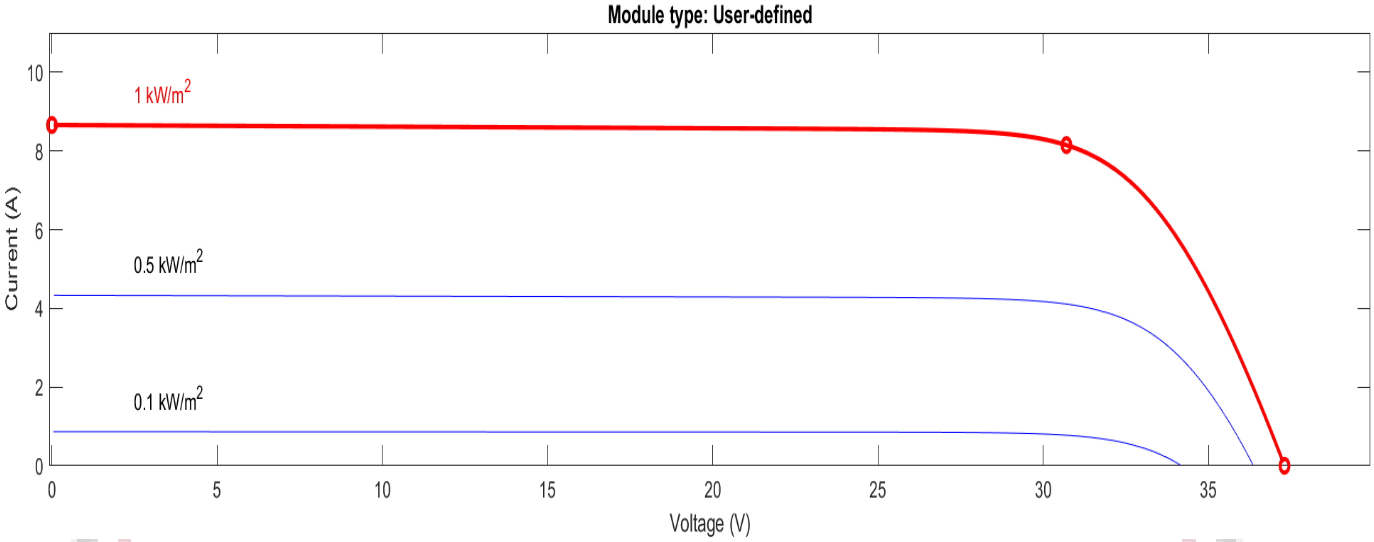

Figure 6 characteristic curve of the PV module

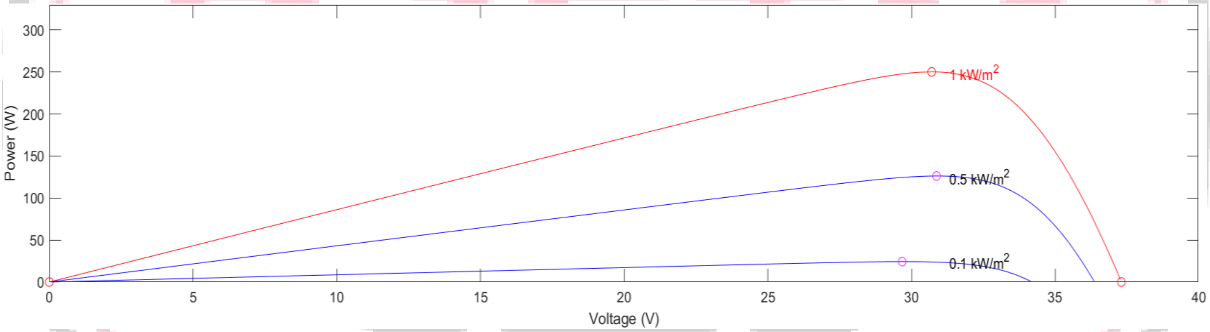

Figure 7 : P-V characteristic curve of the PV module

Figure 7 illustrates the power output characteristics of a solar panel under different levels of solar irradiance. At a standard irradiance level of 1 kilowatt per square meter, which represents full sunlight conditions, the curve reaches its peak at the maximum power point. This point indicates the optimal combination of voltage and current output, resulting in the highest power output from the panel.

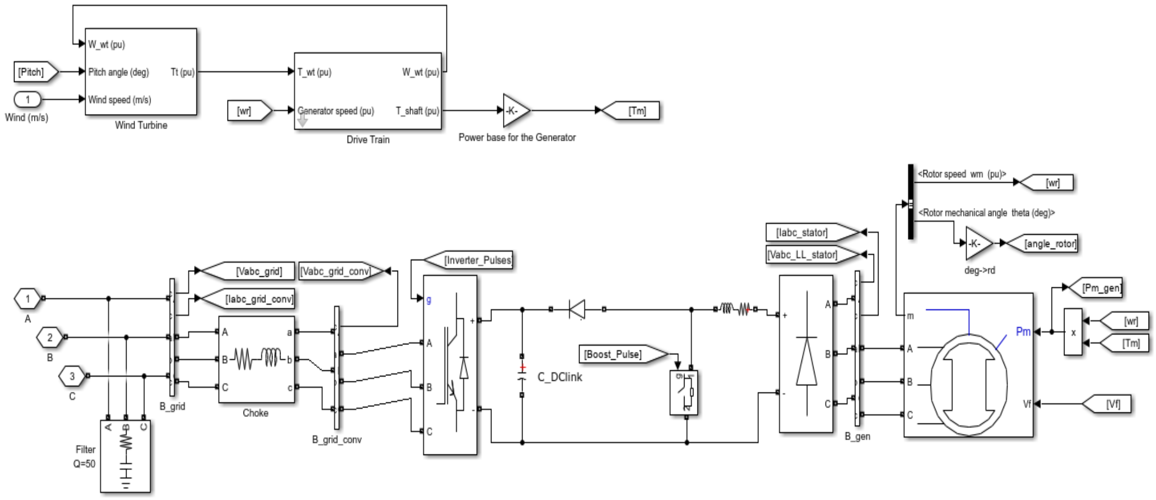

Figure 8 : Designing of wind energy system in SIMULINK.

B. DVR Designing and Control in MATLAB :

Several configurations and control strategies have been investigated in the literature regarding Dynamic Voltage Restorers (DVRs). These configurations can be broadly classified into two main groups. The first group utilizes AC/DC/AC conversion, which involves rectification, capacitive storage, and inversion in sequence. In contrast, the second group employs DC/AC conversion, focusing mainly on inverter operation.

The second group, which focuses on DC/AC conversion, is less common. This is primarily due to limitations observed during significant voltage sags, where a capacitor bank alone may not provide sufficient reactive power, particularly during 'deep voltage sags (i.e., <0.5 p.u.)'.

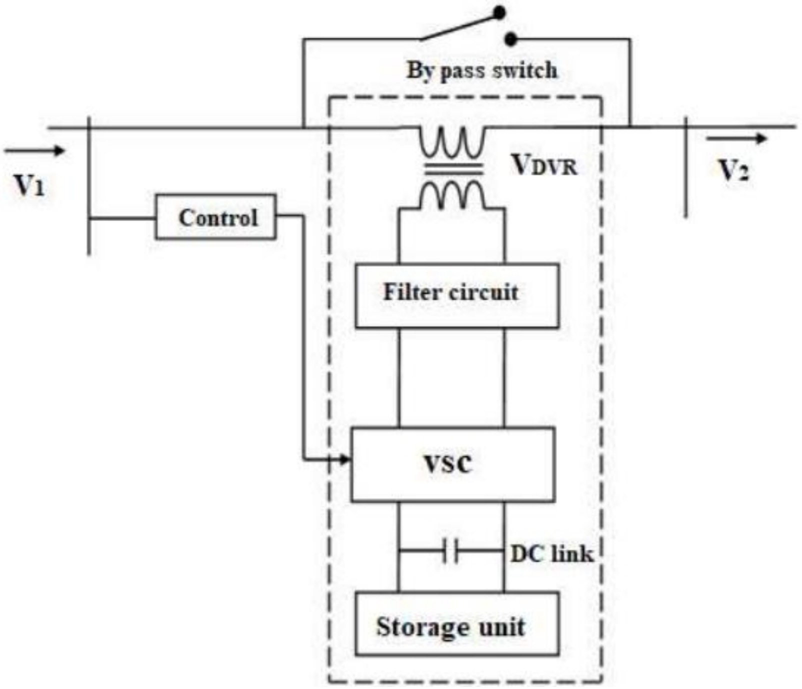

Figure 9 : DVR design in the proposed HS_W system.

The DVR is employed to address voltage quality issues stemming from voltage drops, aiming to prevent critical or sensitive loads from experiencing temporary voltage dips or swells by sequentially supplying the missing part of the supply voltage. To achieve phase advance compensation, a voltage in advance of the line current is injected and then combined with the source voltage. The Quadrature booster facilitates this phase advance operation.

C. Fuzzy Control system :

A Fuzzy Logic Controller (FLC) within a Dynamic Voltage Restorer (DVR) utilizes fuzzy set theory to manage imprecise inputs, making it ideal for complex systems like power distribution networks where obtaining exact measurements and responses can be challenging. Inputs typically include the magnitude of the voltage error (the difference between actual and nominal voltages) and the rate of change of this voltage error. The main output is the control signal that determines the amount and type of compensation voltage the DVR should inject. Fuzzy set theory is a potent tool for dealing with imprecision in decision-making problems involving uncertainty in real-world applications. Fuzzy inference involves mapping from a given input to an output dataset using the theory of fuzzy sets. As a rule-based knowledge base, this knowledge base contains statements that are IF-THEN. This rule base, depicted in Figure 10 , has been utilized in the base model.

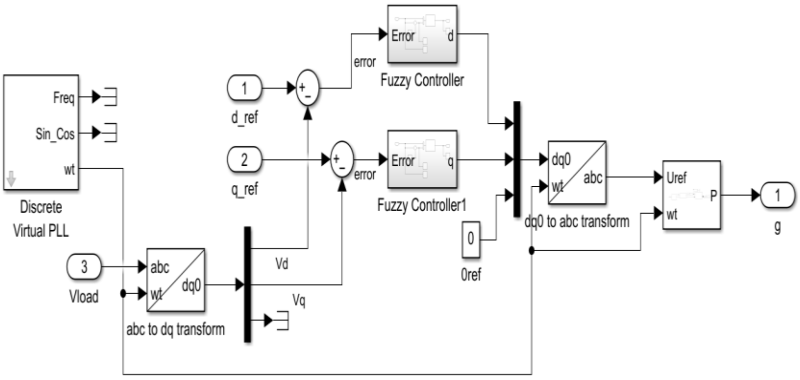

Figure 10 : Fuzzy control system design for DVR operation in HS_W system

A. PI adaptive Bee Colony Optimisation for DVR (ABCO_DVR) :

- ABCO_DVR is a novel optimization algorithm inspired by the foraging behaviour of honeybee swarms. It iteratively enhances candidate solutions by mimicking the exploration and exploitation of food sources.
- This algorithm is designed to optimize the parameters of the DVR control strategy, especially in scenarios where the solution space is limited or fluctuates dynamically.
- DVR systems, PI controllers play a crucial role in regulating the control system responsible for voltage correction. The PI parameters, including the proportional gain (Kp) and integral gain (Ki), dictate how effectively the DVR responds to voltage disturbances.

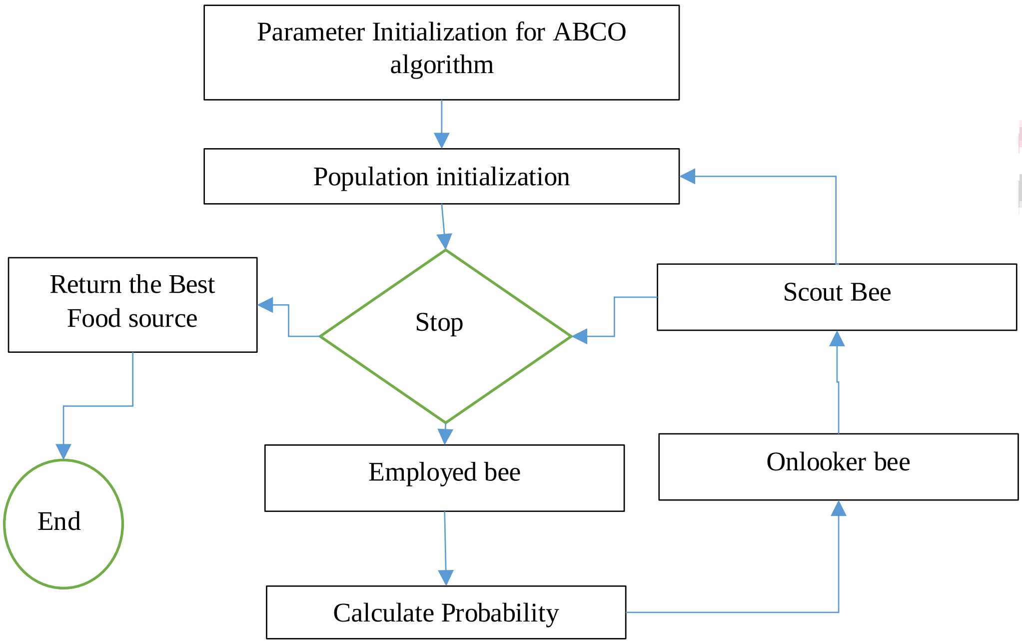

Figure 11 : Adaptive Bee Colony Optimization for DVR (ABCO_DVR) working flowchart.

V. RESULTS AND DISCUSSION :

A Dynamic Voltage Restorer (DVR) is a critical device in power distribution systems, ensuring power quality by mitigating voltage sags, swells, and other disturbances that can harm sensitive industrial equipment. This work focuses on designing a DVR for a system powered by a hybrid of solar and wind energy. This algorithm optimizes the parameters used by the PI controller so as to maximize the quality of the injected voltage to the load. The study compares two algorithms: one based on fuzzy logic and the other on the proposed PI adaptive Bee Colony Optimization for DVR (ABCO_DVR).

- Fuzzy logic controllers excel at handling the variability and uncertainties in renewable energy systems by adjusting control actions based on input degrees, allowing for smoother and more responsive adjustments to voltage variations.
- The ABCO algorithm continuously optimizes the PI controller's parameters, enabling it to maintain optimal performance even as voltage changes.

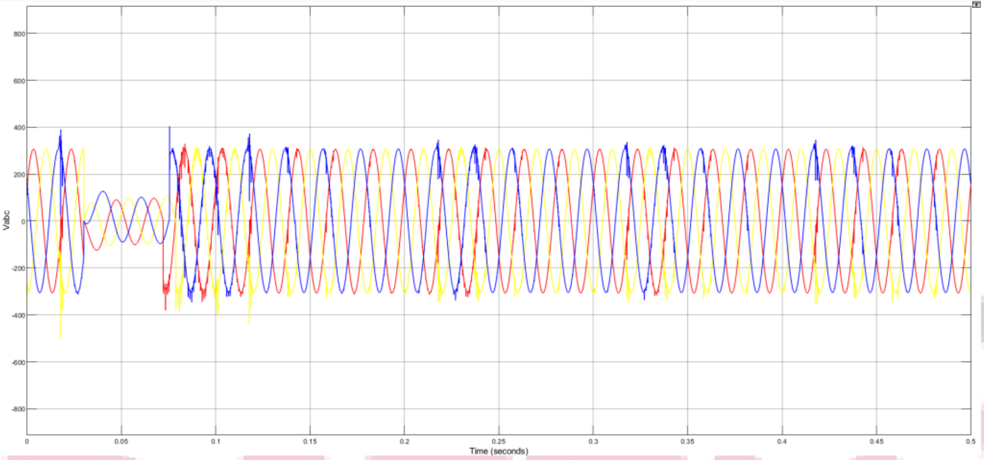

Figure 12 : Three phase voltage in the line in HS_W system with no DVR control.

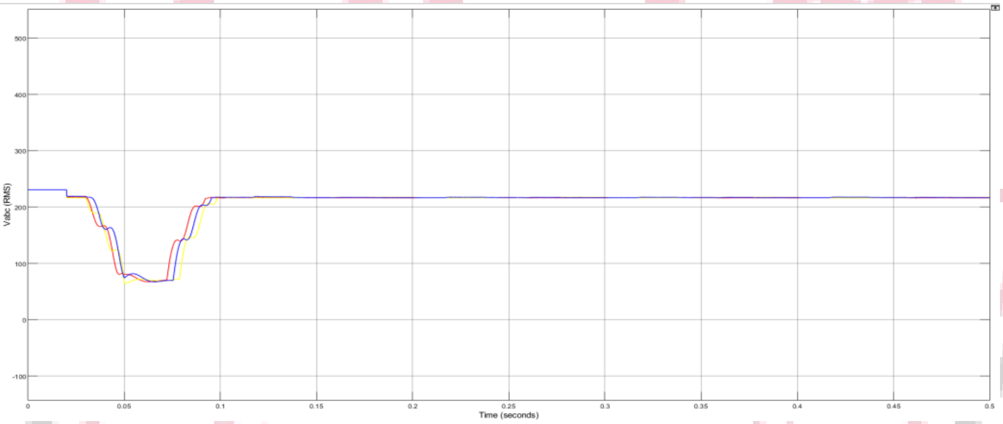

Figure 13: Three phase RMS voltage in the line in HS_W system with no DVR control

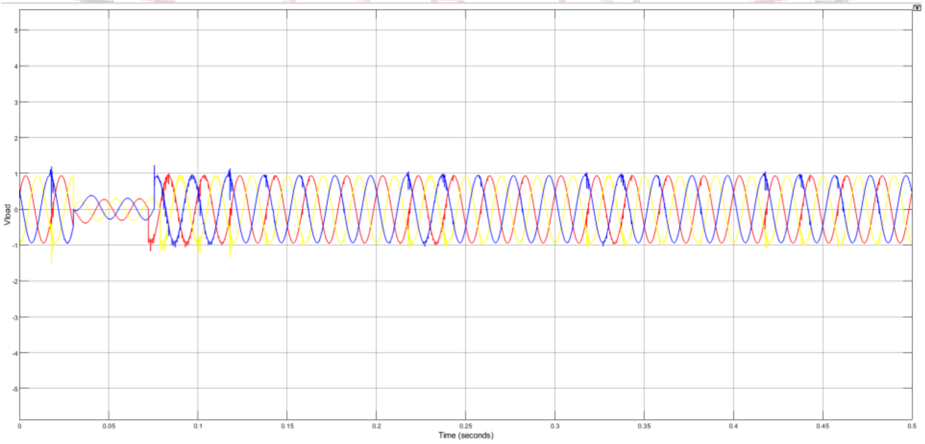

Figure 14: Load voltage in the HS_W system with no DVR control

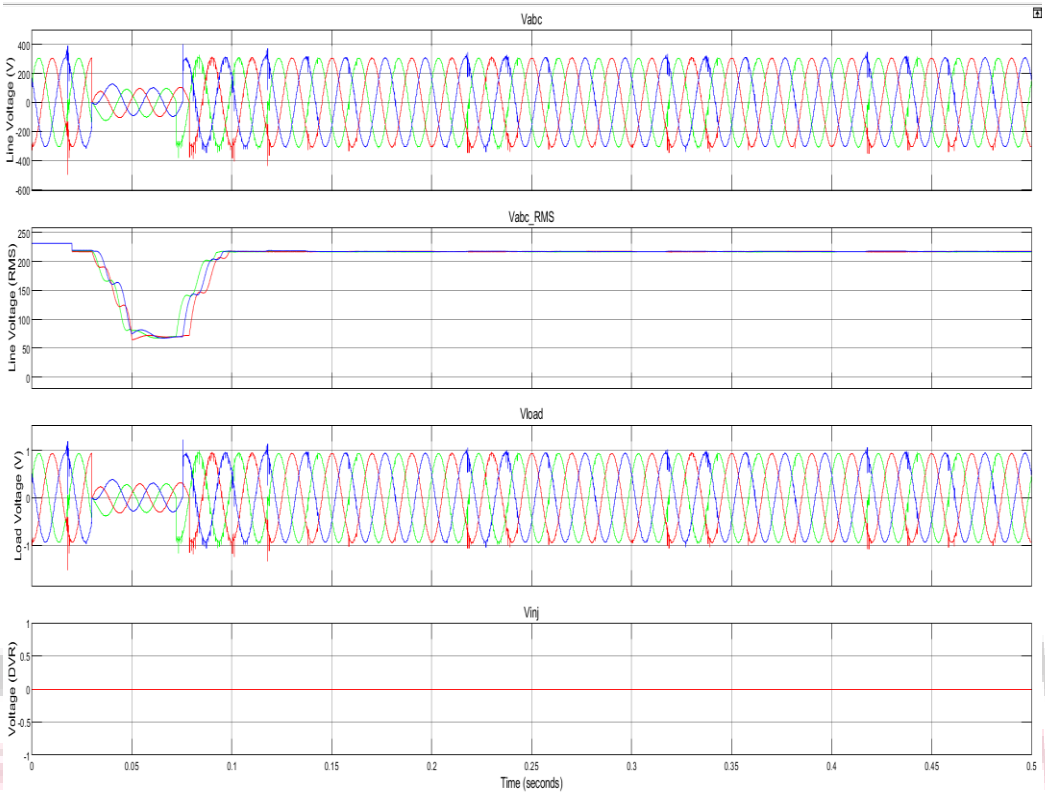

Figure 15: Comparative representation of the outcomes in the HS_W system with no DVR control.

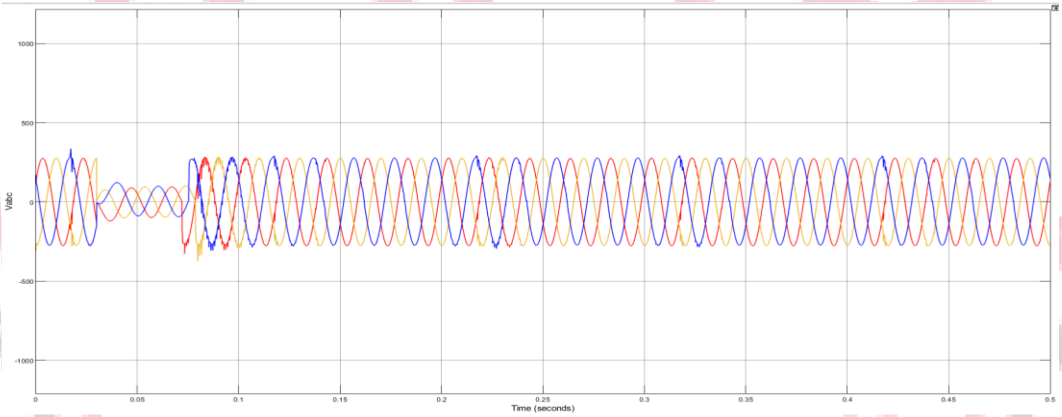

Figure 16: Voltage at the bus where voltage dips at 0.03 sec in HS_W system with fuzzy based control for DVR

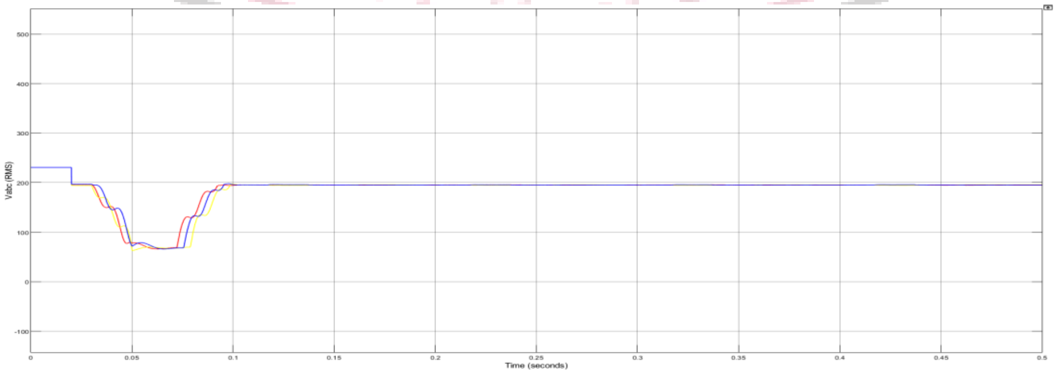

Figure 17: Three phase RMS voltage at the bus where voltage dips at 0.03 sec in HS_W system with fuzzy based control for DVR

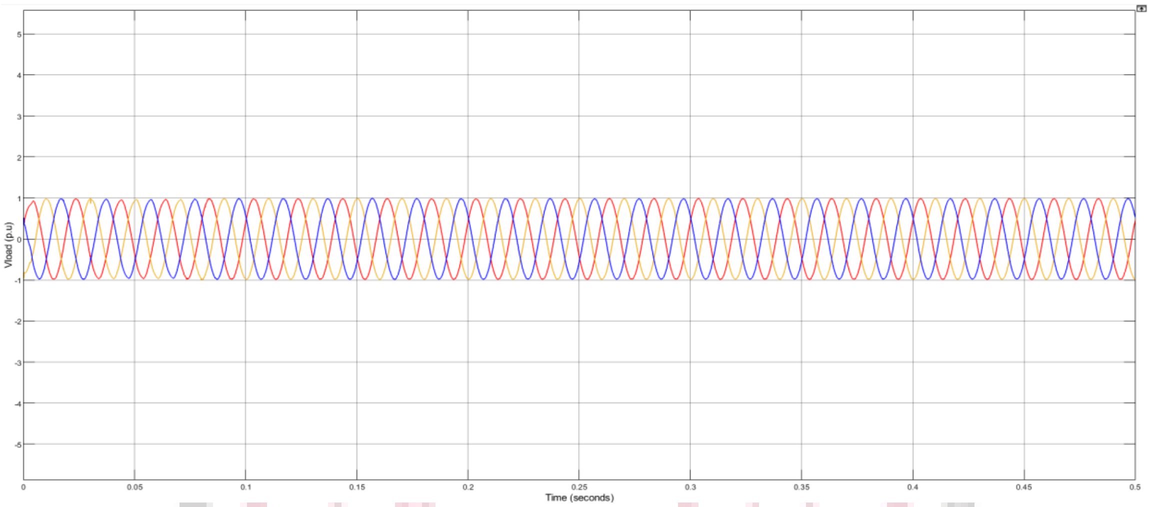

Figure 18: Effect on Load voltage in the HS_W system with fuzzy based control for DVR.

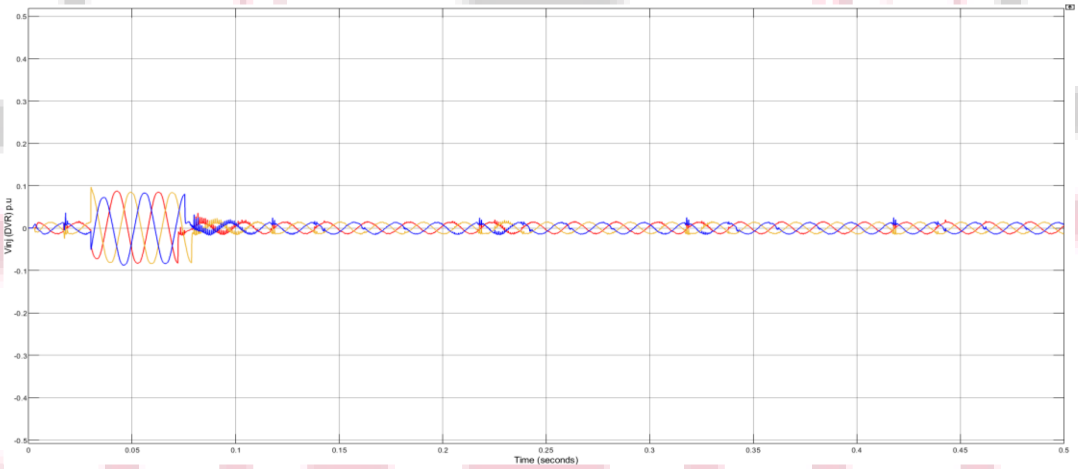

Figure 19 : Voltage injected into the line by fuzzy based DVR

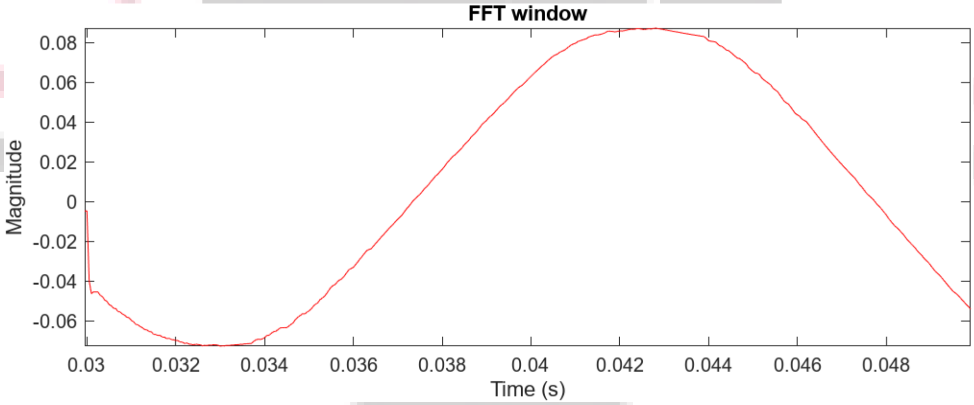

Figure 20: FFT analysis of the voltage in phase 1 injected into the line by fuzzy based DVR

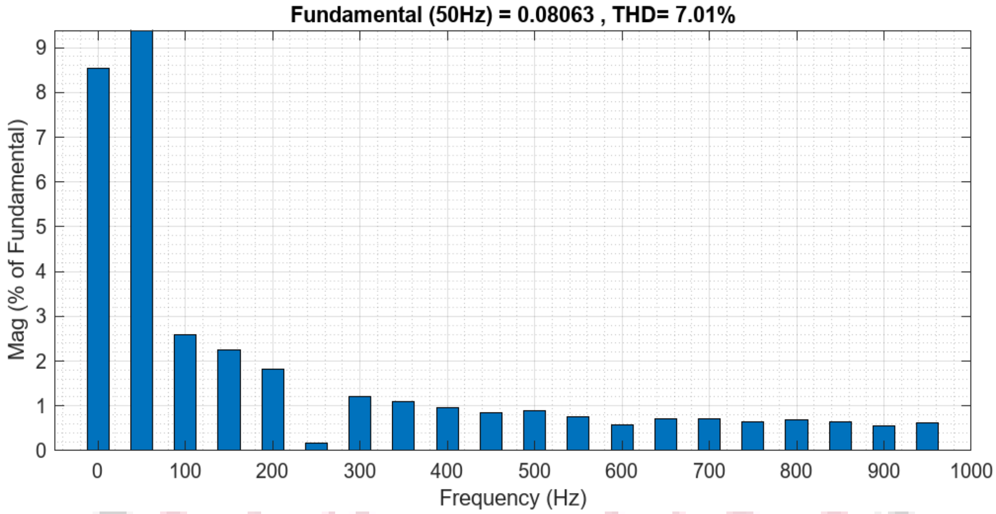

Figure 21: THD% of the voltage in phase 1 injected into the line by fuzzy based DVR

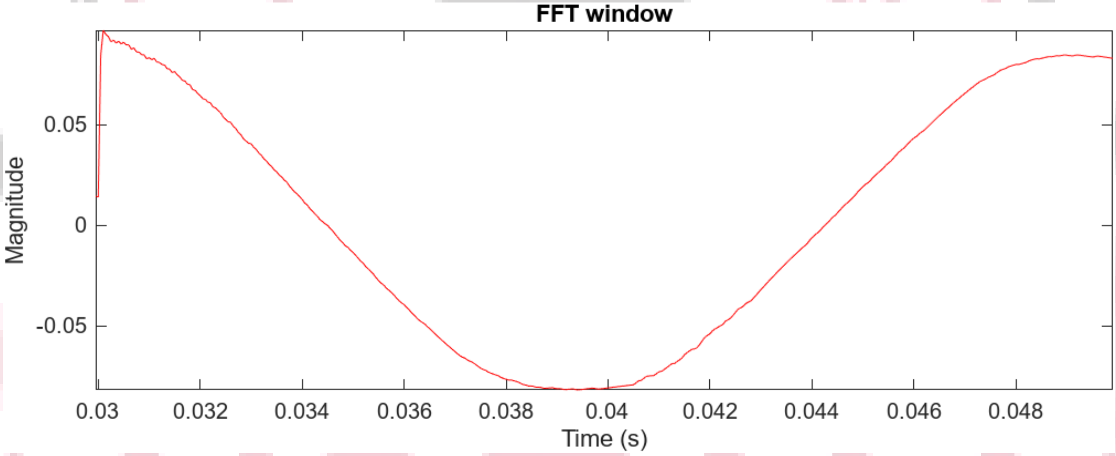

Figure 22: FFT analysis of the voltage in phase 2 injected into the line by fuzzy based DVR

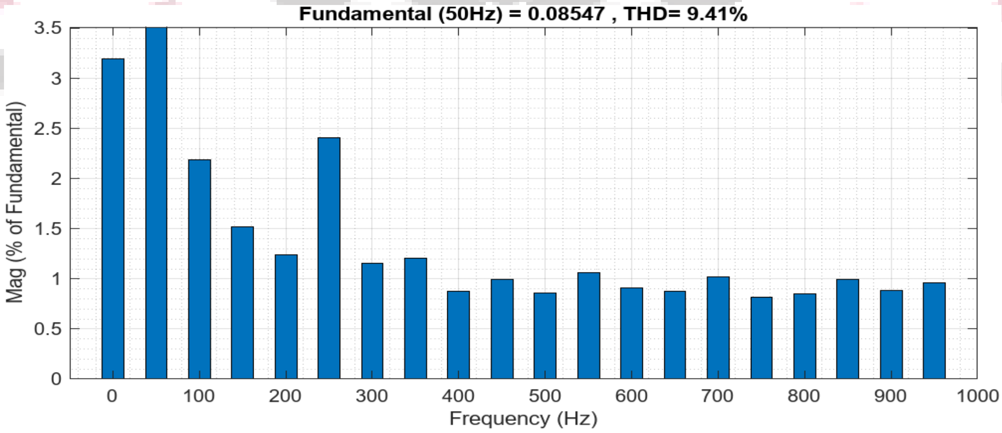

Figure 23: THD% evaluation of the voltage in phase 2 injected into the line by fuzzy based DVR

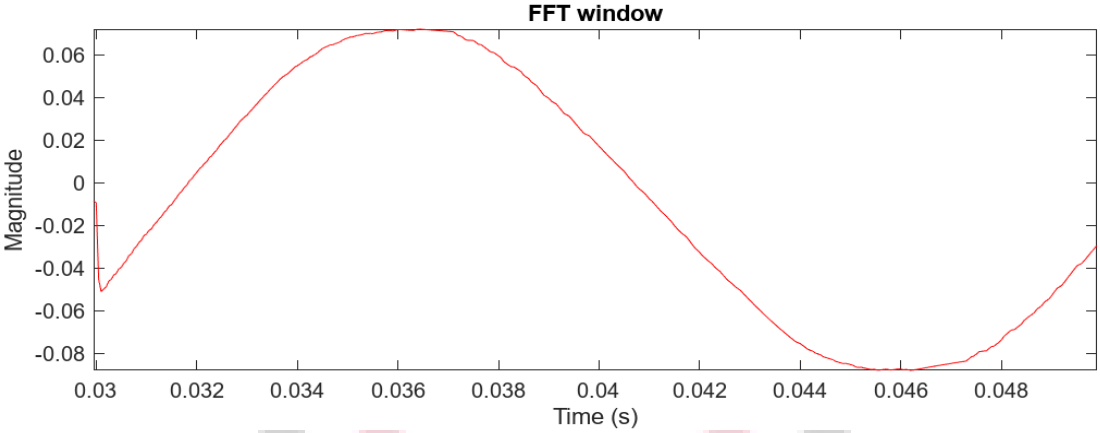

Figure 24: FFT analysis of the voltage in phase 3 injected into the line by fuzzy based DVR

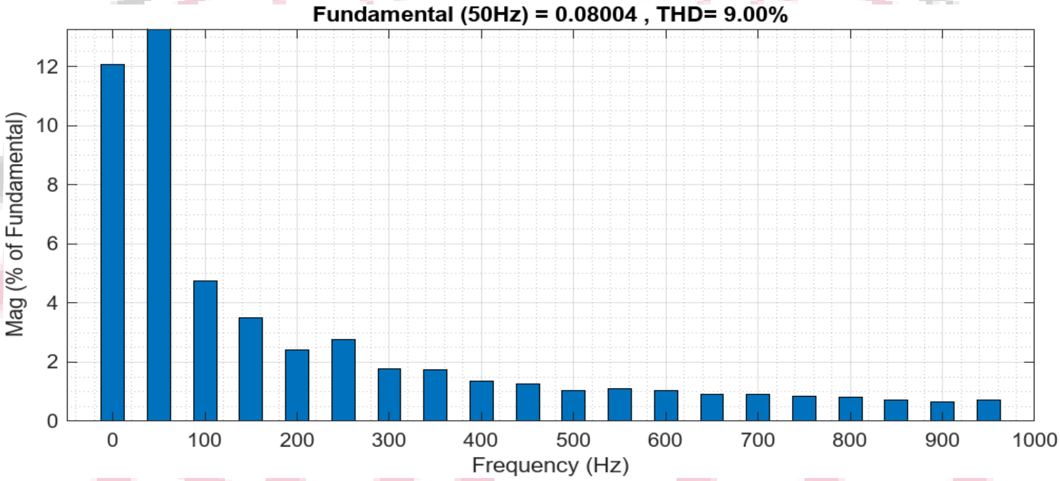

Figure 25 : THD% of the voltage in phase 3 injected into the line by fuzzy based DVR

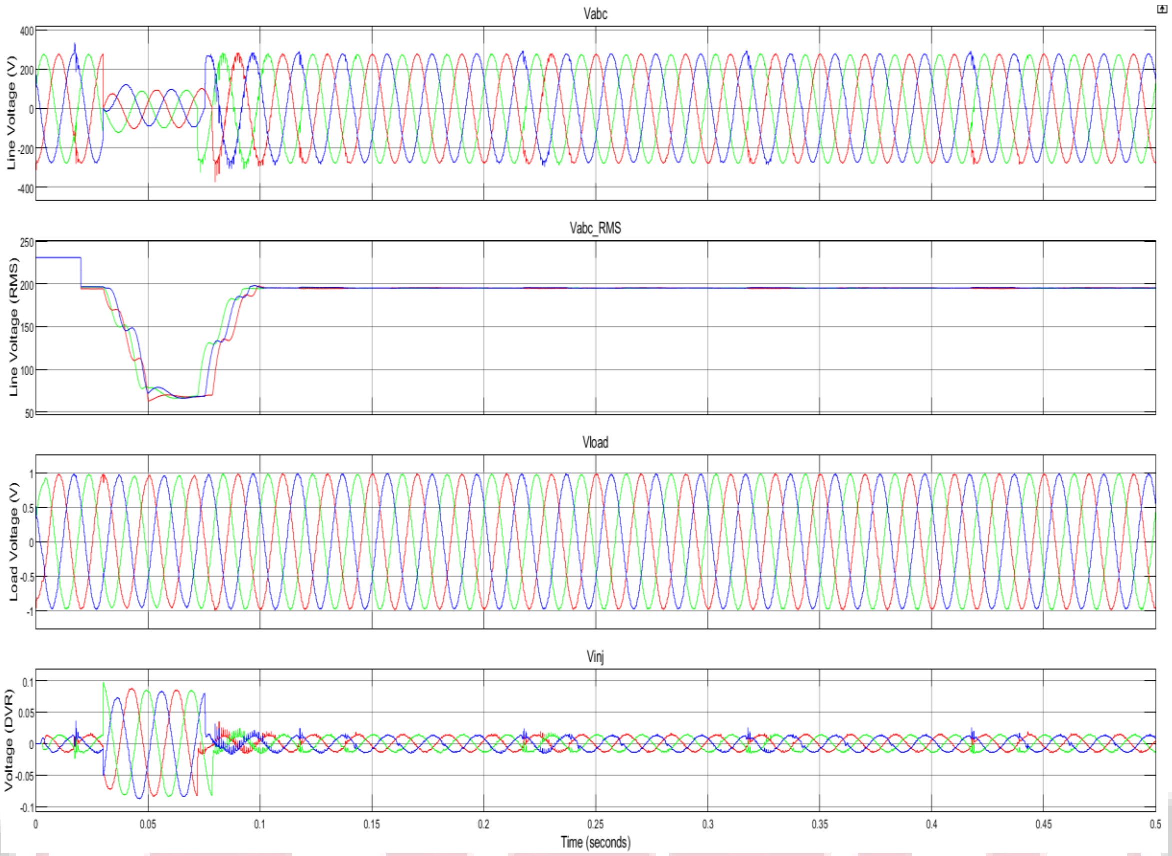

Figure 26: Comparative representation of the outcomes in the HS_W system with fuzzy based control for DVR

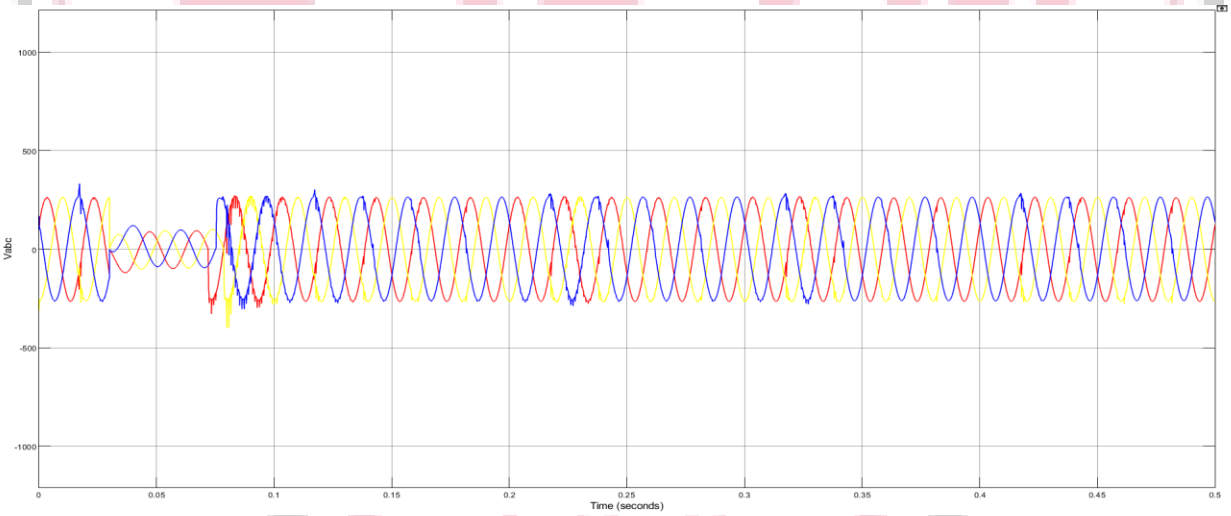

Figure 27: Voltage at the bus where voltage dips at 0.03 sec in HS_W system with ABCO_DVR

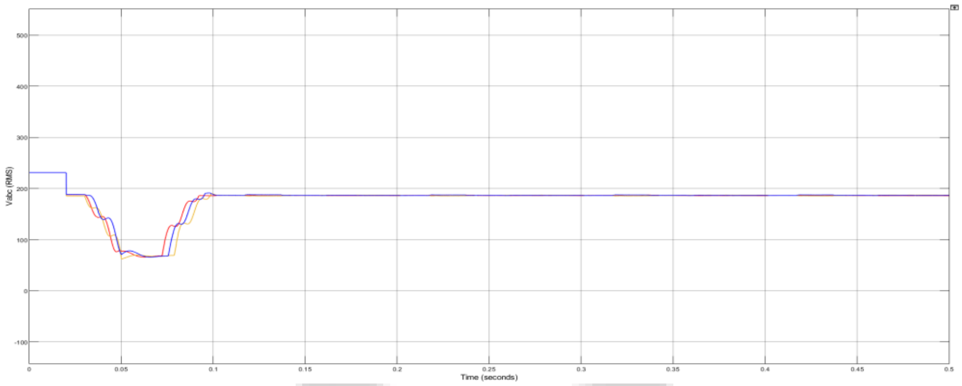

Figure 28 : Three phase RMS voltage at the bus where voltage dips at 0.03 sec in HS_W system with ABCO_DVR.

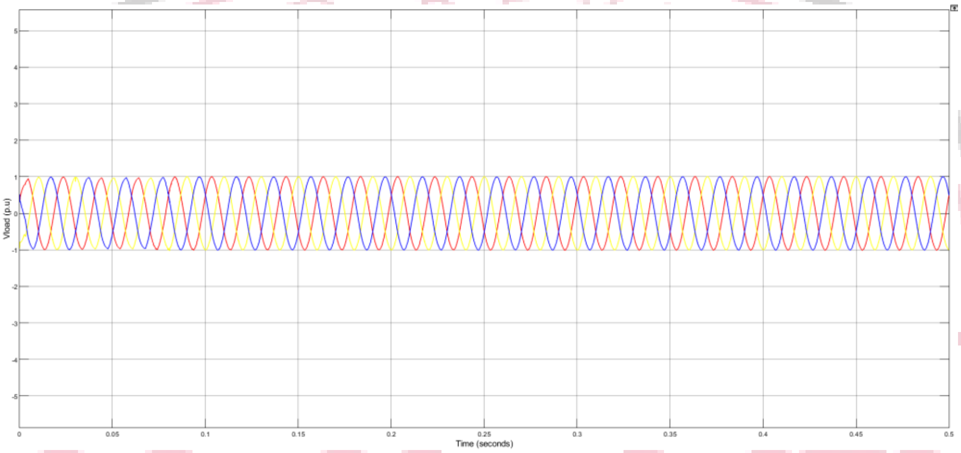

Figure 29: Effect on Load voltage in the HS_W system with ABCO_DVR

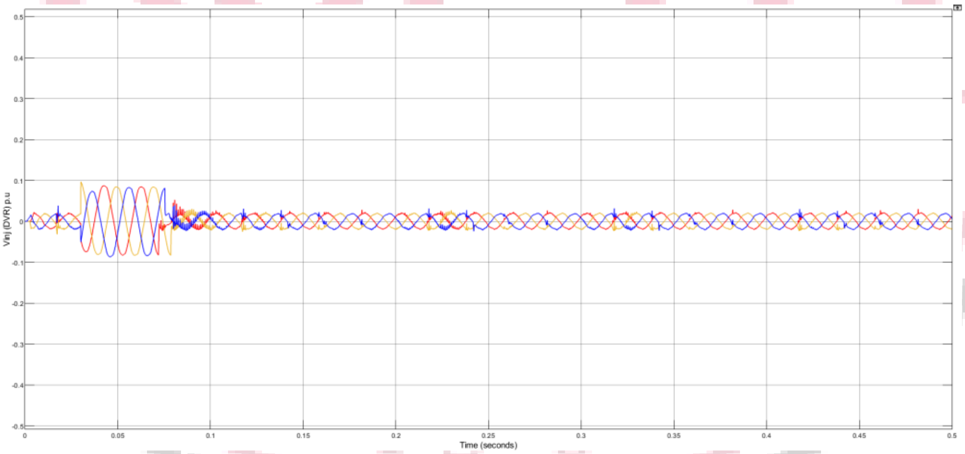

Figure 30: Voltage injected into the line by ABCO_DVR for balancing load voltage

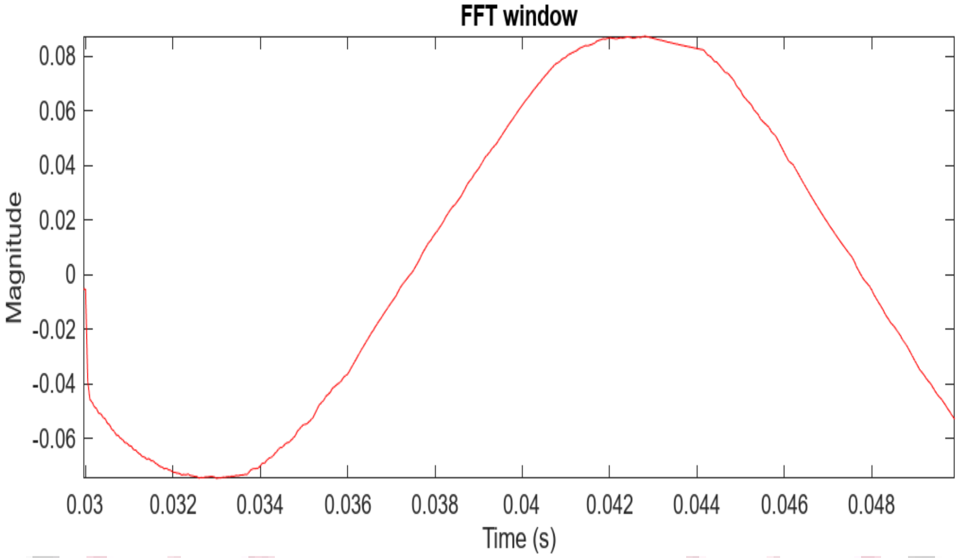

Figure 31: FFT analysis of voltage phase 1 injected by ABCO_DVR for balancing load voltage

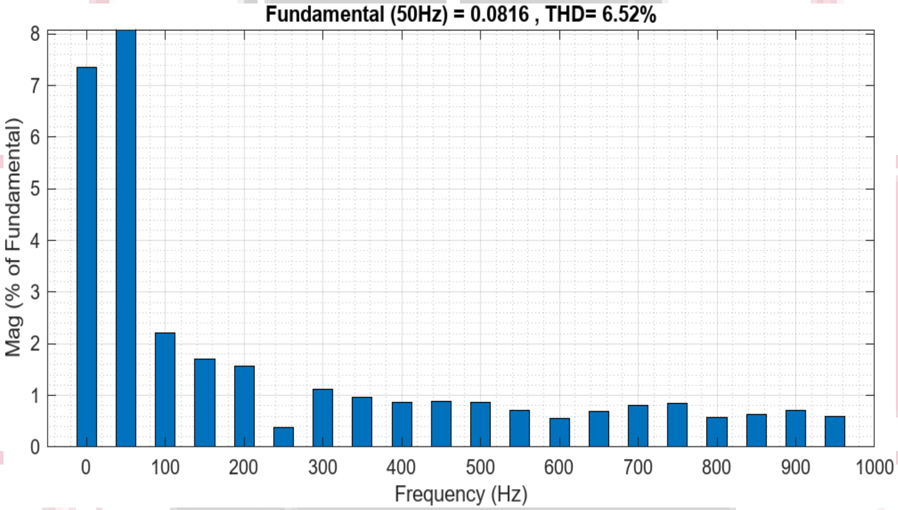

Figure 32: THD% in voltage phase 1 injected by ABCO_DVR for balancing load voltage

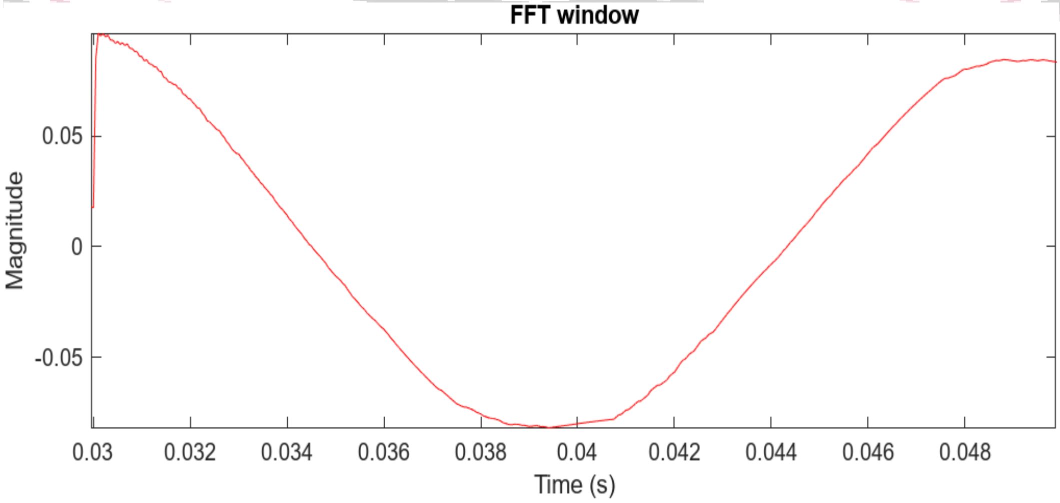

Figure 33 : FFT analysis of voltage phase 2 injected by ABCO_DVR for balancing load voltage

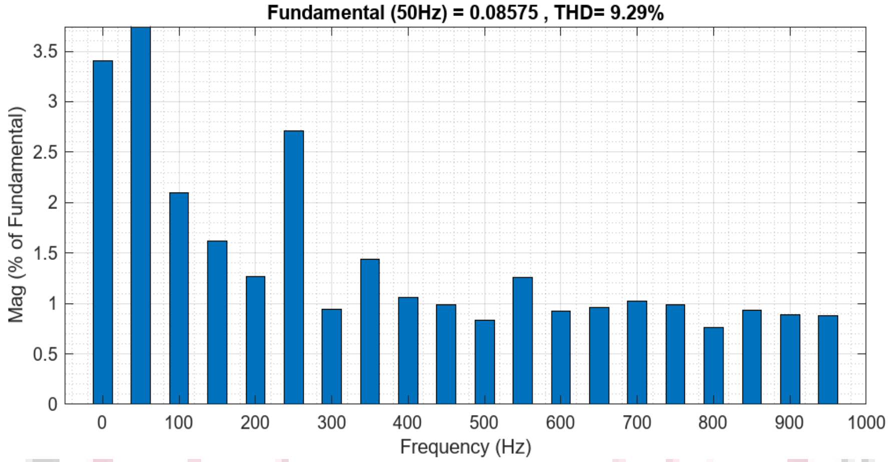

Figure 34: THD% in voltage phase 2 injected by ABCO_DVR for balancing load voltage

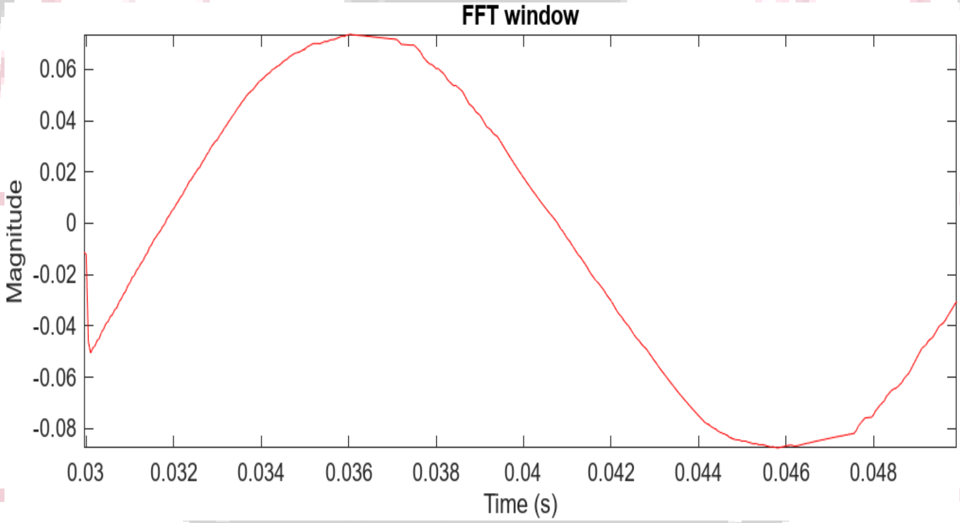

Figure 35: FFT analysis of voltage phase 3 injected by ABCO_DVR for balancing load voltage

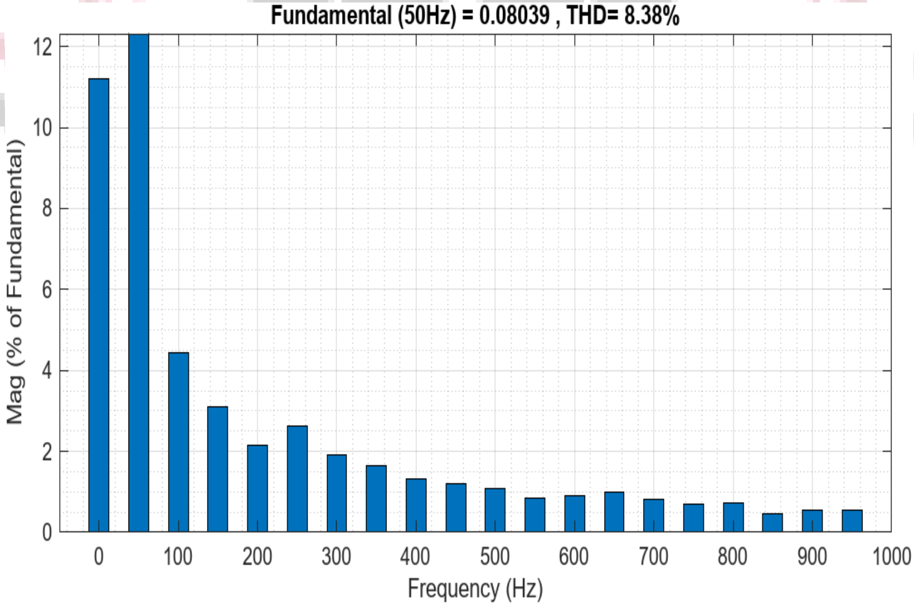

Figure 36: THD% of voltage phase 3 injected by ABCO_DVR for balancing load voltage

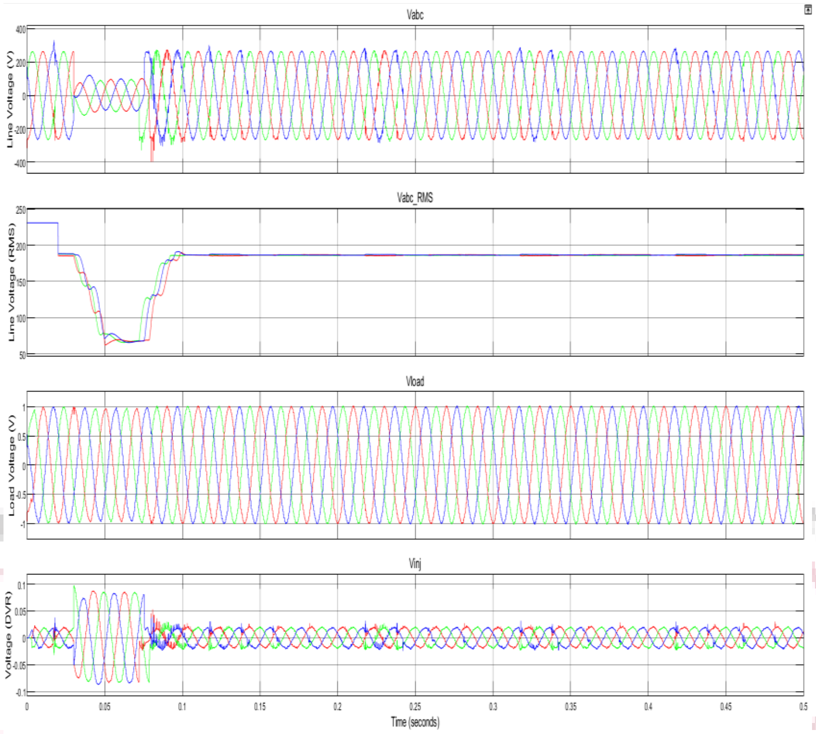

Figure 37: Comparative representation of the outcomes in the ABCO_DVR for balancing load voltage

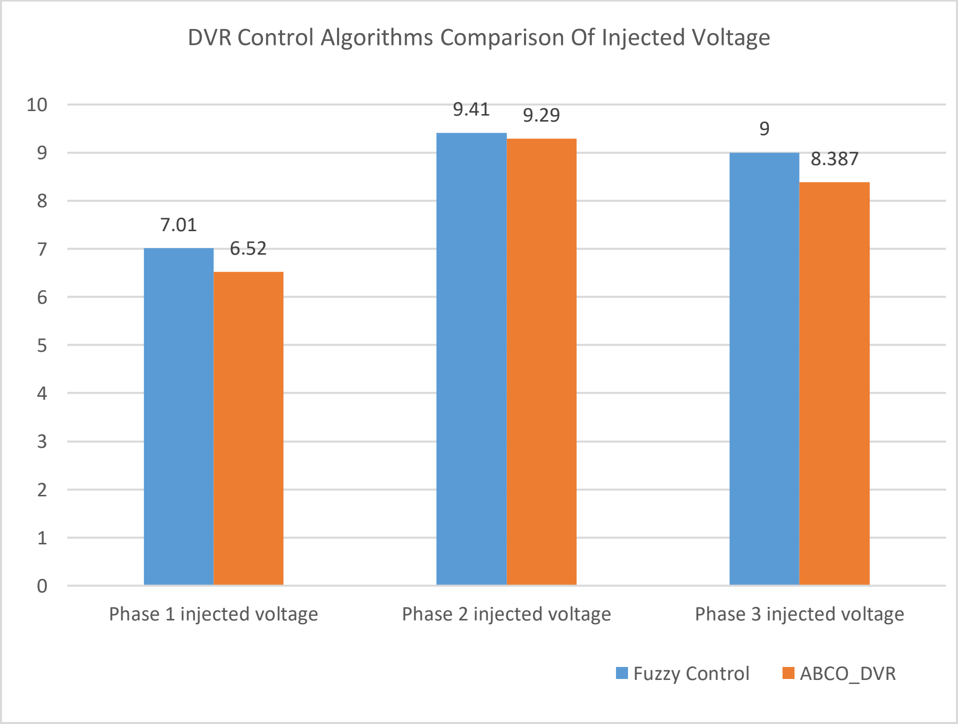

Figure 38: DVR Control Algorithms Comparison of THD% in Injected Voltage

VI. CONCLUSION AND FUTURE SCOPE :

Conclusion

The integration of renewable energy sources like solar and wind into electrical power systems poses challenges in maintaining voltage stability due to their variable nature. Dynamic Voltage Restorers (DVRs) are crucial for ensuring a stable power supply. This project focuses on designing a DVR tailored for a hybrid solar and wind energy system to correct voltage disturbances, particularly faults at load terminals, ensuring high power quality for end-users.

Efficient control strategy design, especially tuning PI parameters, is crucial for DVR performance, efficiency, and Fault Ride through (FRT) capability, extending its service life. Computational intelligence, including bee colony algorithms, helps achieve optimal PI settings for dynamic environments.

. Future directions include implementing advanced AI techniques like deep learning, studying robustness against parameter variability in renewable outputs, and analysing different load impacts for tailored solutions.

The successful implementation of the ABCO_DVR highlights its potential for widespread adoption in similar applications, offering significant improvements in power quality. By reducing Total Harmonic Distortion (THD) across multiple phases, the ABCO_DVR enhances voltage stability, particularly in hybrid solar-wind energy systems.

Future Scope

Here are some potential avenues for expanding this research:

- **Advanced AI Techniques:** Consider implementing advanced AI techniques such as deep learning or reinforcement learning to further improve the DVR's ability to predict and compensate for voltage fluctuations with higher accuracy and efficiency.
- **Robustness Analysis:** Conduct a thorough investigation into the robustness of DVR control strategies against parameter variability and uncertainties in renewable energy outputs. This analysis could lead to enhanced system reliability and efficiency, especially in scenarios with fluctuating energy supply conditions.
- **Load Impact Study:** Study how different types of loads, including resistive, inductive, and capacitive loads, impact the effectiveness of DVR strategies. This research could lead to more tailored solutions for a wide range of industrial and commercial applications, optimizing the DVR's performance based on specific load characteristics.

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