AI Based Converter Control Design for Power Quality Enhancement in Common AC Line Solar-Wind Hybrid System

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Abstract: *Solar wind hybrid systems are a promising solution to address the intermittency of renewable energy sources and ensure a stable and reliable energy supply. These systems combine the benefits of solar and wind energy to provide a more consistent energy output. However, integrating the system with the common AC line is crucial to ensure that the energy produced is usable by consumers. The development of a control system for a DC/AC converter in a hybrid system using AI is an emerging field that holds great promise for improving the efficiency and reliability of renewable energy systems. MATLAB has been used as a platform for developing AI-based control systems that can optimize the performance of the DC/AC converter. AI-based control systems use machine learning algorithms to learn the behavior of the system and adjust the control strategy accordingly. This enables the system to adapt to changing conditions in real-time, improving its efficiency and reducing its environmental impact. In this context, MATLAB offers a suite of AI and machine learning tools that has been used to develop predictive models, optimize control strategies, and automate the control of the DC/AC converter in our work using the reinforcement learning (RL) tool. The work observed Enhancement in the power outcomes from 17020 watts in the system having voltage reference-based converter controller whose reference signal is generated using the space vector modulation to 17800 watts in the system where the controller has been changed to Q learning based reinforcement learning for adaptive control of the inverters that accounts for an improvement of 4.5% in the active power. This accounts for an improvement in the power factor of the system from 0.89 to 0.93.*

Keywords: *Solar/wind hybrid energy system, micro grid, grid integration, DC/Converter, Reinforcement Learning, Quality control.*

I.INTRODUCTION

Microgrid is introduced by USA's CERTS (Consortium for Electric Reliability Technology Solutions) to improve consumer confidence and power quality. Microgrids, defined as power systems which include loads, distributed generation, energy storage and are managed as a single unit in order to exchange power with the grid through a single coupling point, are becoming a way of integrating renewable energies, lowering costs and providing better grid quality all around the world. The microgrid configuration can be dc, ac, or hybrid. The ac microgrid is more focused nowadays due to its ability to operate in conjunction with main grid, simple structure and cost effectiveness.[7] The inverter act as an interface between distributed energy resources and utility grid. Energy from the DG is to be controlled as per load requirement and hence there should be a control scheme to regulate the power flow from the DG and maintain quality and reliability of supply. Most of the renewable energy sources are usually equipped with DC/AC inverters which form a system of parallel inverters, The prominent features that affect the parallel operation of inverters are load sharing capability, voltage harmonic distortions, line impedance, active power filtering. Research work on control of parallel inverters evolved in the early 1980s for the uninterruptible power supply application and protracted with the emergence of microgrid technology during the past decade. The aim of the grid-connected inverter is to export controllable power with the established voltage. The generated power is controlled by the in-phase current component which is proportional to the network power demand. The supervisory controller (SC), receiving power demand information from short-term/long-term prediction values, operates DG units either in a constant power output or in a load-following manner.

A. Characteristics of Micro grids

The high penetration of DG units in a distribution network causes several technical and operational issues, including power quality, network stability, low inertia, and network voltage and fault level change. To overcome the above issues, a micro grid concept has evolved . However, the notion of micro grids is often confused with distribution network control. The key differences with a micro grid are that it has a central control unit with a specific region and a point of common coupling (PCC) to connect and disconnect the micro grid with the grid utility. The features of a typical micro grid are summarised as follows.

It supervises the electrical components, such as powers, voltages and frequencies by means of monitors.
It has a PCC in a distribution network for connecting and disconnecting the grid utility.
It is a subset of LV or medium-voltage (MV) distribution networks.
It consists of generation units, a hierarchical control approach, power consumption places and energy storage systems.
It facilitates an uninterrupted power supply to, at least, the highest priority loads during a grid failure or power quality degradation.
It has two operating modes: (1) grid-connected; and (2) islanded or standalone (autonomous).
It acts as a single controllable entity from the grid perspective.

B. Islanded Operation

The lack of the grid utility supply to a micro grid operation necessitates establishing the reference voltage and frequency. Therefore, DG units operated in an islanded micro grid are responsible for ensuring the reference voltage and frequency, which are the main functions of the inverters

By incorporating renewable energy systems with utility grids, the power distribution model has been moved towards a decentralized structure, resulting in the research of hybrid micro grids. In DC systems, power electronic-based distributed generator (DG) and energy storage of static devices, such as batteries, is more efficiently used. However, AC systems still dominate most of the loads in the power system. This encourages the development of hybrid micro grids combining the benefits of DC and AC systems.

II.LITERATURE REVIEW

JayaprakashKarsh et. al. (2019) [1] Micro grids are emerging as one of the promising solutions to integrate various types of distributed renewable energy sources with the utility grid. Though the existing grids are AC grids, today's electrical loads comprising of power electronic based equipment and distributed renewable energy generation make DC micro grids more attractive. However, an individual AC micro grid and DC micro grid requires multiple conversions of power at the user end for DC loads and AC loads respectively, resulting in less efficient system. Thus, hybrid AC/DC micro grid seems to be the best solution to avoid substantial energy losses in multiple conversions. However, there are several technical challenges in the implementation of hybrid AC/DC micro grid, which need to be addressed. This paper presents a review of hybrid AC/DC micro grid and discusses the important key issues and challenges to be overcome for its practical implementation.

Sohrab Mirsaeidi et. al. (2017) [2]Micro grid is a convenient, reliable, and eco-friendly approach for the integration of Distributed Generation (DG) sources into the utility power systems. To date, AC micro grids have been the most common architecture, but DC micro grids are gaining an increasing interest owing to the provision of numerous benefits in comparison with AC ones. These benefits encompass higher reliability, power quality and transmission capacity, non-complex control as well as direct connection to some DG sources, loads and Energy Storage Systems (ESSs). In this paper, main challenges and available approaches for the protection of AC and DC micro grids are discussed. After description, analysis and classification of the existing schemes, some research directions including coordination between AC and DC protective devices as well as development of combined control and protection schemes for the realization of future hybrid AC/DC microgrids are pointed out.

Shanmugapriya, V et. al. (2021) [3] A micro grid is a conventional breakthrough for the present power grid. A micro grid generally comprises micro sourcesss with diversity such as Solar, Wind, Fuel cells, generators, loads, and storage devices. Micro grid competency has strengthened the grid system by employing green energy to supply excessive load to customers at their premises. This potentiality of the micro grid to the extent has reduced transmission losses and huge investments incurred for the transmission lines. Although micro grid possesses more advantages in the current scenario, the issue arises in the protection and stability when connected with the existing grid. The conventional protection schemes oversight the faults in a microgrid due to varied fault current levels for various operating modes, bidirectional power flow, and renewable energy sources intermittency. The major issues arise in fault detection and identification particularly in an Inverter-based microgrid (IBMG). In this paper, a systematic evaluation of microgrids giving an insight into AC and DC microgrids is presented. Furthermore, the recent developments in AC and DC microgrid protection schemes are comprehensively discussed and classified. Prospective improvements for protection techniques in the future are suggested at the end of this paper.

Ortiz L et. al. (2019) [4] In this paper, a Microgrid (MG) test model based on the 14-busbar IEEE distribution system is proposed. This model can constitute an important research tool for the analysis of electrical grids in its transition to Smart Grids (SG). The benchmark is used as a base case for power flow analysis and quality variables related with SG and holds distributed resources. The proposed MG consists of DC and AC buses with different types of loads and distributed generation at two voltage levels. A complete model of this MG has been simulated using the MATLAB/Simulink environmental simulation platform. The proposed electrical system will provide a base case for other studies such as: reactive power compensation, stability and inertia analysis, reliability, demand response studies, hierarchical control, fault tolerant control, optimization and energy storage strategies.

III. OBJECTIVES

The work proposes to attain following key objectives from the research:

- Designing of a grid integrated solar wind hybrid energy system with common AC line for driving loads for improving its reliability and efficiency.
- Designing an inverter control that attains lower distortion level in the voltage as well as current waveforms.
- Designing of an effective artificial intelligence based algorithm that accommodates the fluctuations at the loading points.
- Improvement in the reactive power output from the system by the inverter control by designed hybrid system that can compensate the reactive power requirement when required.

IV. METHODOLOGY

The development of an AI-based control system for a DC/AC converter in a hybrid system using MATLAB is an exciting area of research that has the potential to significantly improve the efficiency and performance of the system. AI-based control systems can learn from data and adapt to changing conditions, making them more flexible and robust compared to traditional control systems. In this context, MATLAB provides a range of machine learning and deep learning tools that can be used to develop AI-based control systems for the DC/AC converter in a hybrid system. These tools enable the creation of models that can learn from data and optimize the performance of the system in real-time. The AI-based control system can be used to regulate the flow of energy between the different components of the hybrid system, including the solar panels, wind turbines, batteries, and loads, by predicting the energy demand and optimizing the operation of the converter accordingly. The use of an AI-based control system can improve the efficiency and reliability of the hybrid system, reduce costs, and minimize the environmental impact of energy generation.

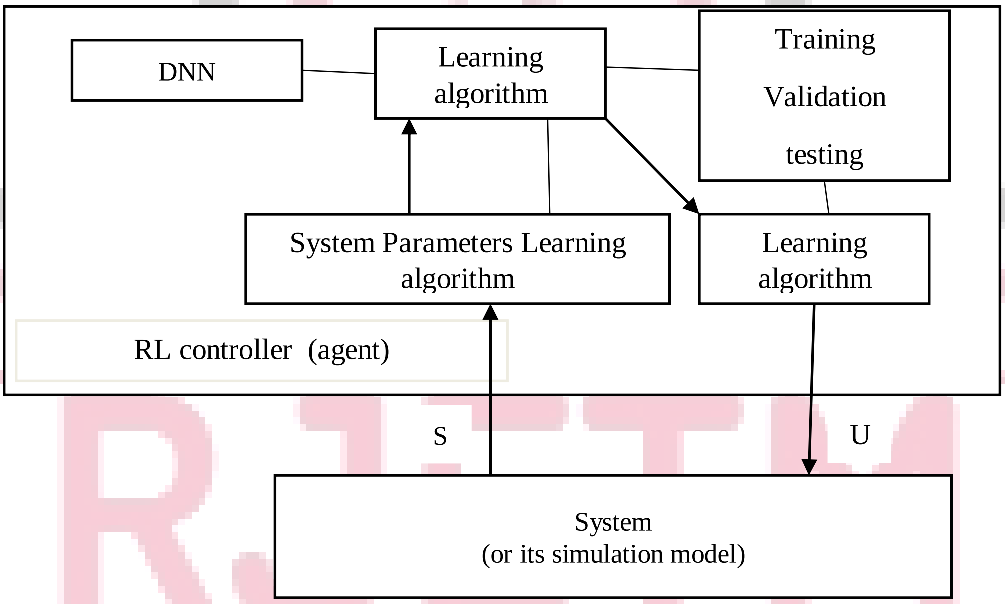

Fig. 1 A general framework of RL with modification for DC/AC inverter

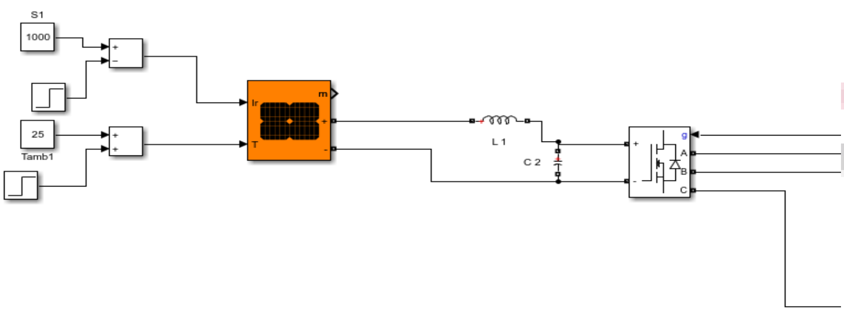

Fig. 2 Modeled solar system

4.1 MATLAB/SMILULINK Description of Wind Energy System

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modeled by the following equations.

Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3$$

Where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2),$C_p$is the coefficient of power conversion and v is the wind speed (in m/s).

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

Where ω_m and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.
The wind turbine mechanical torque output m T given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tip speed ratio λ and the blade pitch angle β (in degrees). Then Power output is given by

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics is defined as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

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.

V. SIMULATION RESULTS

A solar wind hybrid system with a common AC line is a renewable energy system that combines the power output of both solar panels and wind turbines to generate electricity. The common AC line refers to the single line used to connect the system to the grid or the load. In this system, the solar panels and wind turbines are connected to a charge controller that regulates the power output.

The advantage of a solar wind hybrid system with a common AC line is that it can provide a more consistent and reliable power output compared to a standalone solar or wind system. Additionally, the combination of solar and wind power can better match the power demand throughout the day and night, and during different seasons, providing a more stable source of electricity. To model a grid-connected solar wind hybrid system with a common AC line in MATLAB, these steps are being followed:

- Determination of the power output of the solar panels and wind turbines based on their respective characteristics and the available solar and wind resources.
- Combining the power output of the solar panels and wind turbines to get the total power output of the system.
- Conversion of the DC power output of the solar panels and wind turbines to AC power using inverters.
- Connection of the inverters to a common AC line, which is connected to the electrical grid.
- Simulating the system using MATLAB's Simulink tool by modeling the solar panels, wind turbines, inverters, and the common AC line. MATLAB's power system blockset are being used to model the electrical grid, including the distribution lines, transformers, and loads.
- Simulating the system under different operating conditions, such as changes in solar and wind resources, to analyze its performance.

The analysis of the system has been done by deriving two controllers for controlling the output powers of the DC/AC converters. The system 1 which contains voltage reference based converter controller whose reference signal is generated using the space vector modulation and the system 2 where the controller has been changed to Q learning based reinforcement learning for adaptive control of the inverters. First the power quality analysis using the two systems are being done in case 1 and in case two the two systems are analyzed for handling the harmonics in during the load switching analysis.

Case 1: Power and Quality Analysis of Converter system

The inverter proposed is designed to improve the active power output from the system as well as to make it a stable output. The inverter converts the input DC to AC and then it is connected to the transformer for its integration with the grid system. The various loads are also connected to this system. As the active power output is enhanced by using proposed reinforcement learning for controller designed for the inverter the loads of higher rating can also be connected to this system.

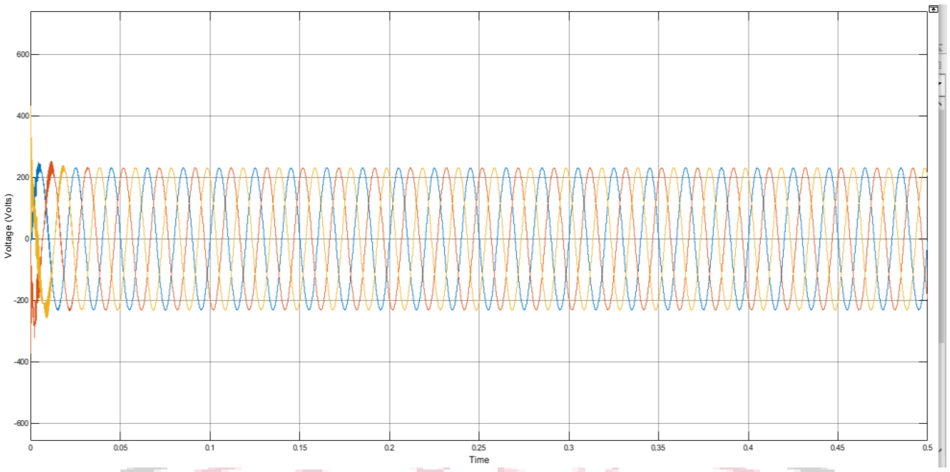

Fig. 3 AC voltage available in the hybrid system having voltage reference based converter controller

The figure 3 depicts the three phase AC voltage presented by three colors for each phase. This voltage output is 230 V in system with voltage reference based converter controller.

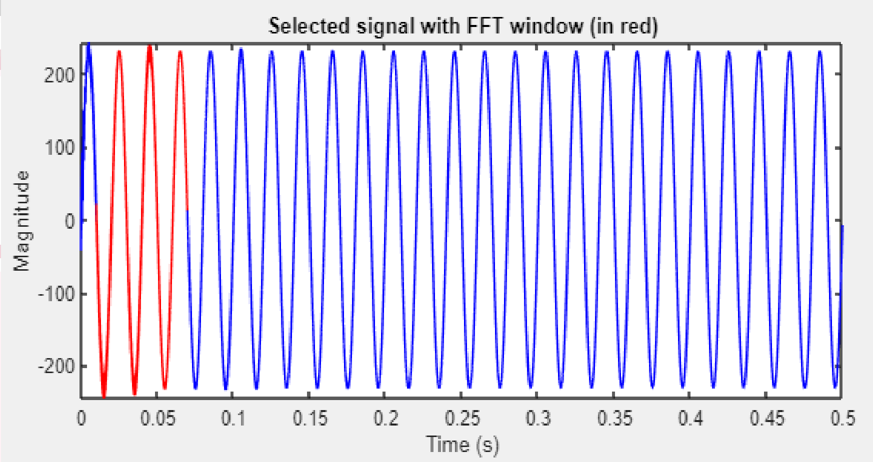

Fig. 4 FFT analysis of AC voltage available in the hybrid system having voltage reference based converter controller

The figure 4 depicts the FFT analysis of the three phase AC voltage for each cycle in the system which is analyzed with controller driven voltage reference based converter and is further used for calculating the total harmonic distortion level.

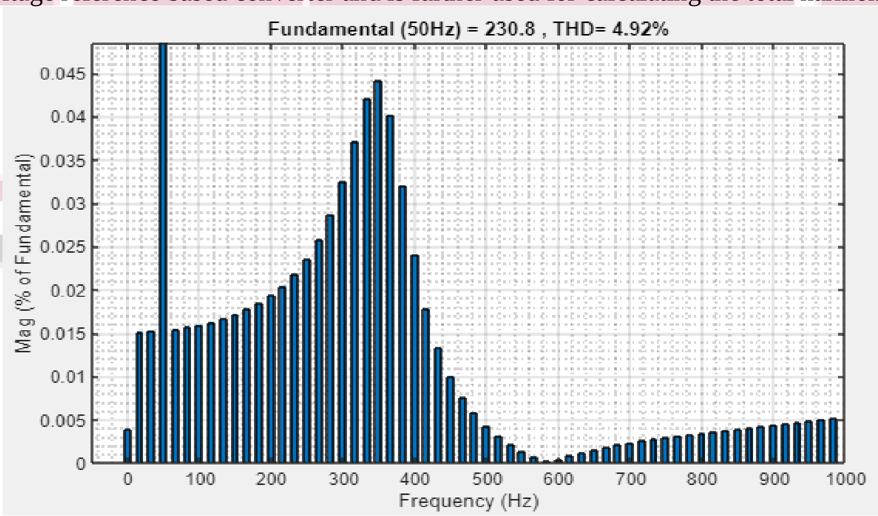

Fig. 5 THD% in AC voltage available in the hybrid system having voltage reference based converter controller

The THD% is calculated in the software which comes to be 4.92% in voltage waveform in system having converter control regulation achieved by voltage reference based controller and lower order harmonics are found in them which is represented in figure 5.

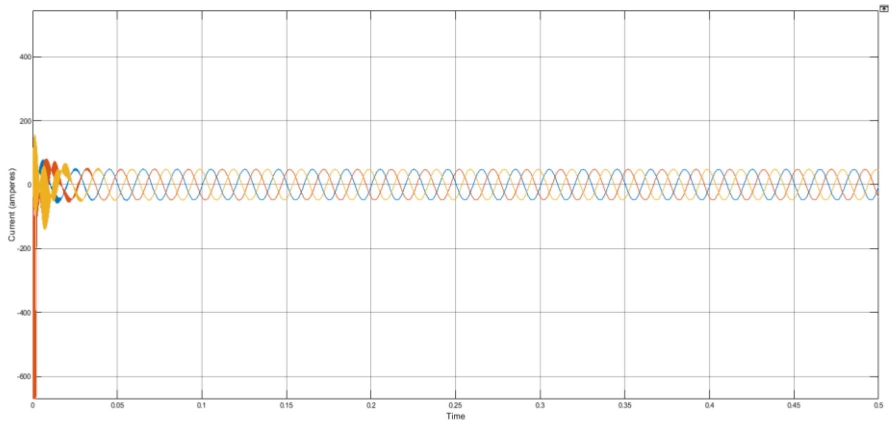

Fig. 6 AC Current available in the hybrid system having voltage reference based converter controller

The figure 6 represents the three phase AC current represented by three colors for each phase. This current output is found at the loading points in hybrid system with controller driven by voltage reference based control and was found to be approximately 48 A

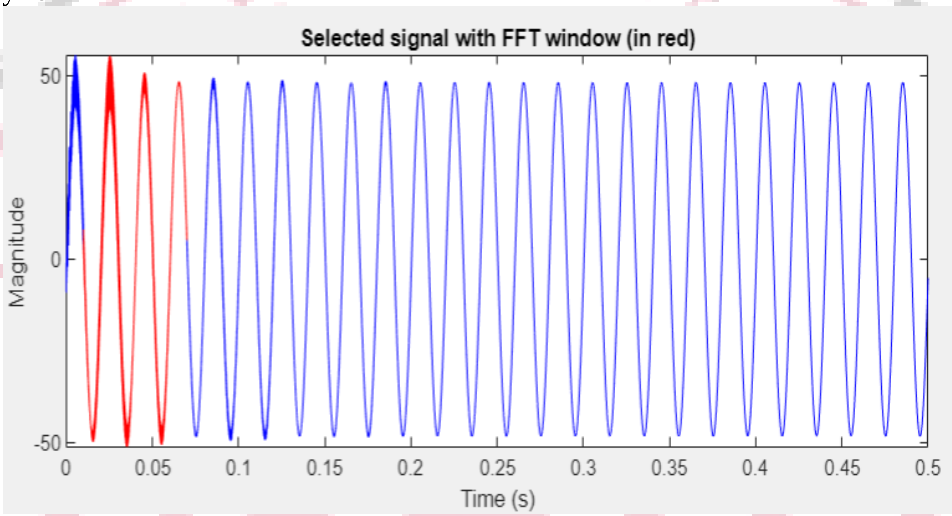

Fig. 7 FFT analysis of AC Current available in the hybrid system having voltage reference based converter controller

The figure 7 depicts the FFT analysis of the three phase AC current for each cycle in the system which is analyzed with controller driven by voltage reference based control and is further used for calculating the total harmonic distortion level

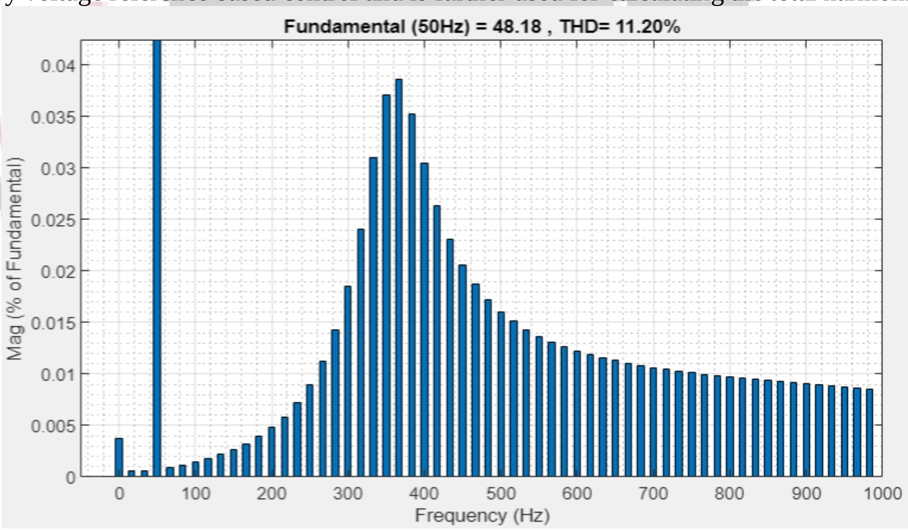

Fig. 8 THD% in AC Current available in the hybrid system having voltage reference based converter controller

The THD% is calculated in the software which comes to be 11.20% in current waveform in system having converter control regulation achieved by voltage reference based control and higher order harmonics are found in them which is represented in figure 8.

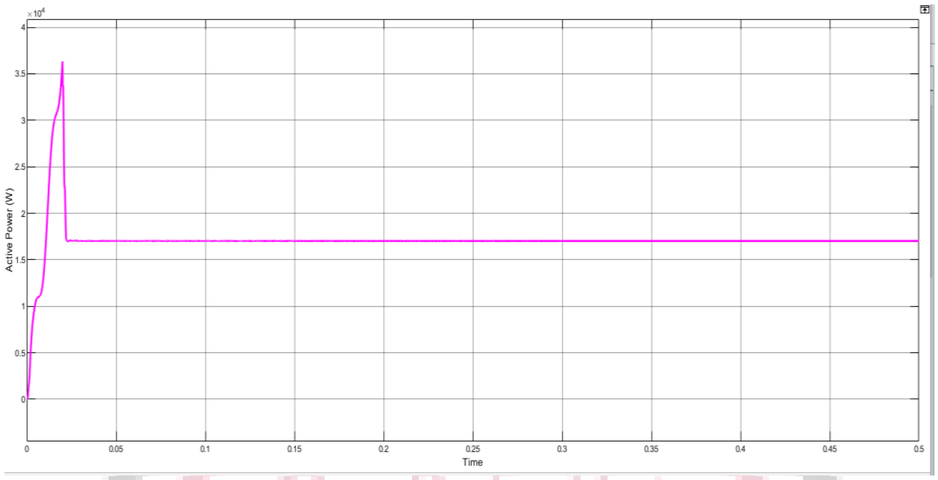

Fig. 9 Active Power available in the hybrid system having voltage reference based converter controller

The active power output calculated to be approximately 17020 W in the system having voltage reference based control for the inverter for the hybrid system at the load points which is presented in figure 5.7.

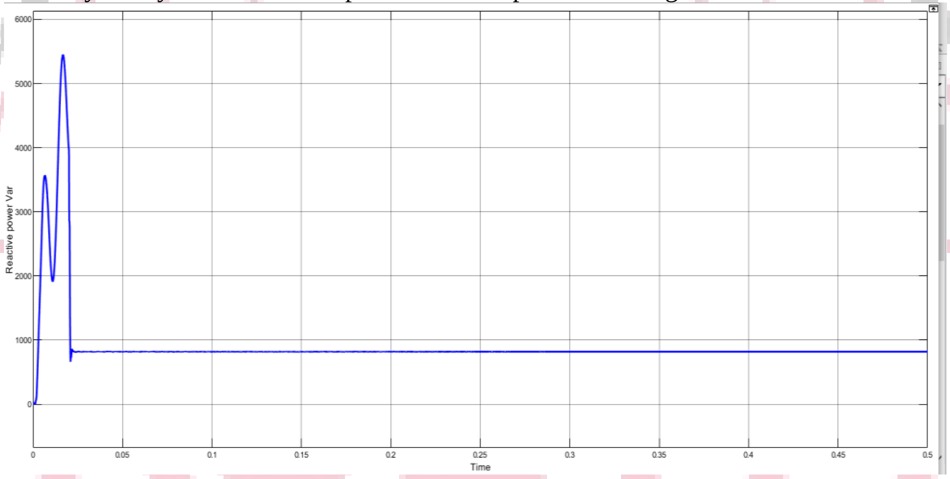

Fig. 10 Reactive Power in the hybrid system having voltage reference based converter controller

The reactive power output calculated to be approximately 817.8 VAR in the system having voltage reference based controller for the inverter for the hybrid system at the load points which is presented in figure 10.

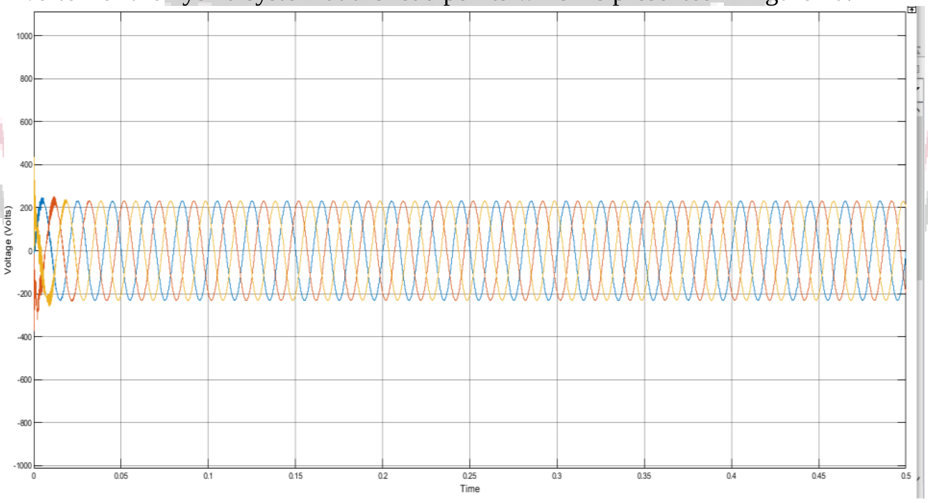

Fig. 11 AC voltage in the hybrid system having proposed Reinforcement learning based converter controller

The figure 11 represents the three phase AC voltage which are represented by three colors for each phase and magnitude approximately 230 V. This voltage output is analyzed with controller driven by proposed Reinforcement learning based converter controller.

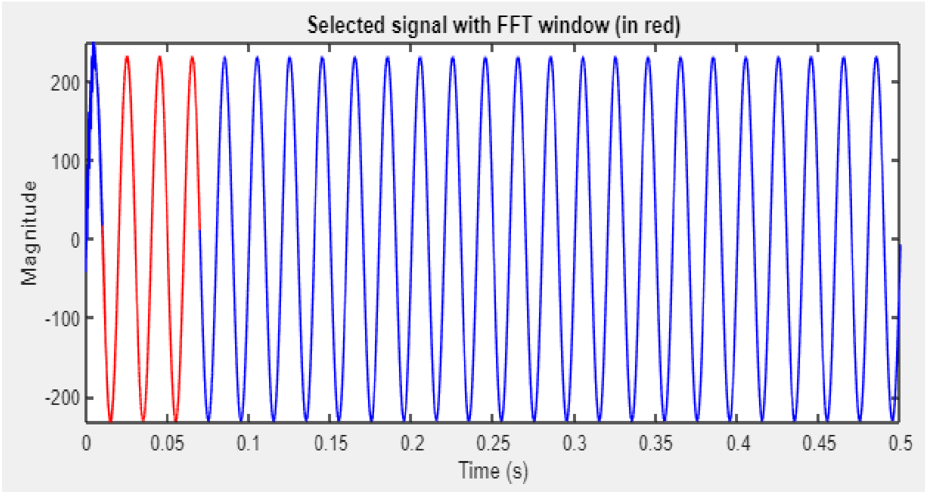

Fig. 12 FFT analysis of AC voltage in the hybrid system having proposed Reinforcement learning based converter controller

The figure 12 depicts the FFT analysis of the three phase AC voltage for each cycle in the system which is analyzed with controller driven by proposed Reinforcement learning based converter and is further used for calculating the total harmonic distortion level in this system

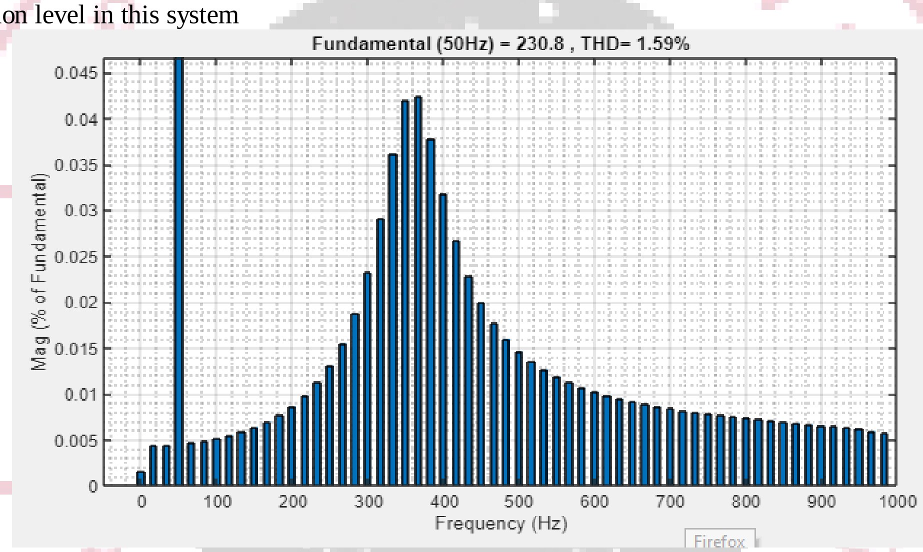

Fig. 13 THD% in AC voltage in the hybrid system having proposed Reinforcement learning based converter controller

The THD% is calculated in the software which comes to be 1.59 % in voltage waveform in system having converter control regulation achieved by proposed Reinforcement learning technique and higher order harmonics are reduced in them.

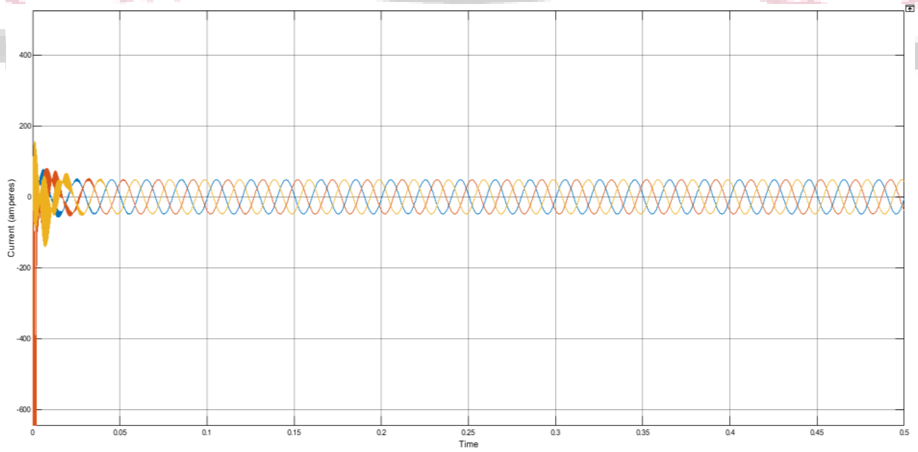

Fig. 14 AC current drawn in the hybrid system having proposed Reinforcement learning based converter controller

The figure 14 represents the three phase AC current represented by three colors for each phase. This current output is found after converter control in hybrid system with Reinforcement learning based converter controller and was found to be approximately 48 A.

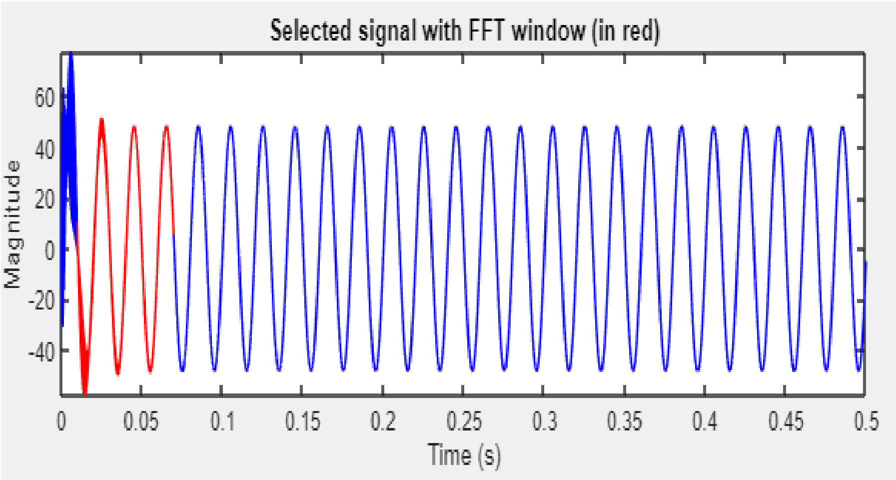

Fig. 15 FFT analysis of AC current drawn in the hybrid system having proposed Reinforcement learning based converter controller

The figure 15 depicts the FFT analysis of the three phase AC current for each cycle in the system which is analyzed with controller driven by Reinforcement learning control and is further used for calculating the total harmonic distortion level in system.

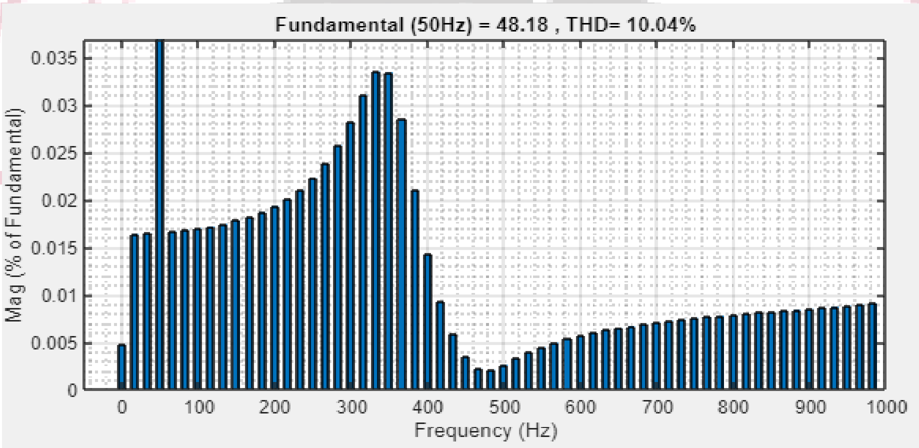

Fig. 16 THD% of current drawn in the hybrid system having proposed Reinforcement learning based converter controller

The THD% is calculated which comes to be 10.14% in current waveform in system having converter control regulation achieved by proposed Reinforcement learning approach and lower order harmonics are found in them which is represented in figure 16.

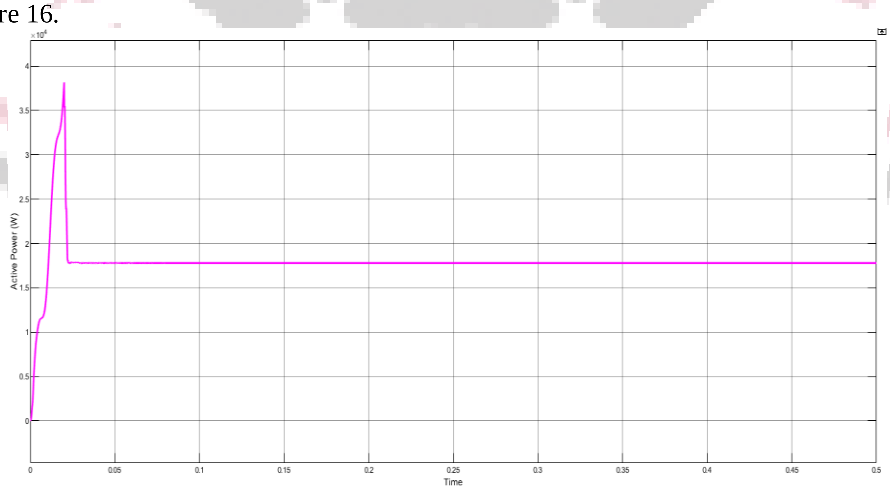

Fig. 17 Active Power available in the hybrid system having proposed Reinforcement learning based converter controller

Figure 17 shows the active power output calculated to be approximately 17800 W in the system having Reinforcement learning approach for the inverter at the hybrid system integration points.

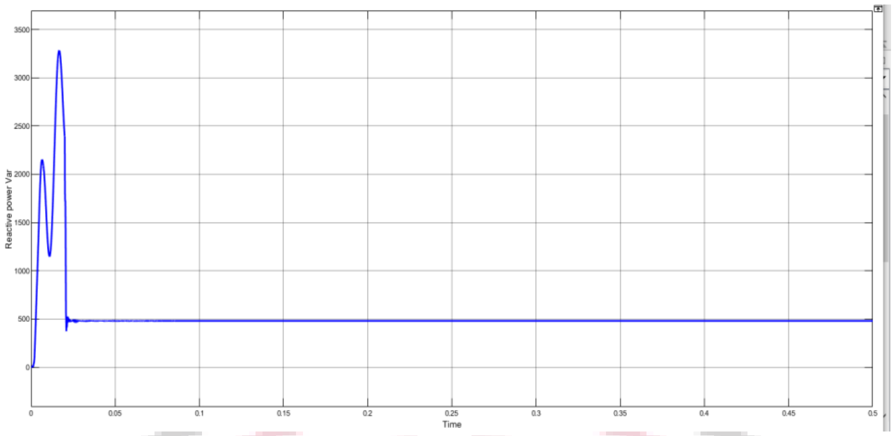

Fig. 18 Reactive Power in the hybrid system having proposed Reinforcement learning based converter controller

The reactive power output calculated to be approximately 480 VAR in the system having proposed Reinforcement learning based controller for the inverter for the hybrid system at the hybrid system integration points which is presented in figure 18.

A Case 2: Loading and Off-loading Switching of Dynamic Loads

For this analysis the changes in the current waveform was analyzed at the interval when the load was switched into the line suddenly. For this purpose three phase line breaker was used along with the dynamic motor load whose initial state remains at off condition. At 0.1 seconds the breaker switches its state to on and the load gets connected to the line. The line voltage remains the same tat is 230 Volts. The changes in the current waveform were studied by analyzing the THD level in current waveform due to sudden loading of line. The load is suddenly removed from the line at 0.2 seconds and the corresponding changes in the current waveforms are observed.

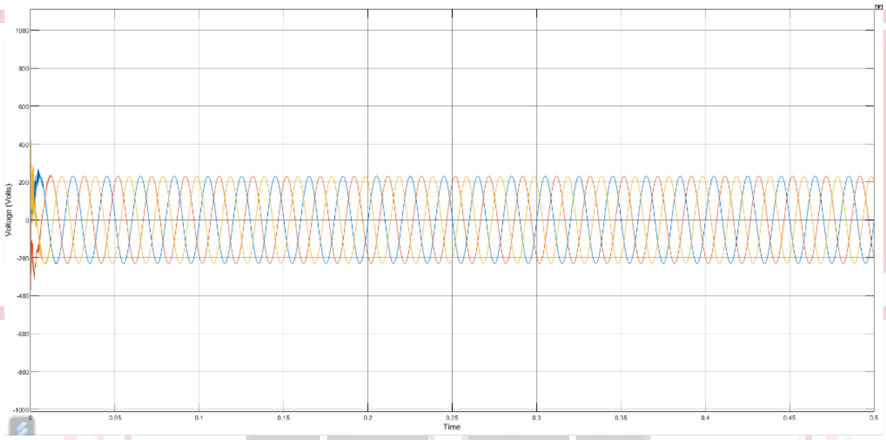

Fig. 19 AC voltage available at the loading points in hybrid system with voltage reference-based converter controller

Figure 19 shows the loading conditions analysis which results in no changes in the line voltage waveform at the loading and offloading points in system driven with voltage reference-based converter controller

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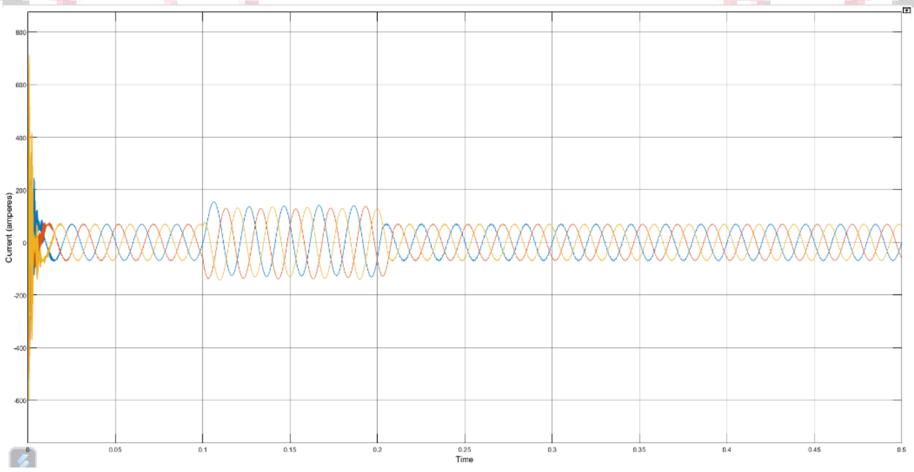

Fig. 20 Current drawn at the loading points in hybrid system with voltage reference-based converter controller

Figure 20 shows the loading conditions analysis which results in changes in the current waveform at the loading and offloading points in system driven with voltage reference-based converter controller.

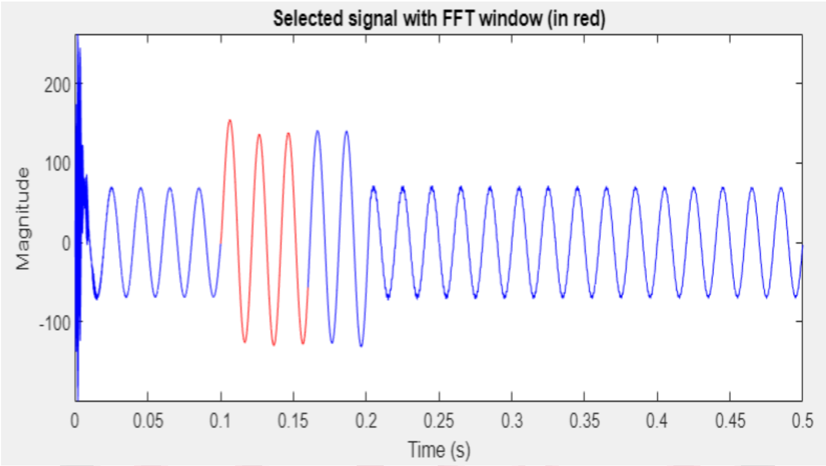

Fig. 21 FFT evaluation at loading point in hybrid system with voltage reference-based converter controller

The FFT analysis of current at the point where the loading is done at 0.1 seconds and the current rises at this point is represented by Figure 21 for each cycle and then the distortion is measured in the current at this point in system driven with voltage reference-based converter controller.

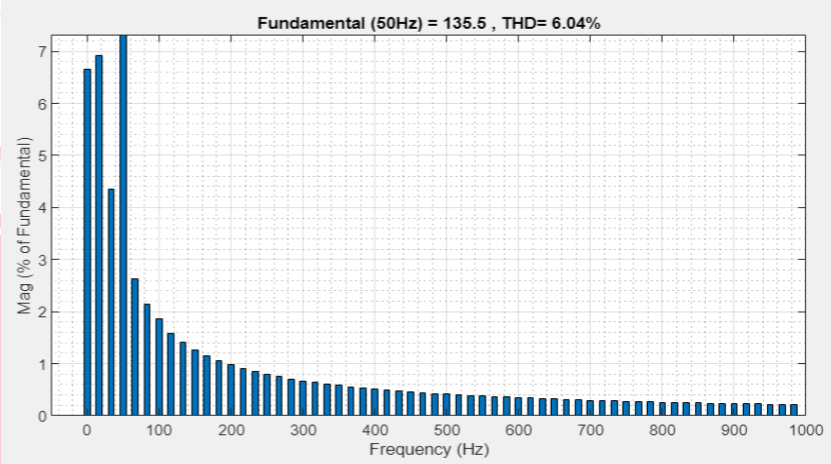

Fig. 22 THD% evaluation at loading point in hybrid system with voltage reference-based converter controller

The total harmonic distortion calculated in the current waveform at the loading point is being represented by figure 22 in system driven with voltage reference-based converter controller which comes to be 6.04%

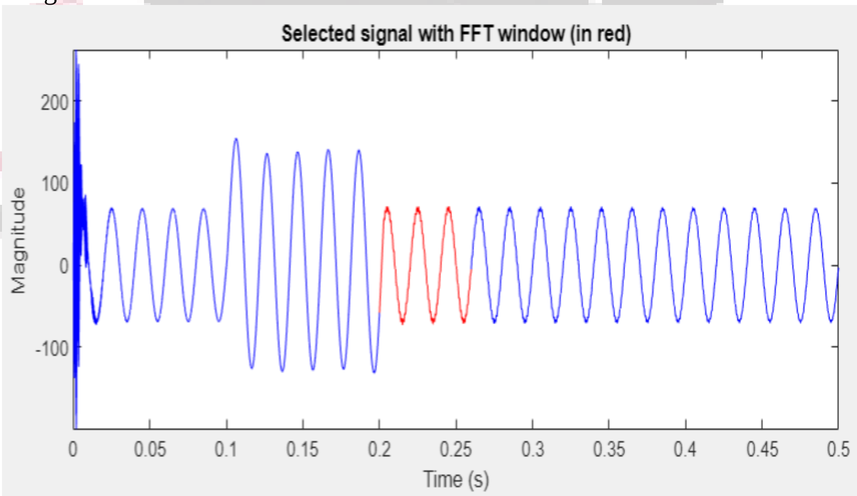

Fig. 23 FFT evaluation at off-loading point in hybrid system with voltage reference-based converter controller

The FFT analysis of current at the point where the off-loading is done at 0.2 seconds and the current decreases at this point is represented by Figure 23 for each cycle and then the distortion is measured in the current at this point in system driven with voltage reference-based converter controller.

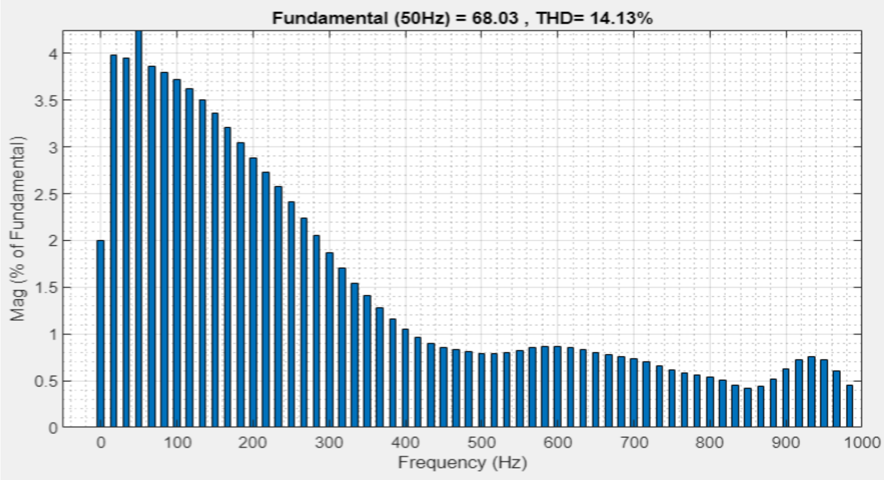

Fig. 24 THD% evaluation at off-loading point in hybrid system with voltage reference-based converter controller

The total harmonic distortion calculated in the current waveform at the off-loading point is being represented by figure 24 in system driven with voltage reference-based converter controller which comes to be 14.13%

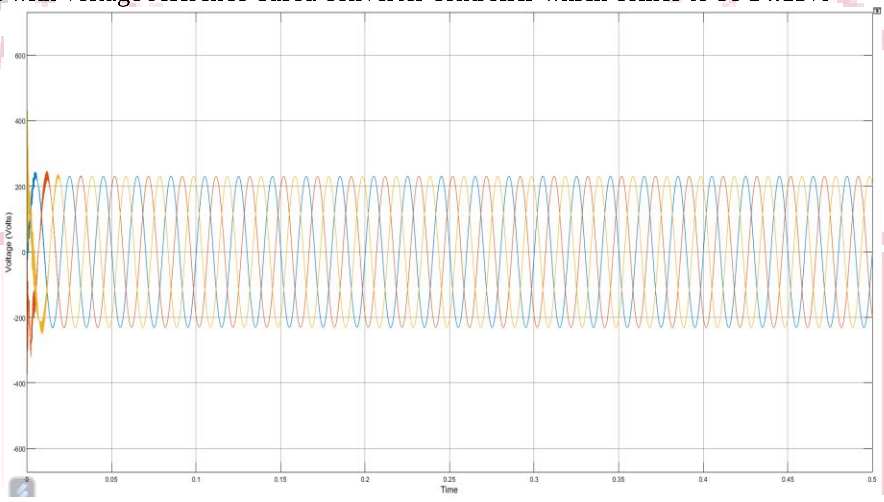

Fig. 25 AC voltage available at the loading points in hybrid system with proposed Reinforcement learning based converter controller

Figure 25 shows the loading conditions analysis which results in no changes in the line voltage waveform at the loading and off loading points in system driven with proposed Reinforcement learning based converter controller

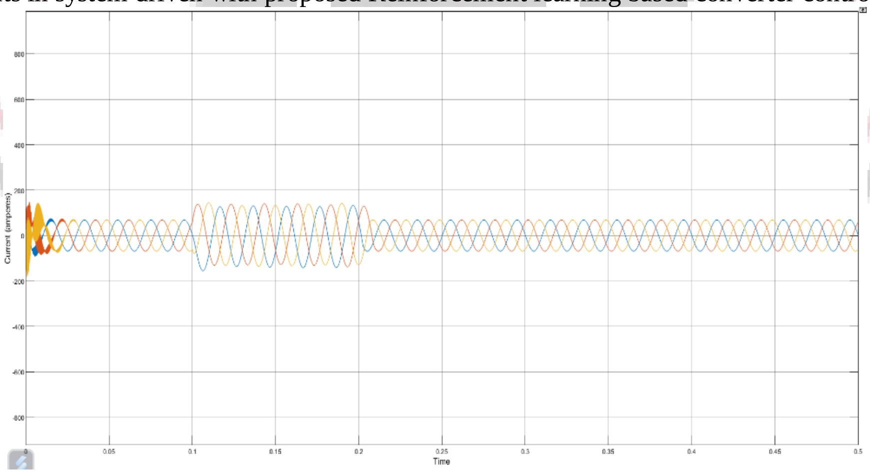

Fig. 26 Current Drawn at the loading points in hybrid system with proposed Reinforcement learning based converter controller

Figure 26 shows the loading conditions analysis which results in changes in the current waveform at the loading and offloading points in system driven with proposed Reinforcement learning based converter controller.

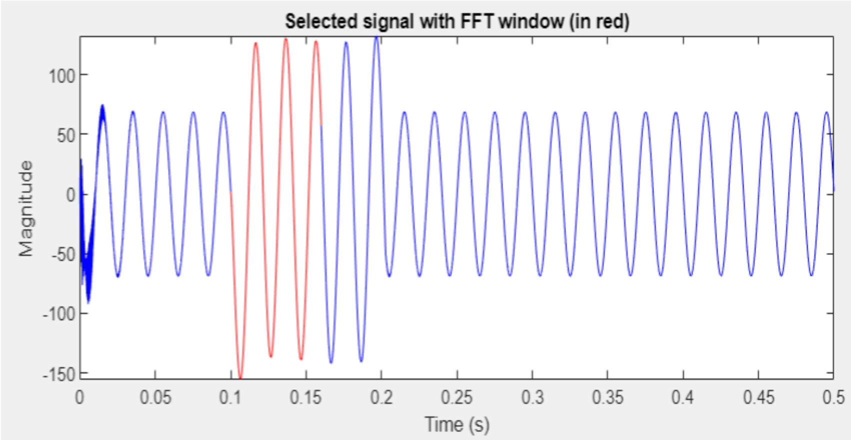

Fig. 27 FFT evaluation at the loading point in hybrid system with proposed Reinforcement learning based converter controller

The FFT analysis of current at the point where the loading is done at 0.1 seconds and the current rises at this point is represented by Figure 27 for each cycle and then the distortion is measured in the current at this point in system driven with Reinforcement learning based converter controller.

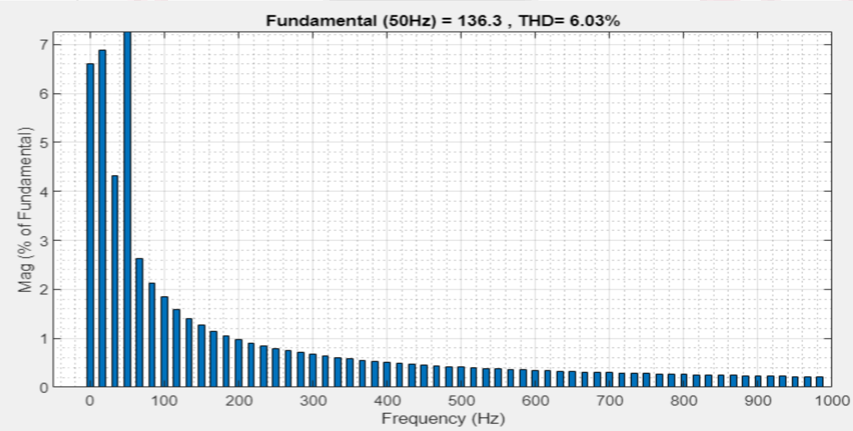

Fig. 28 THD% evaluation at the loading point in hybrid system with proposed Reinforcement learning based converter controller

The total harmonic distortion calculated in the current waveform at the loading point is being represented by figure 28 in system driven with proposed Reinforcement learning based converter controller which comes to be 6.03%

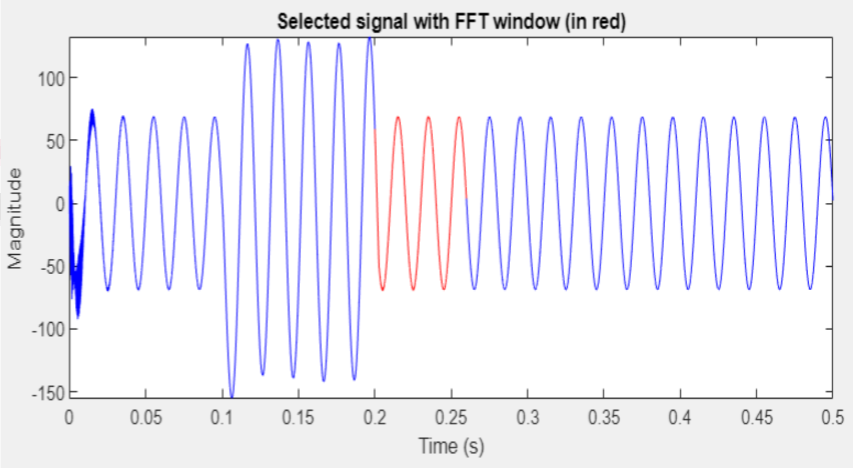

Fig. 29 FFT evaluation at the off-loading point in hybrid system with proposed Reinforcement learning based converter controller

The FFT analysis of current at the point where the off-loading is done at 0.2 seconds and the current decreases at this point is represented by Figure 29 for each cycle and then the distortion is measured in the current at this point in system driven with proposed Reinforcement learning based converter controller.

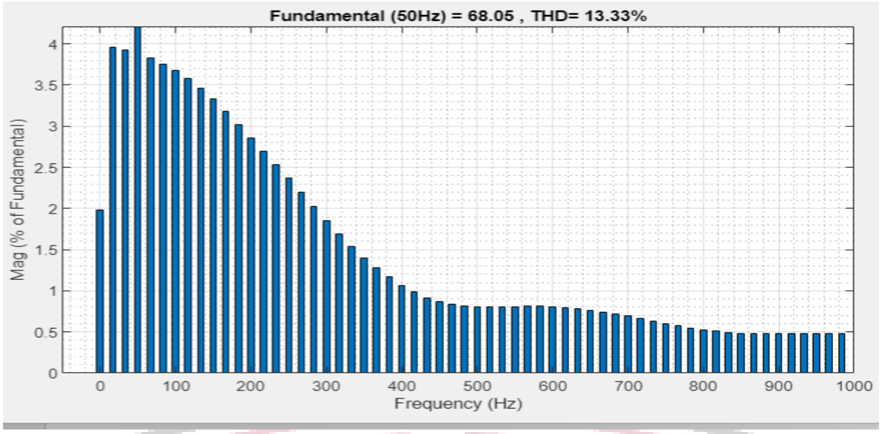

Fig. 30 THD% evaluation at the off-loading point in hybrid system with proposed Reinforcement learning based converter controller

The total harmonic distortion calculated in the current waveform at the off-loading point is being represented by figure 30 in system driven with proposed Reinforcement learning based converter controller which comes to be 13.33%

VI .CONCLUSION AND FUTURE SCOPE

The development of a control system for a DC/AC converter in a hybrid system using AI is an emerging field that holds great promise for improving the efficiency and reliability of renewable energy systems. MATLAB provides a powerful platform for developing AI-based control systems that can optimize the performance of the DC/AC converter. AI-based control systems use machine learning algorithms to learn the behavior of the system and adjust the control strategy accordingly. This enables the system to adapt to changing conditions in real-time, improving its efficiency and reducing its environmental impact.

The work has focused on modifying the controllers of the inverter and study the response under various loading scenarios. In the context of developing control systems for DC/AC converters in hybrid systems, reinforcement learning can be used to optimize the control strategy based on real-time feedback. This approach has the potential to improve the efficiency and reliability of the DC/AC converter by adapting to changing conditions in the environment. The implementation was carried while comparing the outcomes from the controller that used having voltage reference-based converter controller whose reference signal is generated using the space vector modulation and then replacing the same with proposed AI based algorithm. The following key conclusions were drawn from the work.

- Enhancement in the power outcomes from 17020 watts in the system having voltage reference-based converter controller whose reference signal is generated using the space vector modulation to 17800 watts in the system where the controller has been changed to Q learning based reinforcement learning for adaptive control of the inverters that accounts for an improvement of 4.5% in the active power.
- This accounts for an improvement in the power factor of the system from 0.89 to 0.93.
- The system also saw an improvement in the available reactive power of the line which was considerable reduced in the system with proposed inverter control with reinforcement learning for adaptive control of the inverters from 817.8 Var to 480 Var.
- The THD% evaluated in the system while driving loads was calculated to be 4.92% and 11.20% in voltage and current respectively in the system 1 and in system 2 with proposed controller the distortion was reduced to 1.59% and 10.04% in voltage and current respectively.
- The loading condition analysis of the system provided a better outlook of the proposed learning approach for quality enhancement for system in terms of transient load handling capability as well when the distortions level of the current and voltage waveforms where studied.

The computational methodology of the proposed modulation technique is very easy and the technique can be applied to multilevel inverter with any number of levels. This implementation would be preferable in the solar wind hybrid systems having different input parameters and still give output power stable and efficient and reliable.

Future Scope

The modulation technique is easy and simple to be implemented; use of proper facts devices can make it more robust and easy to handle inverter. With the advent of more powerful artificial intelligence, the requirements for low computational complexity and memory consumption of the algorithms will drop and it might be even possible to implement more complicated and more efficient algorithms. The proposed controller has proved to be effective while designing the inverter for hybrid system. This algorithm can further work in an enhanced manner by making a hybrid technique for this algorithm. Therefore, it is certainly true that the area of inverter in RES is and for a long time will remain widely opened sphere for scientific research and commercial applications.

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