Power Quality Improving using FCL and DVR

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Abstarct:- The surge in the adoption of renewable energy systems has sparked significant interest. However, the lack of precise monitoring at the distribution endpoints of many utilities, where a majority of wind turbines tie into the grid, poses potential challenges to the overall system dynamics. Addressing this issue, this study introduces a solution in the form of a FCL-DVR inverter tailored for small to mid-sized wind turbines (10kW-20kW). The FCL-DVR inverter is designed to tackle grid power factor correction issues. By precisely controlling VARs on individual feeder lines, it effectively manages fluctuations in output from renewable sources, particularly wind energy. Active power modulation is achieved through phase angle adjustments, while reactive power control utilizes modulation index control. Furthermore, the inverter incorporates an optimized harmonic stepped waveform (OHSW) technique to mitigate harmonics, enhancing grid stability. Employing a hybrid-clamped topology, the proposed inverter is simulated using the MATLAB/Simulink environment, demonstrating its efficacy in addressing grid integration challenges associated with renewable energy systems.

Keywords:- *Fault Current, Grid Stability, Short Circuits, Electrical Faults, Equipment Protection, Cascading Failures, Reliability, Stress Reduction, Voltage Stability, Voltage Sags, Swells, Power Distribution, Stable Power Supply, Compensating Voltages, Power Quality, Voltage Fluctuations, Sensitive Loads.*

I. INTRODUCTION

By the close of 2011, the United States boasted an aggregate installed wind power capacity of 41,181 MW, equating to the generation output of 10 nuclear facilities. However, recent curtailment challenges in wind energy, particularly evident in regions like Texas, underscore the necessity for significant expansion of the electric grid and the exploration of novel control concepts to meet our administration's ambitious renewable energy targets.

A promising avenue for bolstering wind energy penetration lies within the realm of power electronics, offering enhanced flexibility and control at both transmission and distribution levels. Presently, the focus of power electronic technologies, including various FACTS devices, predominantly centers on the transmission sector due to their high costs and the need for strategic placement to maximize returns on investment. However, this approach overlooks the extensive distribution system, operating at lower voltage levels beyond distribution transformers.

The deployment of conventional FACTS devices for regulating line voltages, power flows, and VAR support at this scale is economically unfeasible. To circumvent the exorbitant costs associated with such devices, a shift towards smaller, distributed solutions proves advantageous. Rather than relying on a single large FACTS device like a unified power flow controller on distribution lines, these control functionalities can be integrated into the power electronics of small-scale distributed wind turbines, either existing or economically viable for installation in rural, wind-rich areas such as the Midwest for residential and small commercial applications.

This paper introduces a novel inverter, the FCL-DVR Inverter, designed to replace existing inverters in small to medium-sized permanent-magnet wind turbines (ranging from 10kW to 20kW). This innovative inverter offers dynamic VAR control and power factor correction, presenting a promising solution to enhance the integration of wind energy into the grid.

A. Introduction to Power Quality

Power quality pertains to the electrical characteristics of the power source that influence the proper functionality of electrical and electronic devices. It encompasses factors like voltage level, frequency, waveform, interruptions, and harmonics. In essence, it revolves around ensuring that the electricity provided to devices and systems adheres to specific standards and does not induce any issues or harm.

➢ *Here's a Breakdown of Some Key Facets of Power Quality:*

- Voltage supplied must fall within defined tolerances. Voltage deviations, whether too high or too low, can harm equipment or induce malfunctions.
- The frequency of the power supply (typically 50 or 60 Hertz) should remain consistent. Fluctuations in frequency can impact equipment performance, especially those reliant on precise timing.
- The voltage waveform should ideally be sinusoidal. Distortions like harmonics or transients can cause equipment malfunction or overheating.
- Power interruptions, even brief ones, can disrupt operations and damage equipment. Uninterruptible Power Supplies (UPS) are commonly utilized to mitigate the effects of interruptions.
- Harmonics, multiples of the fundamental frequency, often arise from nonlinear loads such as variable speed drives or electronic equipment. Excessive harmonics can lead to equipment overheating and inefficiencies in power distribution systems.
- Voltage fluctuations, termed sags or swells, can result in equipment malfunction or failure, particularly affecting sensitive electronic devices.

Ensuring optimal power quality is crucial for the dependable and efficient operation of electrical and electronic systems. This is especially vital in industries employing sensitive equipment, such as manufacturing, healthcare, telecommunications, and data centers. Power quality monitoring and mitigation techniques, such as voltage regulation, harmonic filters, and surge protection devices, are employed to uphold high standards of power quality and minimize the risk of equipment damage or downtime.

B. Power Quality Improvement by Facts

Flexible Alternating Current Transmission Systems (FACTS) represent a suite of power electronics-based tools and systems engineered to augment the manageability and adaptability of AC transmission networks. These devices are instrumental in refining power quality within electrical grids by tackling challenges such as voltage stability, reactive power compensation, and grid congestion. Devices like Static Var Compensators (SVCs) and Static Synchronous Compensators (STATCOMs), belonging to the FACTS family, play pivotal roles in regulating voltage levels across the power system. They adeptly inject or absorb reactive power to uphold voltage within acceptable bounds, thus bolstering stability and mitigating fluctuations.

FACTS devices extend their utility by furnishing reactive power support to offset consumption or generation imbalances within the network. Through real-time adjustments in reactive power output, they foster power factor correction, consequently enhancing system efficiency.

Further enhancing system performance, devices like Thyristor-Controlled Series Capacitors (TCSCs) and Static Synchronous Series Compensators (SSSCs) contribute to transient stability by damping oscillations and fortifying the system's dynamic response. This curtails voltage dips and sags during disturbances, thereby refining power quality.

Certain FACTS devices, exemplified by Active Power Filters (APFs), combat harmonic distortions within power systems. By injecting harmonic currents of opposite phase and equal magnitude, APFs counteract harmonic currents generated by nonlinear loads, thus curbing distortion and elevating power quality.

Moreover, FACTS controllers within the FACTS arsenal alleviate grid congestion by managing power flow within transmission lines. Through optimized utilization of existing infrastructure, these controllers bolster grid reliability and mitigate risks of voltage instability or overloading.

C. Benefits of Facts

Facts provide accurate information about the world around us, helping us to understand how things work and how they relate to each other.When making decisions, having factual information allows for more informed choices, whether in personal matters, business decisions, or policy making. Facts offer clarity and objectivity by providing concrete evidence that can be verified independently, reducing reliance on subjective opinions or biases. Facts serve as the foundation upon which further learning and discovery are built. They provide a starting point for exploring new ideas and concepts. In problem-solving scenarios, facts help identify the root causes of issues and guide the development of effective solutions based on evidence rather than speculation. Engaging with facts encourages critical thinking skills by prompting individuals to evaluate information, discern patterns, and draw logical conclusions. Communicating facts helps to convey information clearly and persuasively, facilitating effective communication among individuals, groups, and organizations. Being truthful and factual builds trust among individuals and institutions. When people can rely on the accuracy of information, trust in relationships and institutions is strengthened. Facts drive progress and innovation by providing a solid basis for scientific research, technological advancements, and societal development. Access to factual information empowers individuals and communities by enabling them to make informed choices, advocate for their interests, and participate actively in society.

Overall, facts play a fundamental role in shaping our understanding of the world, guiding our decisions, and fostering progress and development in various aspects of life.

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D. Importance of Renewable Sources

Renewable energy sources play a pivotal role in addressing urgent global challenges and fostering a sustainable future. Their importance extends across multiple dimensions, from mitigating climate change to enhancing energy security and promoting economic prosperity. By harnessing abundant and clean resources such as sunlight, wind, and water, renewables offer a viable alternative to fossil fuels, reducing greenhouse gas emissions and air pollution while preserving natural habitats and ecosystems. Moreover, the transition to renewable energy sources drives innovation, creates jobs, and stimulates economic growth, positioning countries and communities for long-term prosperity. As renewable technologies become increasingly cost-competitive and accessible, they offer a pathway to energy access for all while enhancing resilience to disruptions and advancing global efforts towards a more equitable, resilient, and environmentally sustainable energy system.

II. PROPOSED METHOD

A. Wind Power

Wind, found abundantly across nearly every corner of the globe, arises from natural processes like the earth's surface heating unevenly and its rotation. This perpetual availability of wind resources contrasts sharply with the finite nature of non-renewable resources like coal, natural gas, and oil. Conventional methods of electricity generation from these non-renewable sources exact a heavy toll on the environment, releasing significant amounts of carbon dioxide into the atmosphere and exacerbating the greenhouse effect, leading to global warming. In response to these environmental challenges, advancements in science and technology have led to the development of methods for generating electricity from renewable sources such as wind. In recent times, the cost of wind power, when integrated into the grid, has become comparable to that of electricity generated from coal and oil. Consequently, the growing popularity of renewable energy, exemplified by wind power, has driven an increase in demand for clean electricity, thus reducing reliance on non-renewable energy sources.

$$Pwind = \{(л/8)* d*D^2*v^3\}$$

Where d = the rotor blades swept diameter , v = velocity of wind

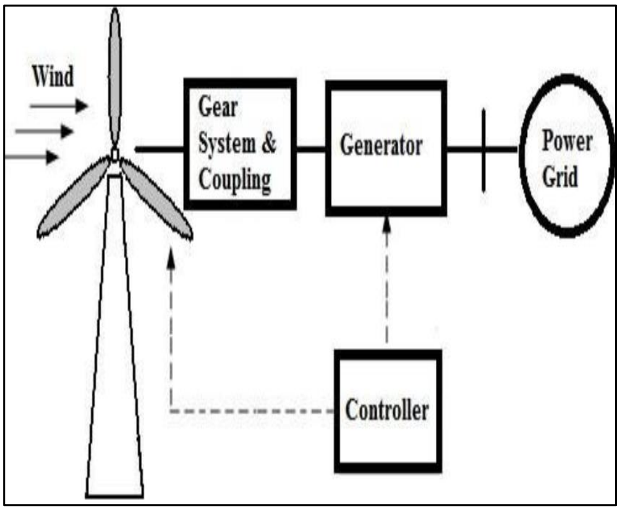

Fig 1: Working of Wind Turbine

B. Mathematical Modeling of FCL-DVR

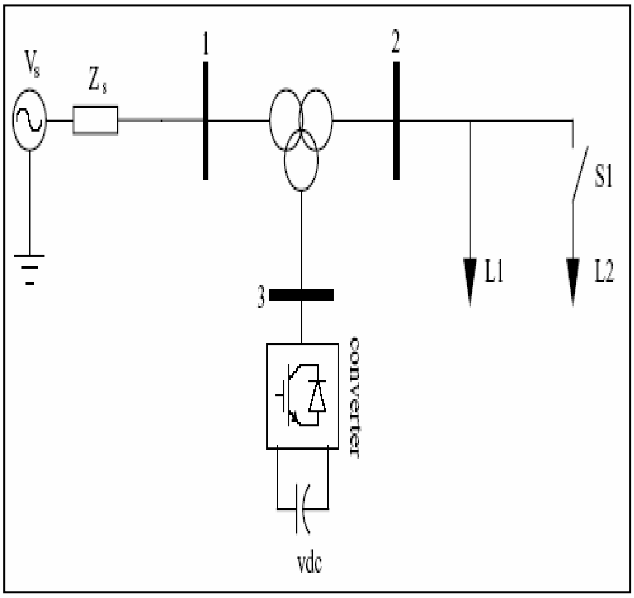

Fig 2: Single Line Diagram of the Test System for FCL-DVR

The FCL-DVR (Fault Current Limiter - Dynamic Voltage Restorer) functions as a shunt device capable of both injecting and absorbing active and reactive current. Unlike capacitors, which have reactive power output proportional to the square of the system voltage, the reactive power output of an FCL-DVR is directly proportional to the system voltage. This characteristic makes FCL-DVRs more suitable for certain applications. While long-term energy storage poses challenges, focusing on real power compensation for voltage control is not always ideal. Consequently, most operations prioritize steady-state conditions, where power exchange is predominantly reactive. In conceptualizing a model for such operations, a typical FCL-DVR configuration would include a small DC capacitor and a voltage source converter.

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Figure 2 displays the integrated DSTATCOM/BESS system configuration, which includes numerous components such as the inverter (also known as the converter), a coupling step-up transformer, a line connection filter, DC bus capacitors, and the battery array. In this configuration, using batteries as a reliable direct current (DC) voltage source simplifies the design of the inverter, making a traditional voltage source inverter (VSI) a cost-effective choice for these types of applications. The selected VSI employs Insulated Gate Bipolar Transistors (IGBTs) arranged in a DC-to-AC power inverter setup, which is well-suited for distributing power at different voltage levels. This is because IGBTs have reduced switching losses and are small in size. Pulse width modulation (PWM) adjusts the voltage to control the DSTATCOM/BESS output. High-power, fast-switching IGBTs efficiently regulate the system's output.

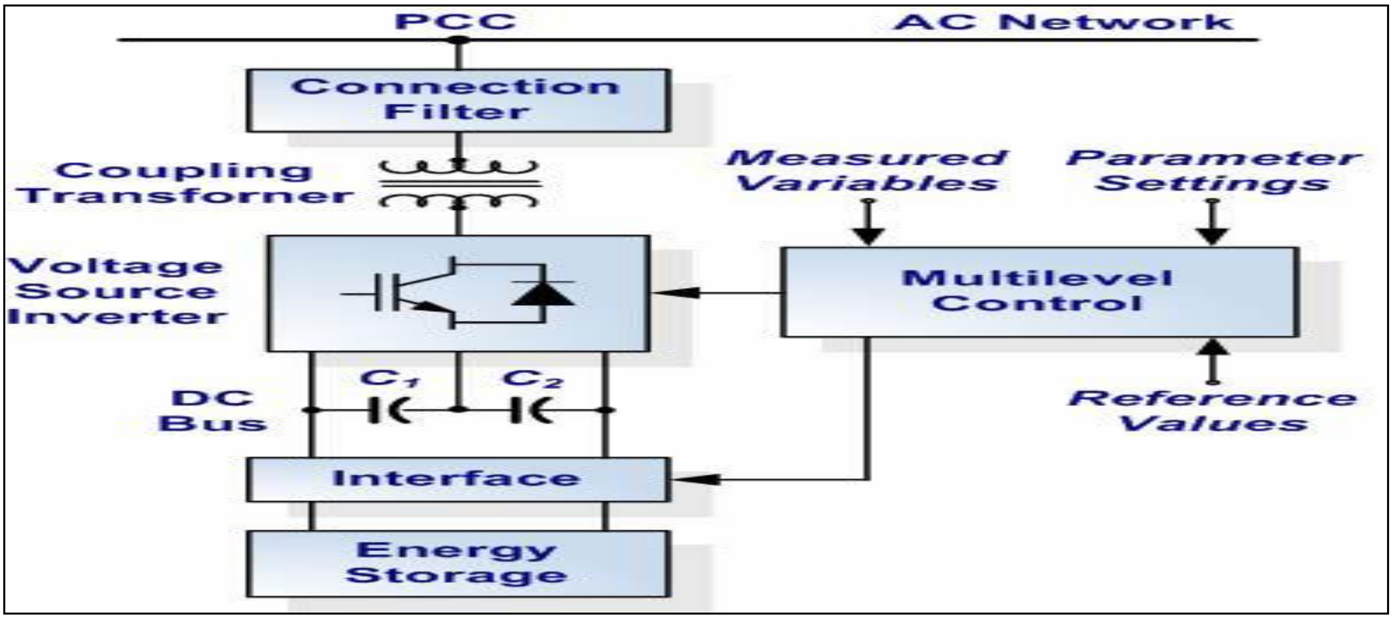

Fig 3: Block Diagram of DSTATCOM

III. RESULTS

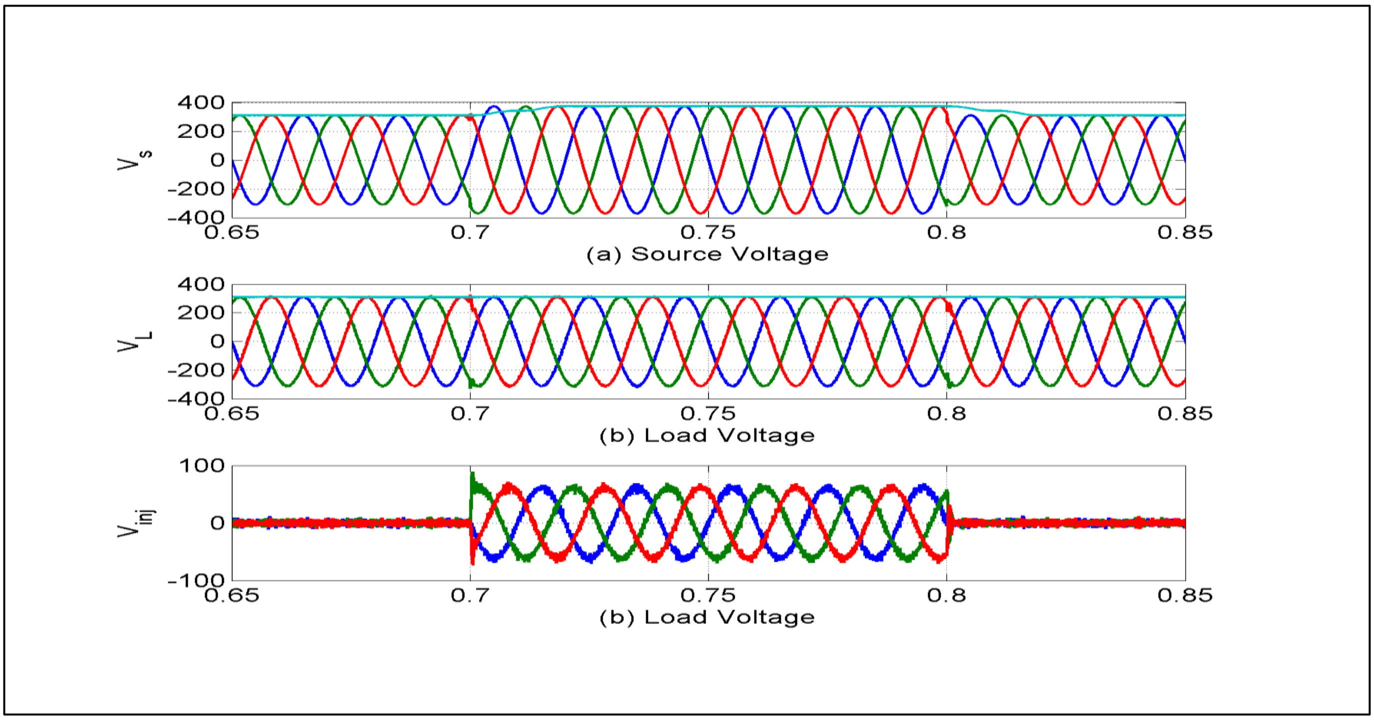

Fig 4: Voltage Swell

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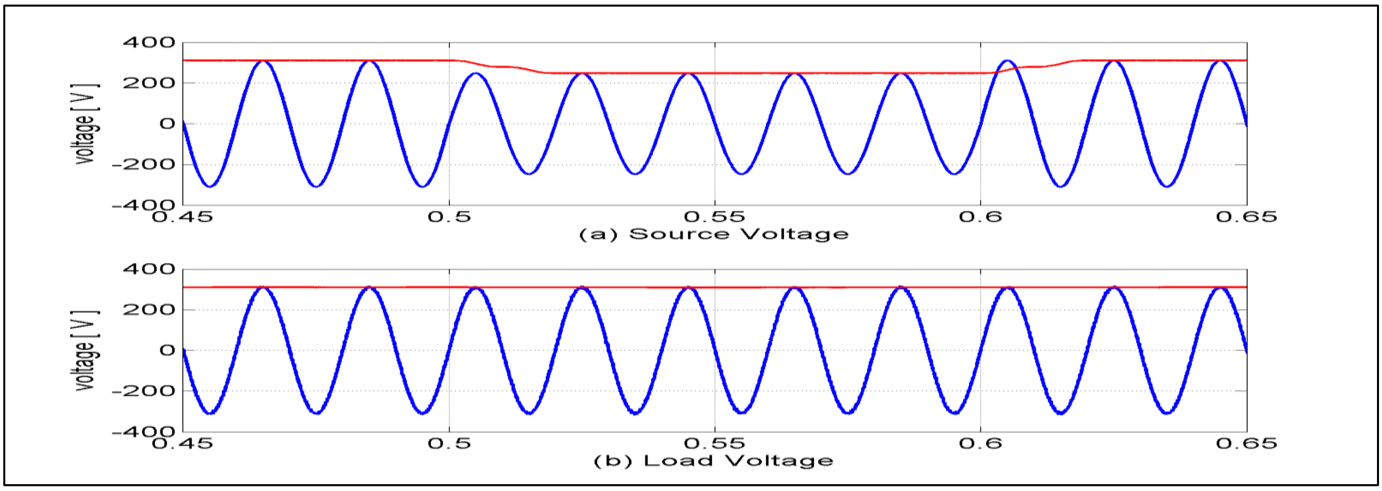

Fig 5: Voltage Swag

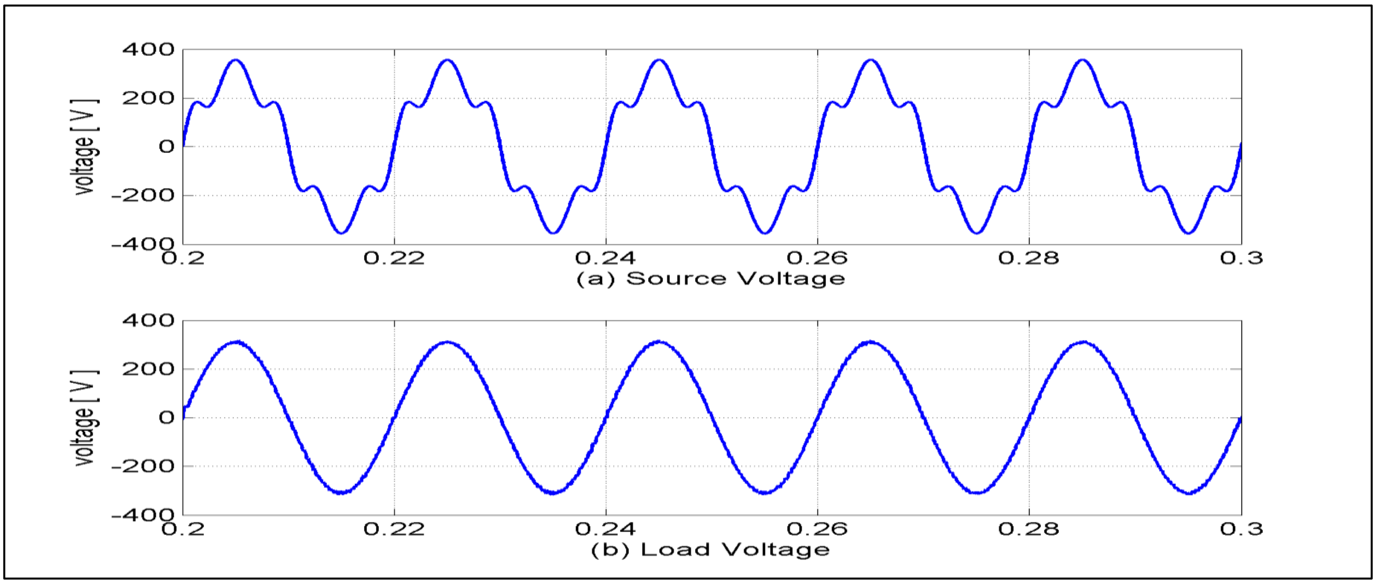

Fig 6: Source Voltage and Load Voltage

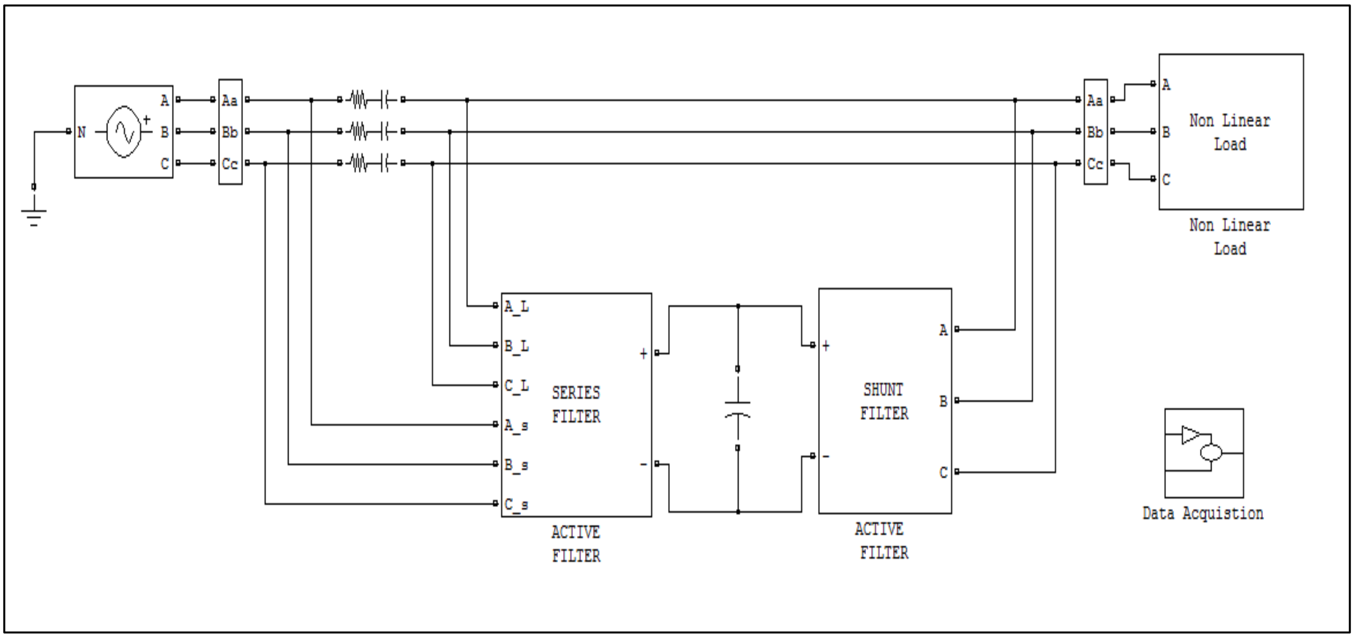

Fig 7: Unified Power Quality Conditioner (UPQC) using PI Control

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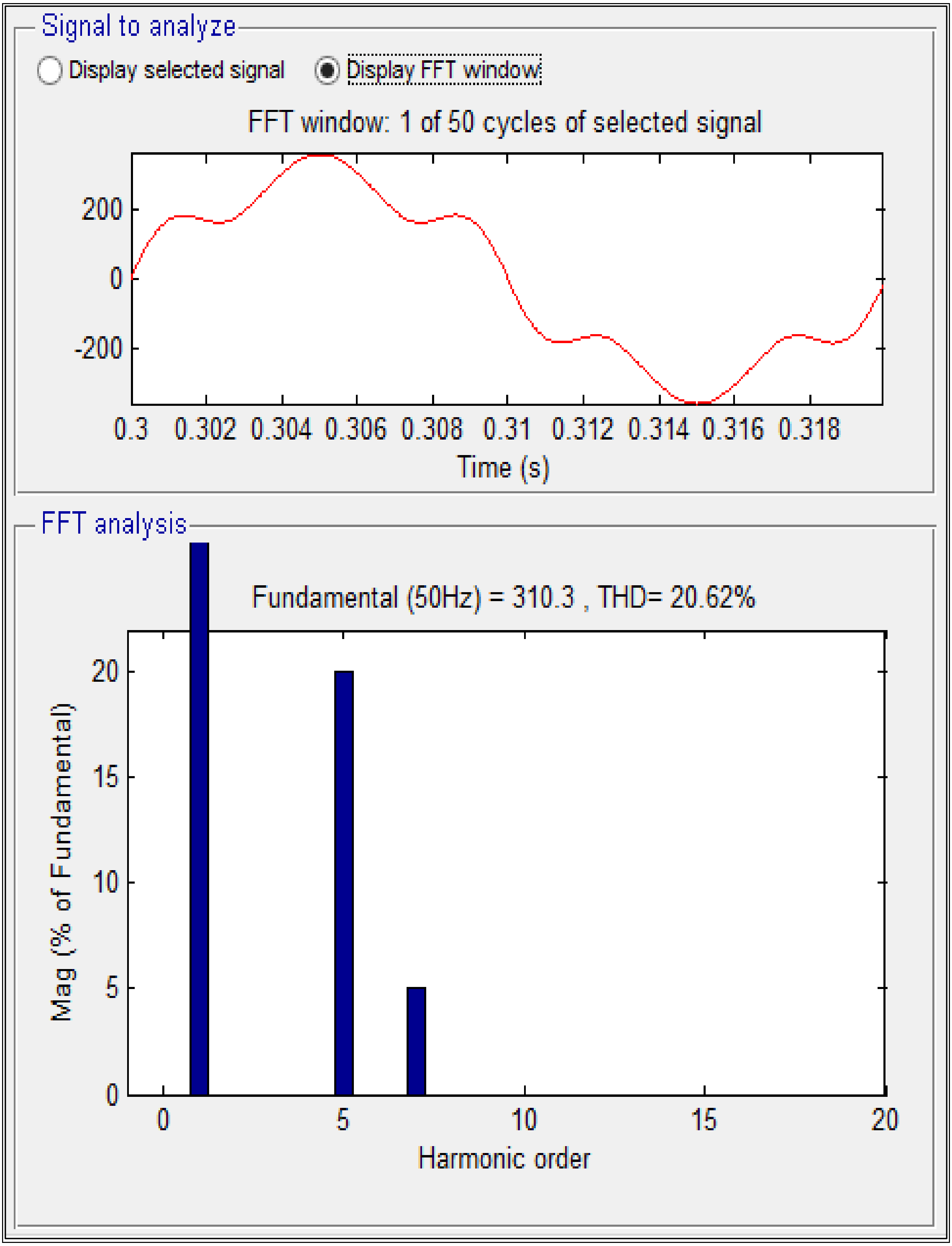

Fig 8: Total Harmonic Distortion Source

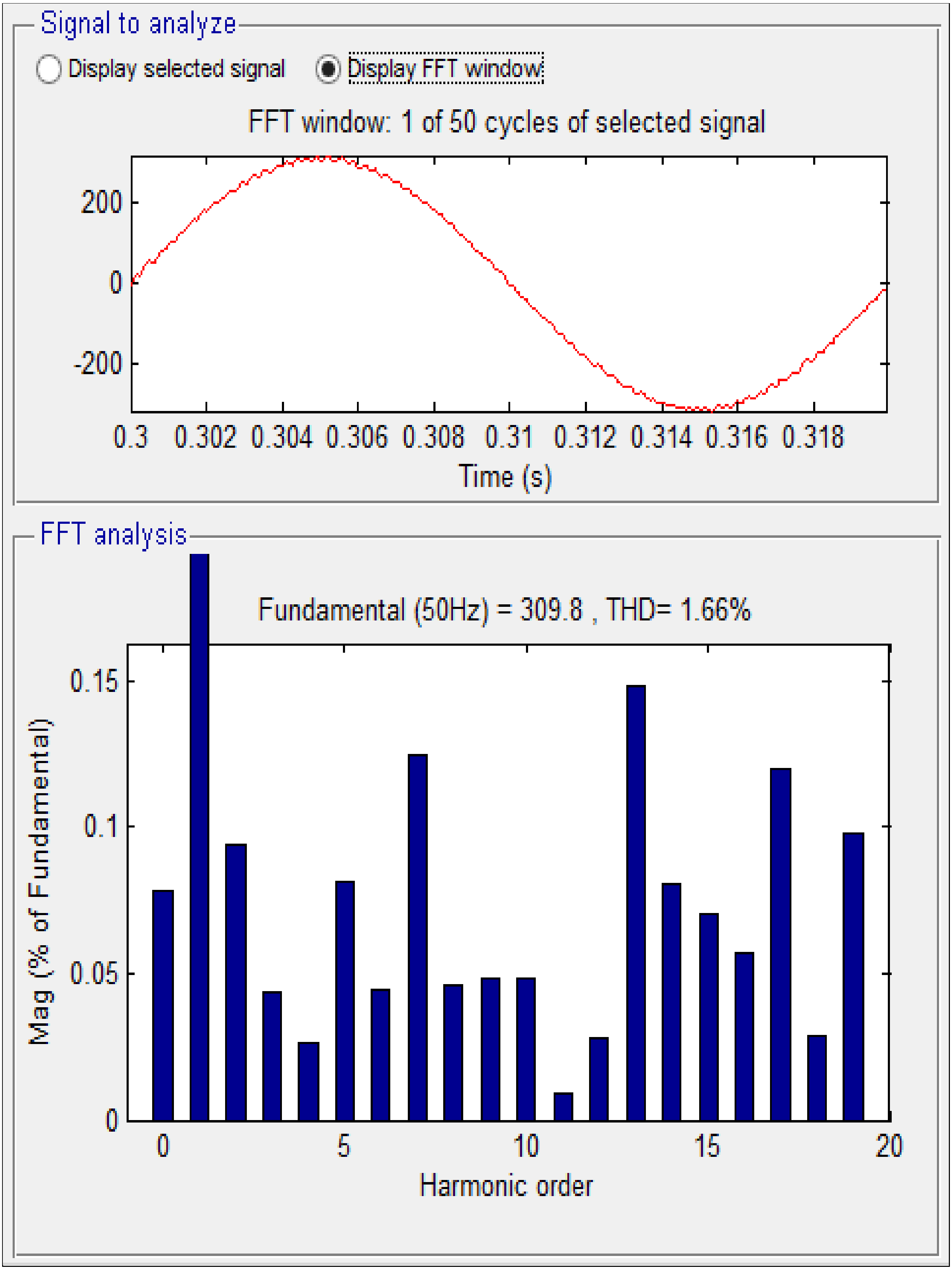

Fig 9: Total Harmonic Distortion Load

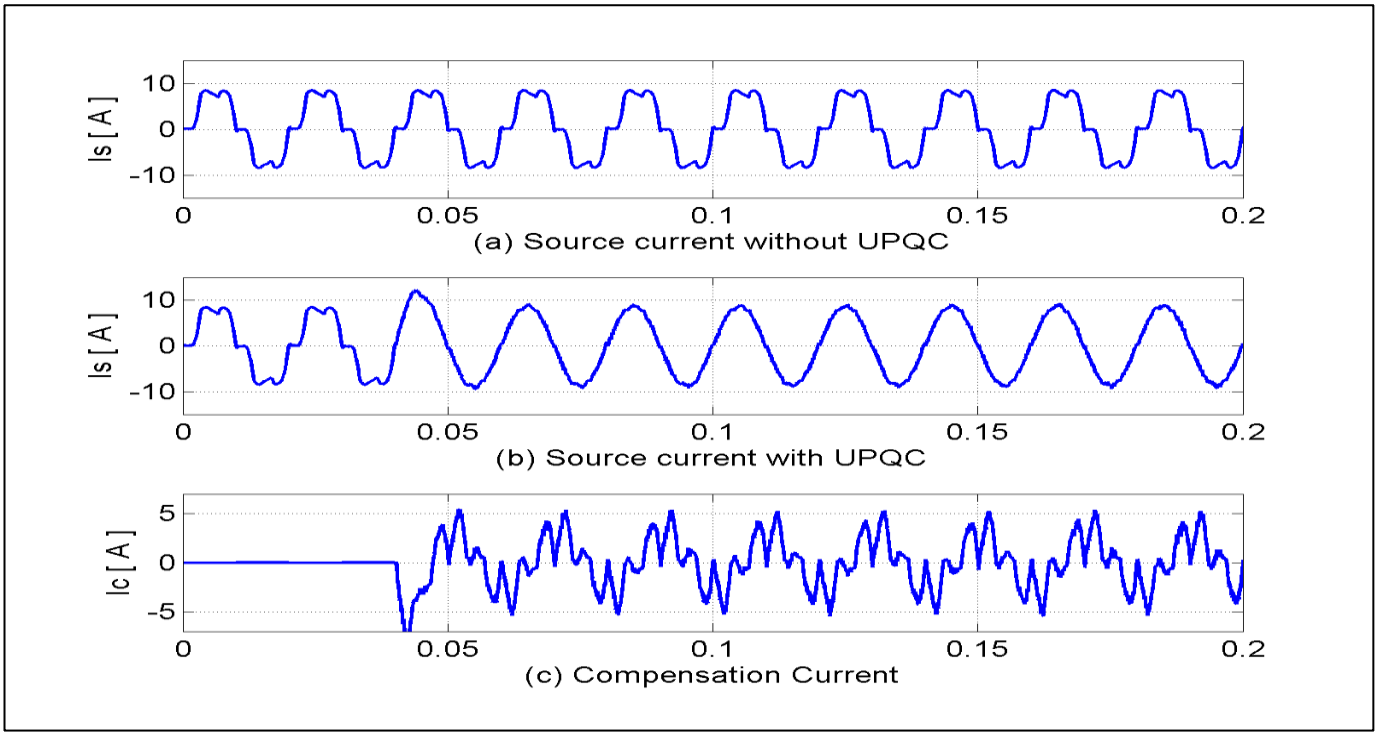

Fig 10: Harmonic Current

IV. CONCULSION

Fault current limiters (FCLs) and dynamic voltage restorers (DVRs) are essential components in modern electrical systems, aiming to enhance reliability and stability. FCLs curb fault currents during electrical faults, preventing equipment damage and reducing disruptions. They also boost system reliability by easing stress on components, albeit facing integration challenges.On the other hand, DVRs mitigate voltage fluctuations, ensuring stable power supply to sensitive equipment and improving power quality. They offer flexibility in addressing various power quality issues, making them suitable for diverse applications.In summary, both FCLs and DVRs play vital roles in bolstering power distribution networks' reliability, stability, and quality. While FCLs focus on limiting fault currents, DVRs prioritize voltage stability and power quality enhancement. Integrating these technologies is crucial for a resilient and efficient electrical system.

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