Reactive load Distribution and Power Quality Enhancement by Converter Controls in a Solar Wind Hybrid System

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Abstract: *This research highlights the benefits of incorporating renewable energy sources into a MATLAB-implemented solar-wind hybrid system. It aims to showcase the superior efficiency, dependability, and sustainability of hybrid systems compared to standalone solar or wind installations. The study also delves into the impact of reactive loads on power system voltage levels, employing two controllers to maintain stability. Notably, the suggested Programmable Linear_CSA technique for the inverter reduces Total Harmonic Distortion (THD%), increases reactive power availability, and decreases voltage distortion. These findings have significant implications for a reliable and uninterrupted power supply, paving the way for a more environmentally responsible energy future*.

Keywords: *Renewable Energy, MATLAB, Solar-Wind Hybrid System, Efficiency, Dependability, Sustainability, Reactive Loads, Voltage Stability, Reactive Power, Environmental Responsibility.*

I. INTRODUCTION

One of the essentials to a good life and a necessary component of all facets of contemporary economics is energy. There is an enormous demand for energy to meet the various necessities of living, which call for consistent and plentiful energy resources. Energy demand in developing nations like India would soar to 60% in the coming days. Growing power consumption will continue to be the main driver of energy requirements, and by 2040, electrical energy will make up 40% of all energy consumed globally. It would take an extraordinary amount of investment and research to keep up with the surge in energy consumption. It has also increased the nation's reliance on fossil fuels like coal, oil, and gas, whose rising costs and probable scarcity have sparked concerns about the future security of the energy supply. Any country's national economy will be directly impacted by its reliance on fossil fuels, and as that use grows, environmental issues will also arise. Utilizing energy sources that are easily accessible, sustainable, ecologically friendly, and profitable from an economic standpoint becomes essential. Renewable energy sources like solar, wind, tidal, and micro-turbines have the potential to produce energy that is clean and limitless, but they also come with a number of drawbacks [1]. These drawbacks include supply reliability issues, scalability barriers, high initial costs, and considerable land requirements [2]. The solution to these problems requires a mix between conventional and renewable energy sources, resulting in an economically viable, stable, and dependable energy supply system [3]. The characteristics of electrical power that affect the secure and effective operation of linked devices are referred to as power quality. It includes a variety of problems, including as harmonics and voltage fluctuations, which can impair operations and raise energy expenses. Maintaining stable and dependable electrical systems in a variety of environments requires managing power quality.

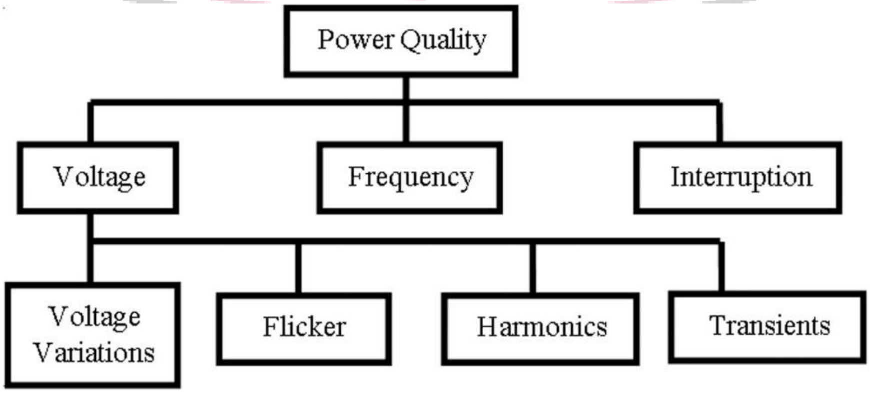

Figure 1: Categorized Power Quality Concerns

Power quality is an essential factor in today's electrical systems, affecting the reliable and efficient operation of machinery and devices in a variety of industries, including residential, commercial, and industrial.

The study outlines a number of important objectives. In order to increase overall reliability and efficiency, it first aims to develop a grid-integrated solar-wind hybrid energy system using a shared DC line. The second goal of the study is to develop an inverter control system that reduces distortion of the voltage and current waveforms, especially when dealing with reactive loading conditions. Thirdly, it attempts to create an artificial intelligence-based algorithm capable of managing load point oscillations. Last but not least, the research concentrates on increasing the system's reactive power output through the hybrid system's inverter management, enabling it to supply reactive power when needed, so improving its performance.

II. LITERATURE REVIEW

According to R.P.K. Naidu et. al. [5] Modern power grids need renewable energy sources (RES), but integrating them might lead to problems with the quality of the power they produce. Custom power devices (CPDs) are applied to address these issues and enhance grid stability. This paper presents a novel coordinated PQ theory-based distributed power flow controller (DPFC) with a fractional order PID (FOPID) controller. This DPFC, which consists of shunt and series controllers, efficiently deals with voltage variations, harmonics, and load shedding in solar and wind-powered distribution systems. The DPFC-FOPID controller performs better than other controllers, giving improved voltage profiles, lower DC voltage fluctuations, and improved active power regulation, as shown by comparative study. Utilizing MATLAB/Simulink, a case study on an IEEE 12 bus system verifies the DPFC's effectiveness in voltage compensation and harmonics suppression.

Arjun Kumar et al. [6] Examines the design, operation, and evaluation of an autonomous hybrid wind solar system (AHWSS) that powers batteries and three-phase loads. The system incorporates two PWM voltage source converters, the Grid Side Converter (GSC) and Rotor Side Converter (RSC), as well as a Doubly Fed Induction Generator (DFIG) and a Wind Energy Conversion System Connected to the Grid (WECS). Maximum Power Point Tracking (MPPT) is guaranteed for solar and wind inputs using an algorithm. Grid voltage-oriented control balances reactive power on the grid and maintains a constant DC bus voltage. Effective active and reactive power management at the stator is achieved via stator voltage-oriented vector control, which also achieves MPPT through Tip Speed Ratio control. The Sim-power-system package for MATLAB is used to create the model, which is tested in a variety of scenarios while retaining low Total Harmonics Distortion (THD) below 4% in all cases.

Naggar H.Saad et al. [7] Proposes a novel hybrid centralized and distributed control of hybrid renewable energy system consisting of AC/DC micro grids. An Interlinking Converter (IC) is used to connect both sides of the micro grid systems together. Improved Particle Swarm Optimization (IPSO) which acts as a master controller is used to control the power of the sources based on IC control. Also, there are different slave controllers for 100 kW photovoltaic, fuel cells and 100 kW wind, which are designed to supply continuous load power. Coordination between two grids is satisfied through droop control for both AC and DC micro grids to achieve power sharing process and control of renewable energy sources supplying different loads. The model has been implemented in MATLAB/SIMULINK. The proposed controller succeeded to manage energy between micro grids under different scenarios. The control technique using IPSO strategy improves the dynamics of the hybrid system connected to the grid.

Amir Mushtaq Palla et al. [8] This research paper presents a new model of hybrid grid connected inverter (HGCI) which replaces the use of capacitive-coupled grid connected inverter (CGCI) and inductive coupled grid connected inverter (IGCI). As CGCI have narrow operation range and IGCI needs more PV panels thus HGCI overcomes the limitations of both inverters by providing wide operation range and less PV panels are required. The proposed model has a three-phase full-bridge DC/AC electrical converter with a thyristors-controlled LC (TCLC) filter to transfer active power and performs reactive power compensation and also harmonic compensation. At the end results, parameter design and performance of HGCI have been verified by MATLAB/Simulink.

Li-Yuan Liu et al. [9] The objective of this paper is to propose a reactive power control strategy of the grid-connected inverter for microgrid application. The proposed strategy can actively participate to regulate the voltage, realize the islanding detection, reduce the power quality impact of islanding detection and simplify the controller design. When the distributed energy resource (DR) of the microgrid system generates power to the grid, it may cause the voltage of the point of common couple (PCC) rising. The proposed strategy is to use the grid-connected inverter with the reactive current control to regulate the PCC voltage. Meanwhile, the reactive current disturbance is used to detect the variable frequency in islanding condition. Also, the experimental results are shown to confirm the validity of the design concept of the proposed strategy.

C.-H. Chang et al. [10] This paper presents a new methodology for optimal design of transformerless photovoltaic (PV) inverters targeting a cost-effective deployment of grid-connected PV systems. The optimal switching frequency as well as the optimal values and types of the PV inverter components is calculated such that the PV inverter LCOE generated during the PV system lifetime period is minimized. The LCOE is also calculated considering the failure rates of the components, which affect the reliability performance and lifetime maintenance cost of the PV inverter. A design example is presented, demonstrating that compared to the nonoptimized PV inverter structures, the PV inverters designed using the proposed optimization methodology exhibit lower total manufacturing and lifetime maintenance cost and inject more energy into the electric-grid and by that minimizing LCOE.

III. MODELLING AND SIMULATION

This project aims to explore the design and simulation of a grid-connected hybrid solar-wind energy system using MATLAB, with a focus on efficient energy generation, grid integration, and optimization.

Simulating solar PV components and their interactions with the grid using software like Simulink and Simscape Power Systems is required for modeling a grid-integrated solar energy system in MATLAB. Defining the system's components and parameters, incorporating a solar irradiance model, building a PV panel model, simulating the behavior of the inverter, defining electrical loads, connecting to the grid, putting control strategies into practice, and running simulations to assess system performance are all steps in the process.

The output power of a solar panel is based on the incoming solar irradiance and panel characteristics. The simplest model is the single diode model:

$$I = I_{ph} - I_o\left(e^{\frac{V+I.R_S}{a-V_t}} - 1\right) - \frac{V+I.R_S}{R_p}$$

Where:

- I is the panel current
- V is the panel voltage
- I_{ph} is the photogenerated current
- I_0 is the reverse saturation current
- R_s is the series resistance
- R_p is the parallel resistance
- a is the diode ideality factor
- V_t is the thermal voltage

The output power of the inverter is typically determined by the efficiency and the power extracted from the solar panels:

$$P_{inv\_out} = \eta_{inv}.P_{panel\_out}$$

P_{inv_out} is the inverter output power

P_{panel_out} is the inverter efficiency

η_{inv} the solar panel output power

The interaction with the grid involves equations for power flow, voltage, and frequency regulation. For example, for power flow between the solar system and the grid:

$$P_{grid} = P_{inv\_out} - P_{load}$$

P_{inv_out} is the inverter output power

P_{load} is the load power

P_{grid} is the power exchanged with the grid.

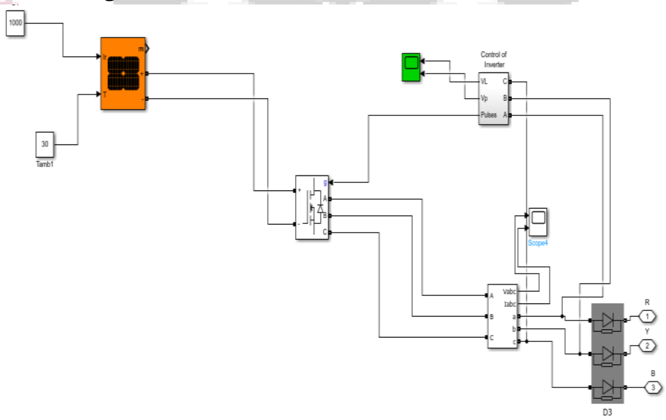

Figure 2: MATLAB SIMULINK Implementation diagram of solar energy system

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

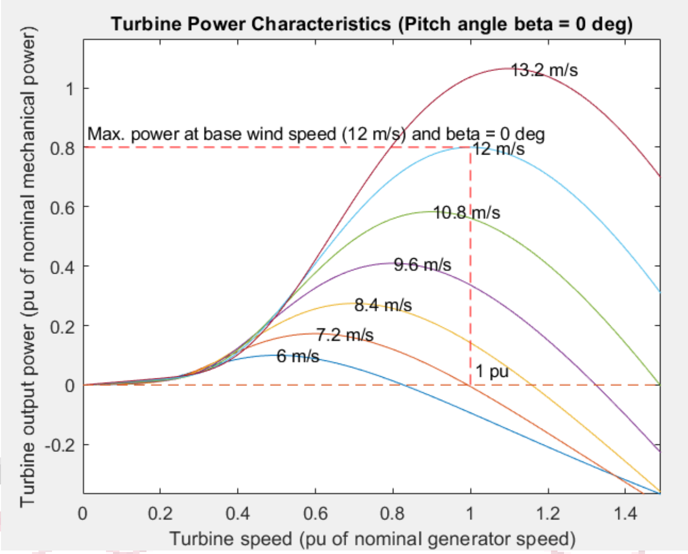

Figure 3: Wind Turbine characteristic cure used in MATLAB at different wind speeds

Table 1: Wind energy system parameters used in MATLAB	
Wind speed	variable
Pitch controller gain	15
Maximum Pitch Angle	27
Frequency	50 hertz
Maximum rate of change of Pitch Angle	10
Wind turbine inertia constant	4.32
Initial Output Torque	1
Viscous Damping	4.5

A power converter in a DC/AC converter control system changes DC voltage into three-phase AC voltage so that a motor can transfer electrical energy to mechanical energy. Frequently used are voltage source inverters with clearly defined voltage waveforms. The control system provides secure operation by adjusting output voltage and frequency using feedback control loops and a mathematical model of the converter. Switching devices are controlled by PWM signals using a three-phase bridge setup to produce the necessary AC voltage waveform.

A. Linear_CSA approach algorithm Designing

It is crucial to understand that complex engineering design issues may be difficult for traditional search methods to solve due to a large number of variables and complicated objective functions when developing the Linear_CSA approach algorithm. Effective optimization techniques are necessary to address these issues and locate global optima. In addition, crows, one of the smartest bird species, have a remarkable brain-to-body ratio that is only marginally lower than that of humans. They have shown outstanding cognitive skills, such as self-awareness, tool-making, facial recognition, complex communication, and great memory, which they used to remember where food was hidden months later.

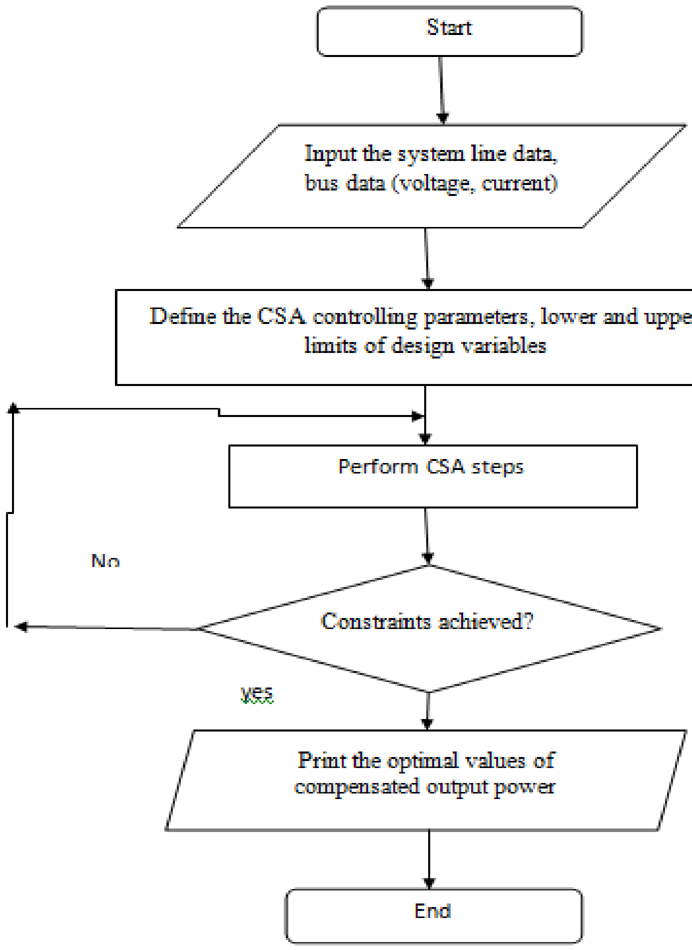

Figure 4: Designing of proposed methodology

In solar-wind hybrid systems, such as inverter pulse control, the linear_CSA metaheuristic optimization technique is used to improve control strategies. It starts with the identification of significant control variables, such as pulse width, frequency, or modulation index. With regard to energy production, losses, and power quality, an objective function is defined to assess inverter control performance. The method starts with a population of starting solutions, which are represented as crows in a multidimensional space, and assesses their fitness using the objective function. Movement rules are updated based on fitness and interactions and are inspired by crow behavior. The following generation of solutions is formed by higher fitness crows, which are selected after iteratively evaluating fitness and updating position until convergence. The ideal answer encapsulates the most effective inverter pulse control method.

IV. SIMULATION RESULT AND DISCUSSION

The work focuses on utilising MATLAB to create a solar-wind hybrid energy system. Photovoltaic (PV) panels for solar energy production and a wind turbine for using wind energy will make up the hybrid system. The system tries to alleviate the intermittent problems present in standalone solar or wind systems by merging these two sources, increasing overall power output and energy production with its reliability. The work discuss the results in the following two cases.

Case 1: Quality Enhancement of the power distribution at reactive load terminals in a solar/wind hybrid energy system with converters having voltage source control which is addressed as system 1

Case 2: Quality Enhancement of the power distribution at reactive load terminals in a solar/wind hybrid energy system with converters having Programmable Linear_CSA approach which is addressed as system 2

Reactive components affect how circuits react to abrupt voltage or current changes. To understand how circuits respond to disturbances, transient behaviour is simulated and examined using MATLAB. In order to examine the quality issues at the load distribution end, the various types of loads selected are examined for their levels of distortion in the power delivered to them. For improved outcomes, the two methods have been used to analyse the Total Harmonic Distortion (THD) percentage in the line. These diagrams make it easier to see how reactive elements influence a circuit's behaviour at various frequencies and switching patterns.

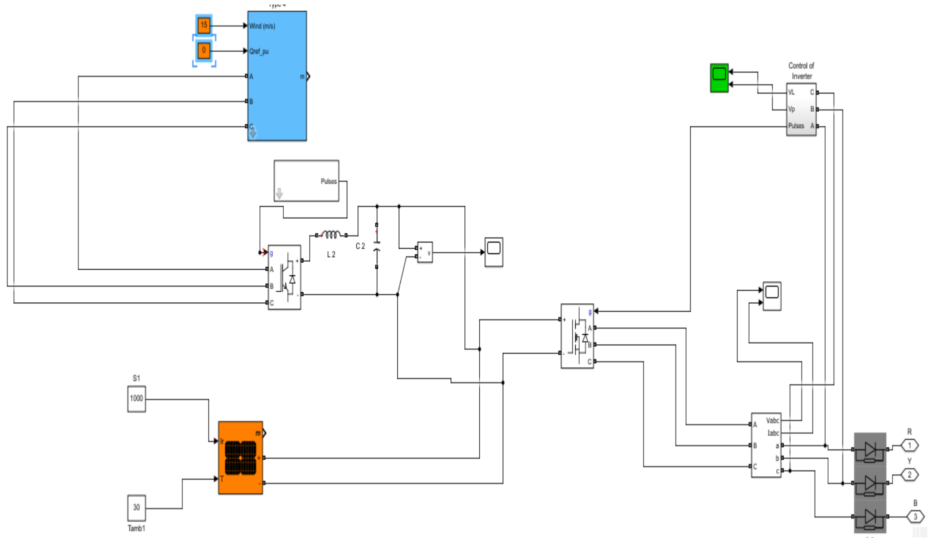

Figure 5: Solar wind hybrid energy system modelling in MATLAB

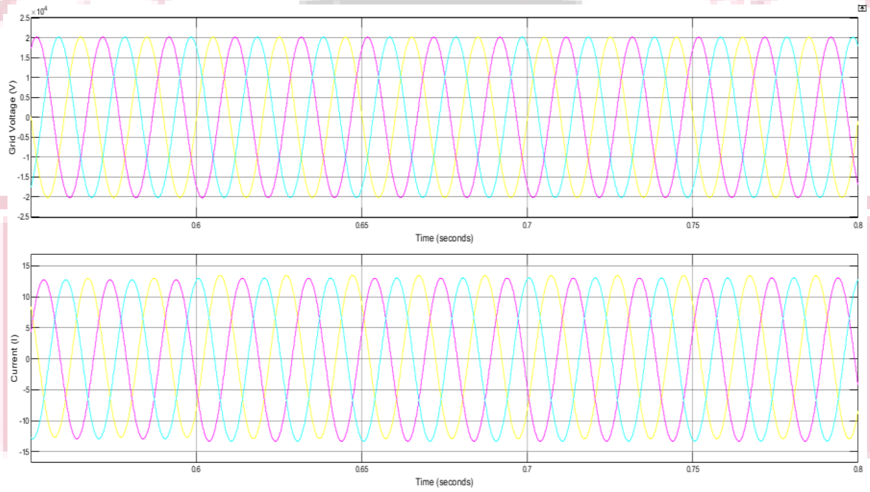

Figure 6: Grid voltage and current in the Solar_Wind hybrid system

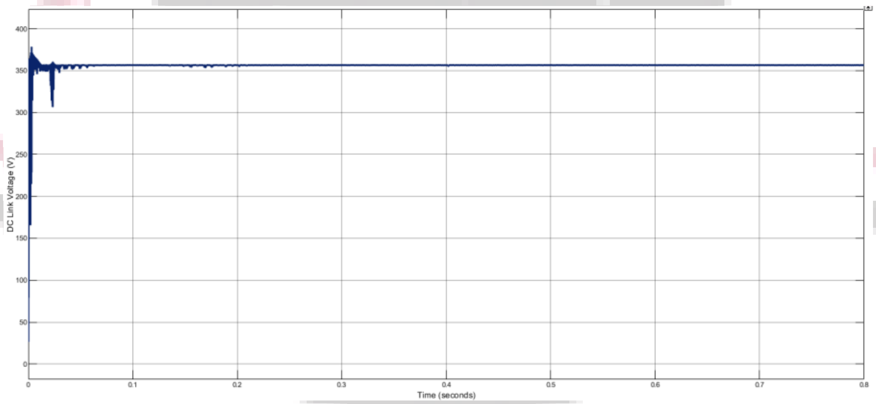

Figure 7: Common DC line voltage of the hybrid system

A. Case 1: Quality Enhancement of the power distribution at reactive load terminals in a solar/wind hybrid energy system with converters having voltage source control

A hybrid solar/wind energy system combines solar and wind energy sources with voltage-controlled converters to increase efficiency and dependability. It increases energy production by converting DC electricity generated by solar panels and wind turbines into AC power. For seamless integration, proper system design—including sizing, component compatibility, control algorithms, and safety measures—is crucial. In order to ensure constant voltage and frequency output, this system continuously checks load distribution, keeps an eye on solar and wind outputs, and controls converters.

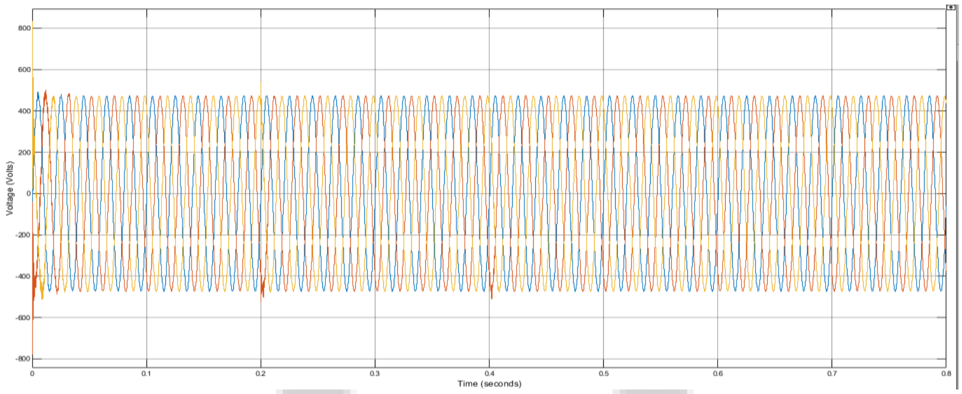

Figure 8: Three phase voltage available in the reactive load line in hybrid system with converters having voltage source control

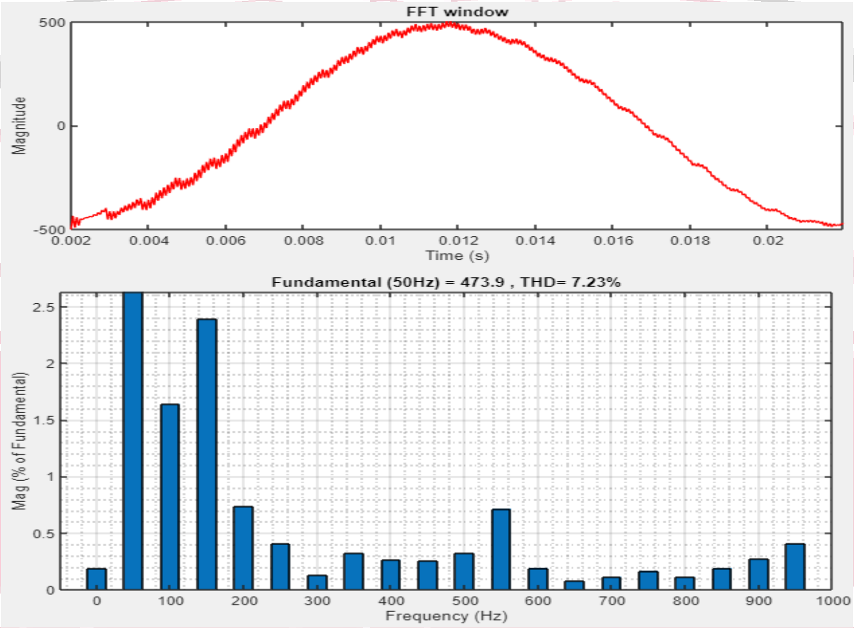

Figure 9: THD% of three phase voltage available in the reactive load line in system 1

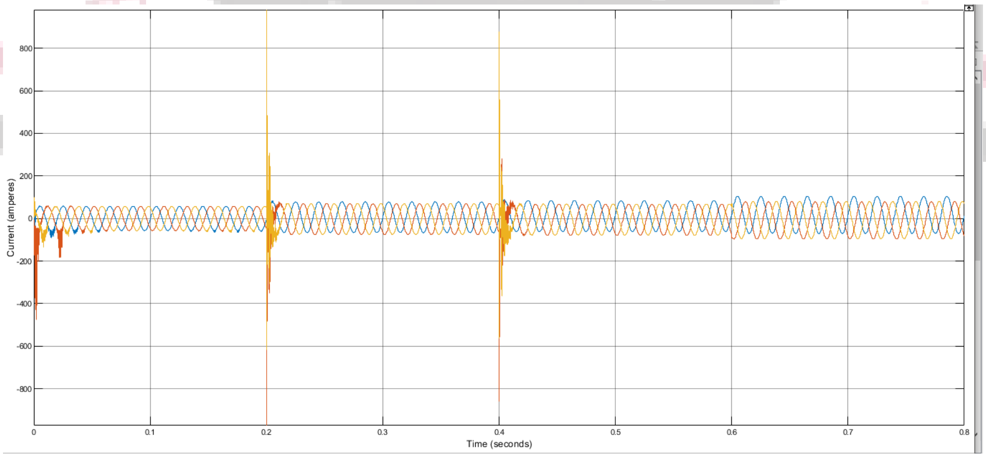

Figure 10: Three phase current available in the reactive load line in hybrid system with converters having voltage source control

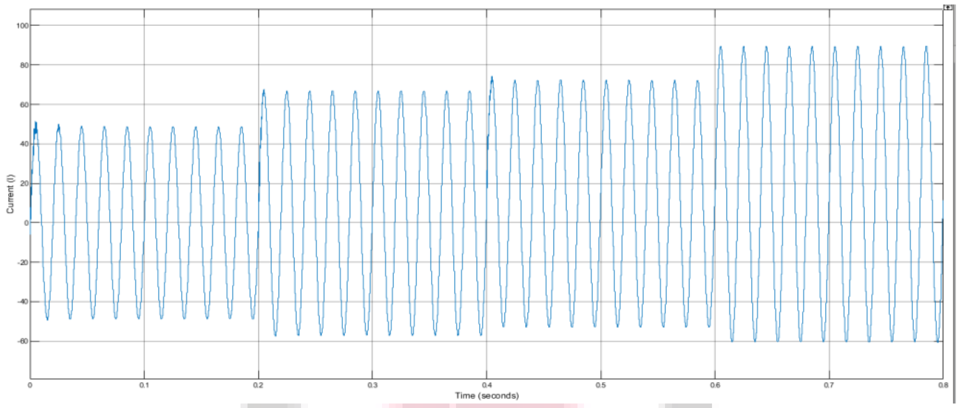

Figure 11: Current drawn with the switching of reactive loads in line in hybrid system with converters having voltage source control

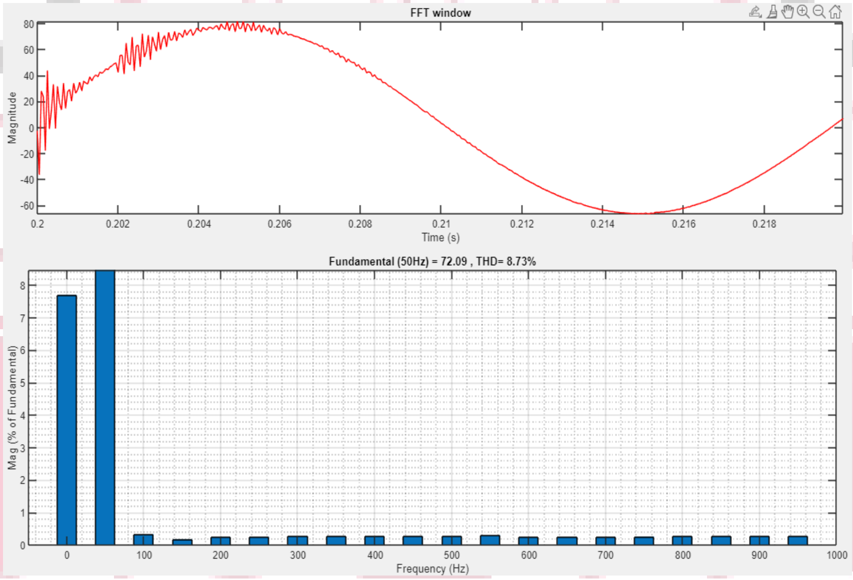

Figure 12: THD% at the switching of RLC load at 0.2 seconds in the hybrid system with converters having voltage source control

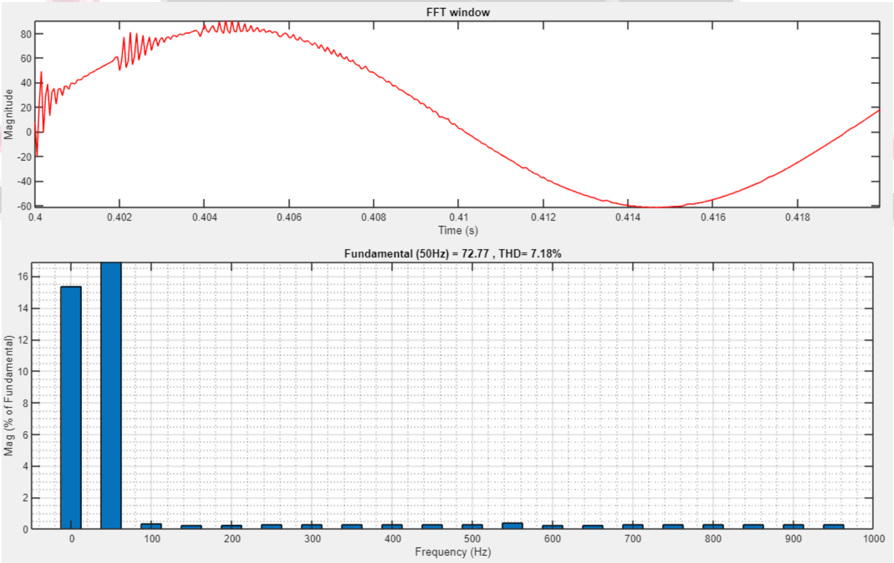

Figure 13: THD% at the switching of LC load at 0.4 seconds in the hybrid system with converters having voltage source control

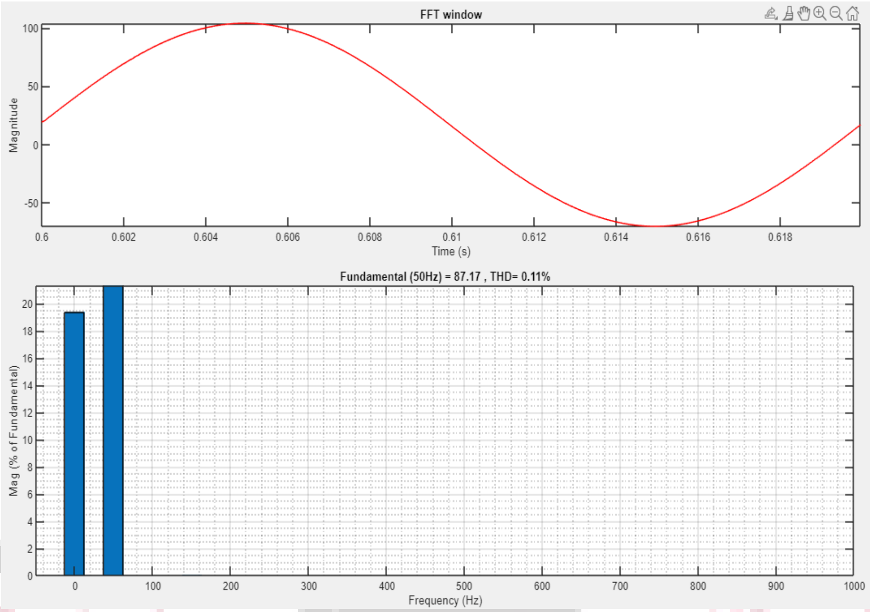

Figure 14: THD% at the switching of RL load at 0.6 seconds in the hybrid system with converters having voltage source control

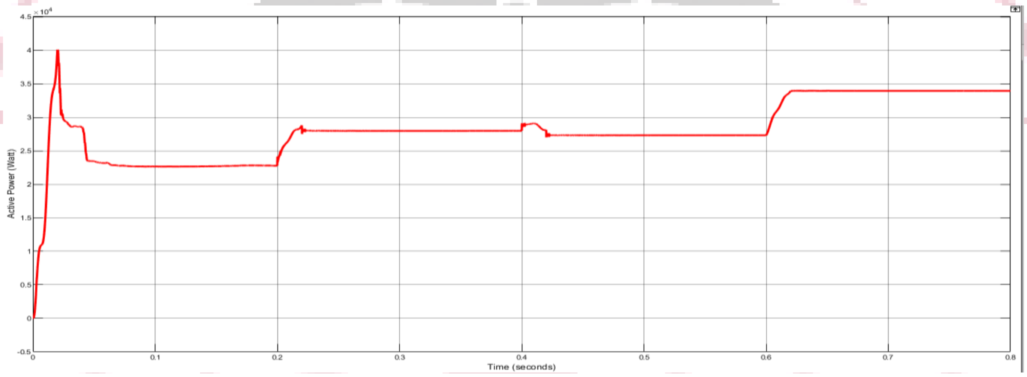

Figure 15: Active power drawn at the loading points with loads switching at different time intervals in hybrid system 1

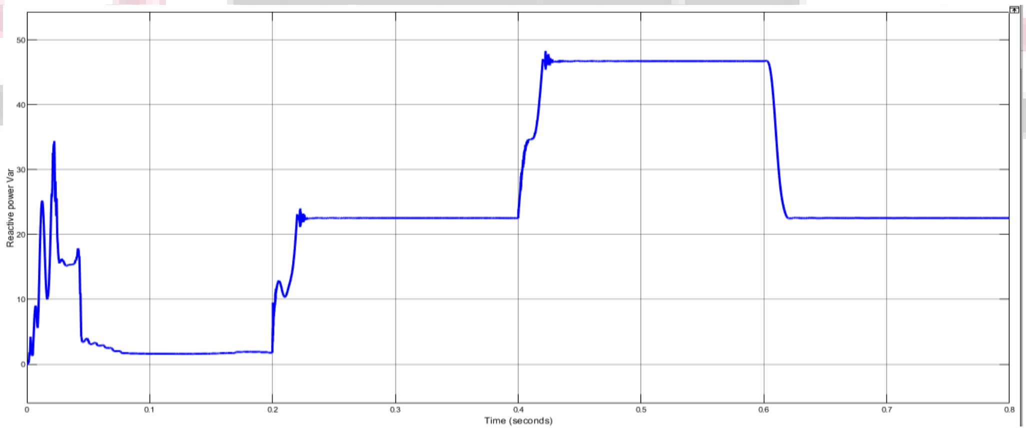

Figure 16: Excessive reactive power available in the line after driving loads in system 1

The reactive power output calculated to be maximum 45 VAR in the system having voltage source control for the inverter for the PV_wind hybrid system at the load points which is presented in figure 16.

B. Case 2: Quality Enhancement of the power distribution at reactive load terminals in a solar/wind hybrid energy system with converters having Programmable Linear_CSA approach.

Programmable linear control with current source amplifiers (Linear_CSA) controls converters in a solar/wind hybrid energy system to ensure stable energy conversion. It ensures compatibility by adjusting the output voltage to match the grid. These amplifiers adjust current and voltage levels in response to output and grid requirements while the control algorithm continuously monitors them. For the transmission of high-quality power, the algorithm also monitors the line power requirements and incorporates safety features like overcurrent and overvoltage prevention.

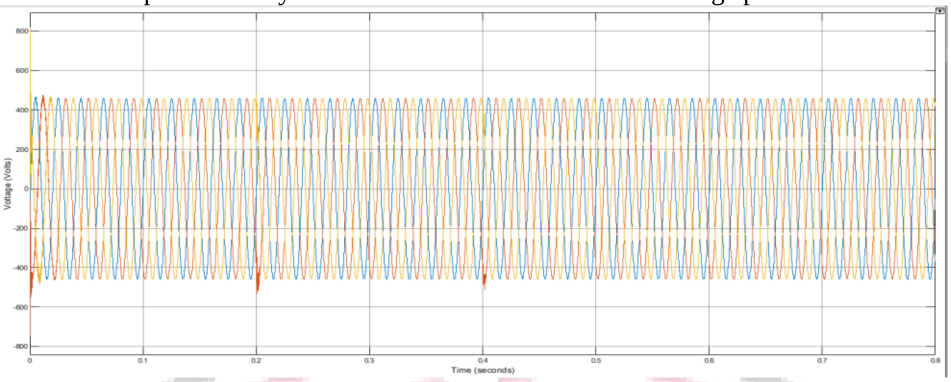

Figure 17: Three phase voltage available in the reactive load line in hybrid system with converters having Programmable Linear_CSA approach

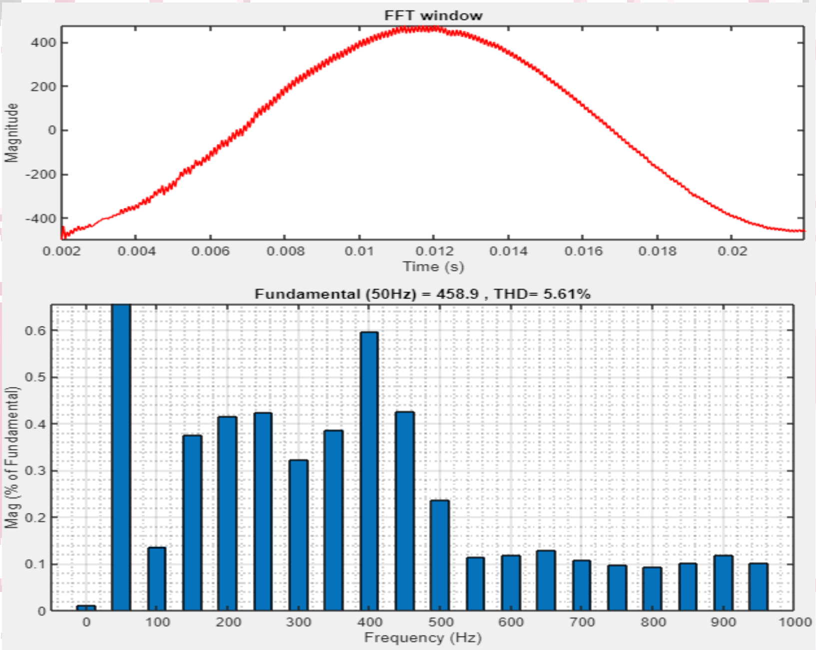

Figure 18: THD% of three phase voltage available in the reactive load line in system 2

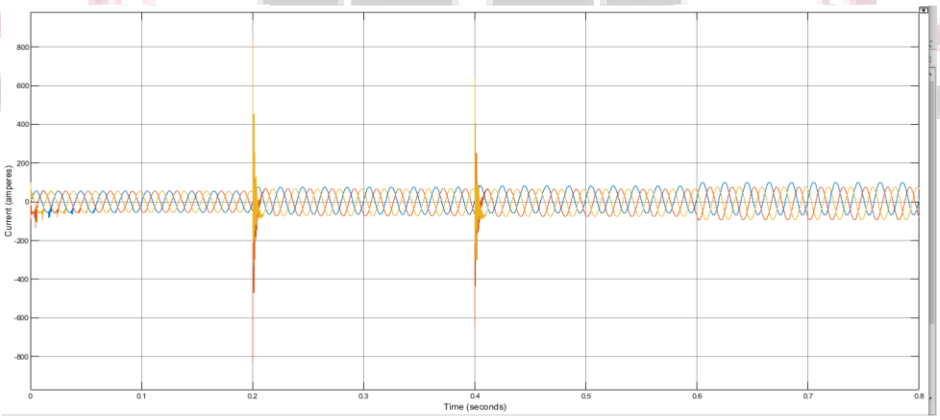

Figure 19: Three phase current available in the reactive load line in hybrid system with converters having Programmable Linear_CSA approach

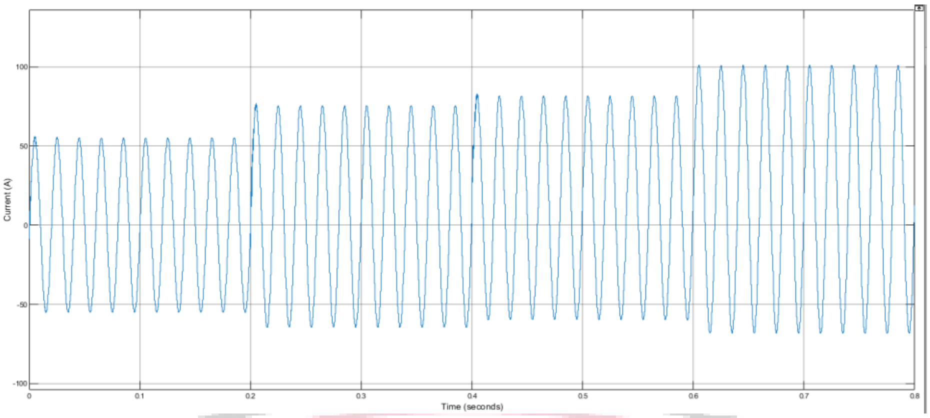

Figure 20: Current drawn with the switching of reactive loads in line in hybrid system with converters having Programmable Linear_CSA approach

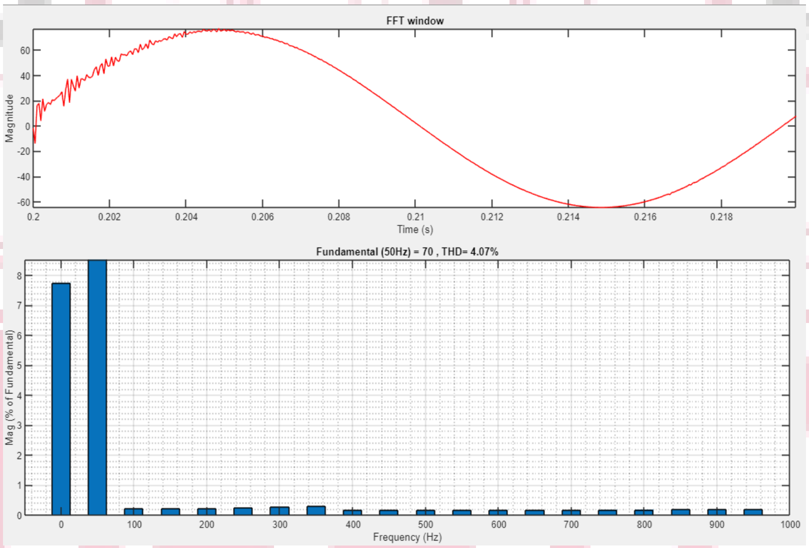

Figure 21: THD% at the switching of RLC load at 0.2 seconds in the hybrid system 2

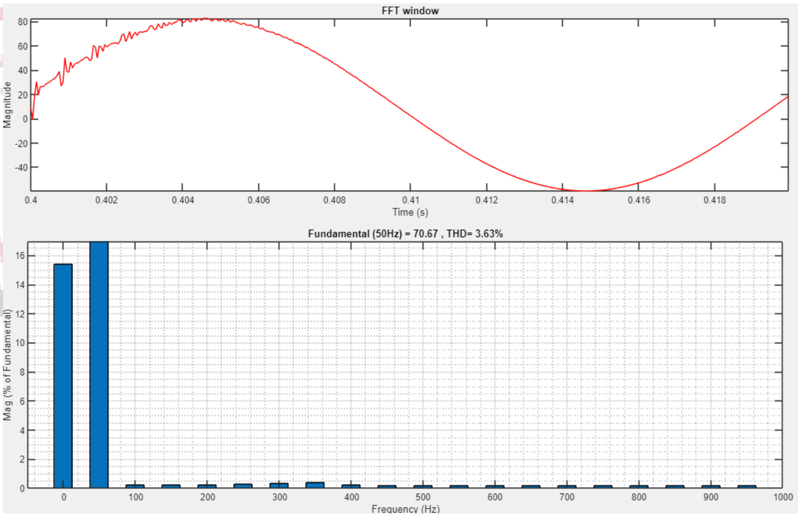

Figure 22: THD% at the switching of LC load at 0.4 seconds in the hybrid system 2

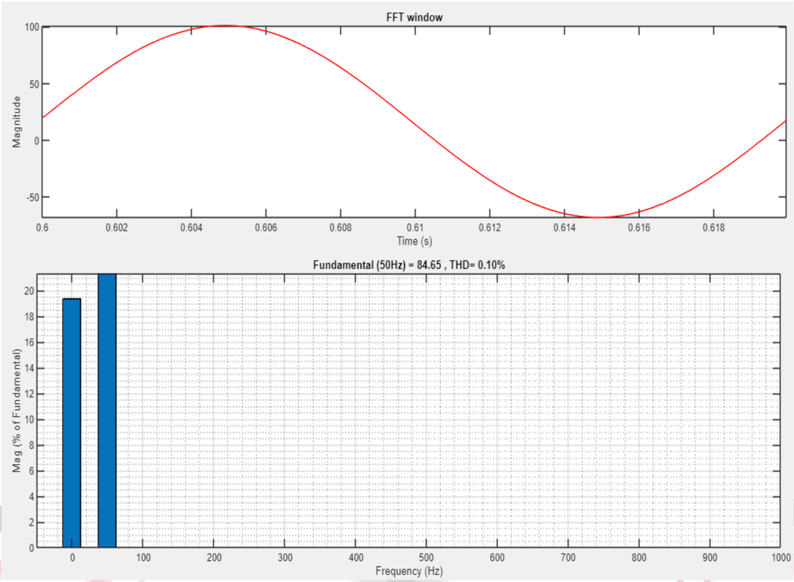

Figure 23: THD% at the switching of RL load at 0.4 seconds in the hybrid system 2

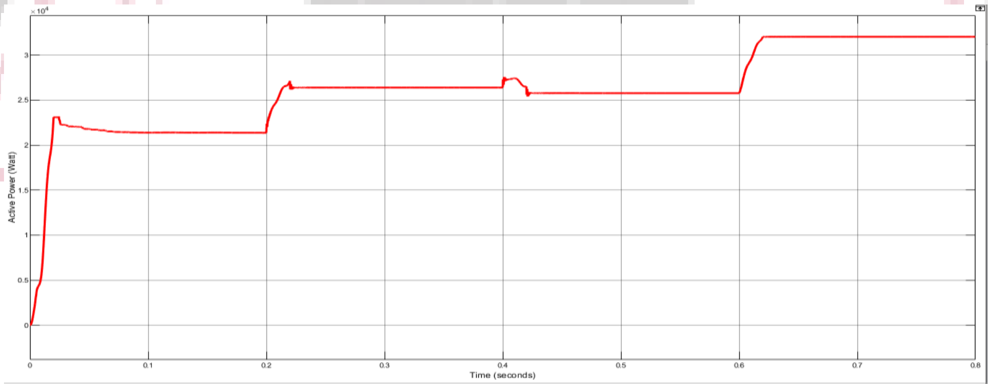

Figure 24: Active power drawn at the loading points with loads switching at different time intervals in hybrid system 2

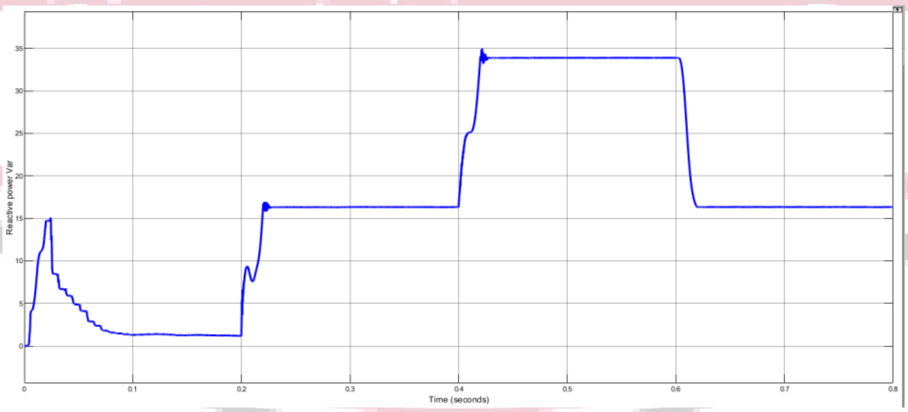

Figure 25: Excessive reactive power available in the line after driving loads in system 2

C. Validation

The system analysis is concluded in this chapter by making comparisons in between the systems designed with inverters driven by voltage source control and the second system having Programmable Linear_CSA approach for driving inverter.

The table 5.1 compares the stability performance of both systems. It studies which strategy exhibits fewer oscillations and deviations in voltage and current during load changes and source transitions.

Table 2: Comparison of quality issues at the load distribution terminal

Parameters	System 1	System 2
THD of Voltage in the load line (%)	7.23	5.61
THD of current of RLC load switching at 0.2 seconds (%)	8.73	4.07
THD of current of LC load switching at 0.4 seconds (%)	7.18	3.63
THD of current of RL load switching at 0.6 seconds (%)	0.11	0.10
Reactive power (Var)	Maximum 45	Maximum 36

V. CONCLUSION

Incorporating renewable energy sources into a solar-wind hybrid system that is implemented using MATLAB may have certain benefits, as this research highlights. Through the creation of realistic models and accurate control procedures, the main objective is to demonstrate how hybrid systems outperform solo solar or wind installations in terms of efficiency, dependability, and sustainability. The practical use of hybrid energy systems is significantly affected by these findings, providing the way to a more dependable and ecologically responsible energy future. The study also explores how reactive loads affect voltage levels in the power system, highlighting how they may affect machinery, result in inefficiencies, or even lead to blackouts because of voltage fluctuations.

The research makes sure that voltage levels stay within reasonable bounds by closely monitoring reactive loads with the use of two controllers, which promotes system stability overall. Additionally, multiple reactive load scenarios, such as RLC, LC, and RL, were evaluated at various time intervals, with observable decreases in Total Harmonic Distortion (THD%) achieved by the suggested Programmable Linear_CSA technique for the inverter. The available reactive power was also significantly increased as a result of this strategy, and the line voltage distortion was also significantly decreased. This strategy eventually increased inverter operational stability and ensured a reliable and constant power supply.

REFERENCES

[1] Kumar. J, C.R., Majid, M.A. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. Energ Sustain Soc 10, 2. https://doi.org/10.1186/s13705-019-0232-1

[2] Venkatasamy, B., & Kalaivani, L. (2018). Performance analysis of grid- tie inverter for reactive power injection mode in hybrid wind solar energy system Conference 2nd International Conference on Trends in Electronics and Informatics (ICOEI).

[3] Aleem, Sk. A., Hussain, S. M. S., & Ustun, T. S. (2020). A review of strategies to increase PV penetration level in smart grids. Energies, 13(3), 636. https://doi.org/10.3390/en13030636

[4] Sowmya Sree, Vemuri and Ankarao, Mogili. (2023). Power quality enhancement of solar–wind grid connected system employing genetic-based ANFIS controller. Paladyn, Journal of Behavioral Robotics, 14, 1, 20220116. https://doi.org/10.1515/pjbr-2022-0116

[5] R. Pavan Kumar Naidu, S. Meikandasivam, (2020). Power quality enhancement in a grid-connected hybrid system with coordinated PQ theory & fractional order PID controller in DPFC, Sustainable Energy, Grids and Networks, 21 , 100317, ISSN 2352-4677, https://doi.org/10.1016/j.segan.2020.100317.

[6] Arjun Kumar, Shivashankar, Keshavamurthy, (2021). Design and control of autonomous hybrid wind solar system with DFIG supplying three-phase four-wire loads, Ain Shams Engineering Journal, 12, 3, 2875-2890, ISSN 2090-4479, https://doi.org/10.1016/j.asej.2020.11.027.

[7] Naggar H.Saad, Ahmed A.El-Sattar (2018). A novel control strategy for grid connected hybrid renewable energy systems using improved particle swarm optimization. Ain Shams Engineering Journal. 9, 4, 2018, 2195-2214.

[8] Amir Mushtaq Palla, Nipun Aggarwa. (September 2019). Design of Hybrid Grid-Connected Inverter for Renewable Energy Generation with Power Quality Conditioning. International Journal of Recent Technology and Engineering (IJRTE) 8, 3, ISSN: 2277-3878.

[9] Li-Yuan Liu, Jun-Ting Gao and Kuo-Yuan Lo, (June 2017). A Reactive Power Control Strategy of the Grid-Connected Inverter for Microgrid Application", Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia) IEEE 3rd International 10.1109/IFEEC. 2017.7992134,.

[10] C.-H. Chang, Y.-H. Lin, Y.-M. Chen, and Y.-R. Chang, (2014). Simplified reactive power control for single-phase grid-connected photovoltaic inverters, IEEE Trans. Ind. Electron., 61, 5, 2286-2296, 2014.