Design of Efficient Power Filter with Reduced Distortion Using Control Algorithm

Rahul Dhakad
M. Tech Scholar
Shri G.S. Institute of Technology & Science
Indore, M.P, India
rakeshdhakad2009@gmail.com

Dr. Rakesh Saxena
Professor
Shri G.S. Institute of Technology & Science
Indore, M. P, India
rakeshsaxena@hotmail.com

Abstract: **The electrical distribution system is facing undesirable power quality disturbances due to different types of linear/nonlinear loads on the supply system. The objective of the project is to reduce the distortion level in voltage or current input to the load and at the output of the filter. To design a simple but highly viable hybrid active power buffer that is capable of feeding less distorted voltage to the nonlinear load model. To present an optimal controlling of these buffers so as to minimize the voltage distortion by designing a different algorithm for the same. Comparing the THD levels of the output voltage waveform with the standard controlling method with the proposed control design to further enhance the proposed design such that it is practically feasible to be implemented in grid system having renewable energy resources. In this work, a power filter has been designed using different algorithms with an objective to reduce the Total Harmonic Distortion in the voltage output waveforms. The total harmonic distortion in the voltage output waveform being fed to the load using only the PQ_RLS algorithm is found to be 2.18 %. In the case of the output voltage from the power buffer using PQ_RLS algorithm, the THD level is 0.17 %. The distortion level in the output voltage waveforms in both the cases being fed to the load when compared, it is found that RLS algorithm in combination with PQ algorithm is more effective in reducing the distortion as compared to standard RLS method or PQ method.**

Keywords: **THD, RLS, AC, DC.**

I. INTRODUCTION

Electrical distribution system is facing undesirable power quality disturbances due to different types of linear/nonlinear loads on supply system. Some of these power quality disturbances and problems include waveform distortion, high reactive power burden, and unbalanced currents in the three phases, excessive neutral current, voltage sag/swell, imbalances in supply voltage, flicker and notching etc [1]. Due to the proliferation of power converter based non-linear loads in the distribution system, power quality related problems are on the rise; further, as these converters which actually cause these power quality problems are also vulnerable to them. Voltage quality in a distribution system very much depends on various phenomena of the network disturbances and the quality of power coming from the distribution network; on the other hand, current quality mostly depends upon the nature of connected loads [2]. AC–DC conversion of electric power is required in adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs), arc furnaces, welding systems and utility interface with non-conventional energy sources such as wind, solar PV etc. One of the major culprits causing power quality problems lies in these AC-DC uncontrolled converters. With the emphasis on electric vehicles to reduce greenhouse gas emission, the battery charging for electric vehicles is likely to form a major chunk of the load on the distribution system. Similarly, mobile phone users are on a steep rise which makes the requirements of telecom towers to shoot up; hence telecom tower power supplies are also contributing to a huge non-linearity in the distribution system.

II. LITERATURE REVIEW

Francisco De La Rosa et al. [3] this article presents various harmonic sources in detail, their effects on the energy system and its mitigation techniques. First, the measurement of harmonics with the digital memory oscilloscope (DSO) is briefly discussed. Next, the different techniques of passive filter and active filter are explained. In addition, Matlab simulations for active and passive filters are presented.

Jos Arrillaga et al. [4] this document is intended to provide an overview of the harmonics of power systems and is intended for those with electrical training who, however, have little or no knowledge of harmonics. The basis of harmonics, including Fourier theory, are briefly explained. The common types of

 DOI: https://doi.org/10.24113/ijosthe.v7i4.129

harmonic sources existing in the sector are treated with particular emphasis on frequency converters. The possible negative effects of harmonics are described in detail. Next, a proactive approach for adding large nonlinear loads is presented and alternative methods for harmonic reduction are discussed.

Chakrabortty, S. D [5] in modern distribution systems, the propagation of nonlinear charges leads to a deterioration in the quality of the voltage profiles at the common coupling point (CCP) of different consumers. Energy conditioning systems are therefore becoming increasingly important for electricity suppliers and their customers. With the rapid development of semiconductor components in power and control circuits, a new generation of energy quality devices has been developed, the active power filter. There are two basic methods for generating the reference current: (i) frequency domain methods based on Fourier analysis and (ii) time domain analysis based on instantaneous imaginary power theory in three-phase circuits, often called pq theory

J. Mindykowski et al. [6] this article deals with grid quality problems in different frequency systems equipped with a passive harmonic filter. The main differences between the naval system and the coastal network have been highlighted. The influence of variable frequencies on the correct functioning of the passive harmonic filter was presented. The simulation circuit and the results of the simulation of the theoretical research have been described.

III. Objective

The prime objective of the project is to reduce distortion level in voltage or current input to the load and at the output of the filter. The research problem is further broken into following sub-objectives.

- To design a simple but highly viable hybrid active power buffer that is capable of feeding less distorted voltage to the nonlinear load model.
- To present an optimal controlling of these buffers so as to minimize the voltage distortion by designing a different algorithms for the same.
- Comparing the THD levels of the output voltage waveform with the standard controlling method with the proposed control design
- To further enhance the proposed design such that it is practically feasible to be implemented in grid system having renewable energy resources.

IV. Methodology

A. PV Module Modeling

PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I. A simple equivalent circuit of PV cell is shown in Fig. 1.

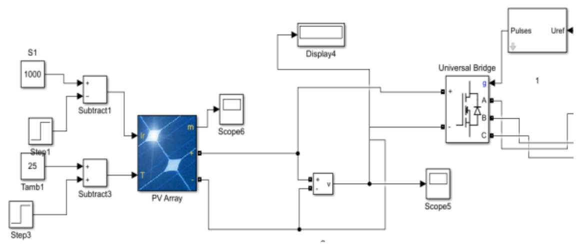

Fig. 1 Modeled Solar System

Table :1 PV module Parameters	
Maximum Power	213.5 Watts
Number of parallel strings	40
Number series modules	10
Open circuit voltage	36.3 Volts
Shot circuit current	7.84 Ampere

A cell series resistance (Rs) is connected in series with parallel combination of cellphotocurrent (I_{ph}),exponential diode (D), and shunt resistance (R_{sh}) , I pv and Vpv are the cells current and voltage respectively. It can be expressed as

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$ (1)

Where:

I_{ph} - Solar-induced current

I_S - Diode saturation current

q - Electron charge (l.6e^{-l9}C)

K - Boltzmann constant (l.38e^{-23}J/K)

n - Ideality factor (l~2)

T - Temperature ^{0}K

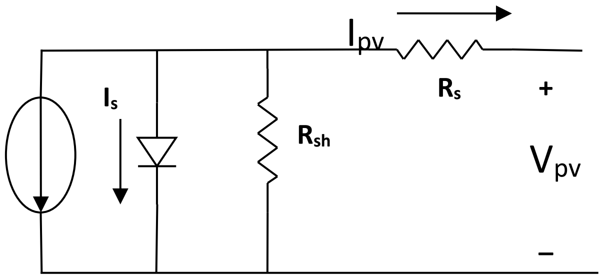

Fig. 2 Equivalent circuit of solar PV cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000} \quad (2)$$

Where:

I_{SC} Short-circuit current of cell at STC

K_i Cell short-circuit current/temperature coefficient (A/K)

I_r Irradiance in w/m

T_C ,T_r Cell working and reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occur at the knee of the curve as shown in the Fig 3.

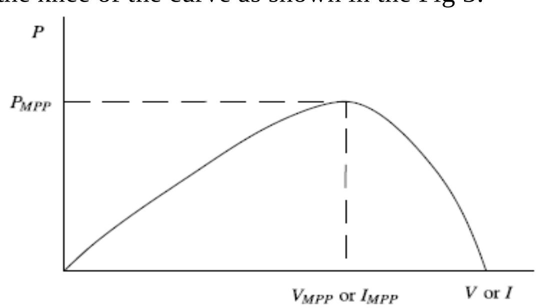

Fig. 3 Characteristic PV array power curve

The P&O algorithm will track the maximum power to supply the DCMGs system. The assumptions for model derivation are that the ideal current source can be presented as the PVs behavior. In addition, all power converters are operated under the continuous conduction mode (CCM) and the harmonics are also ignored.

B. *Wind Energy System Modeling*

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 (3-7).

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

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

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

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v} \quad (4)$$

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:

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m} \quad (5)$$

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

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3 \quad (6)$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics described in [2], [7-9] and [11] as:

2

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)} \quad (7)$$

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.

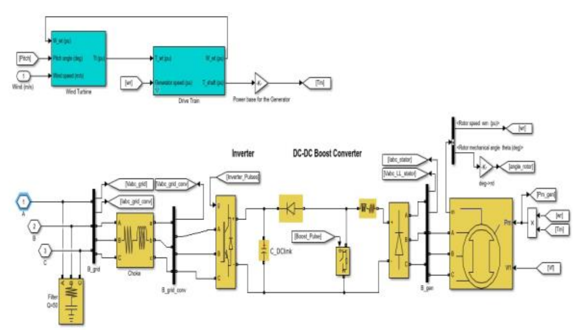

Fig. 4 Modeled Wind system

This mechanism uses the variable torque output w_m and tries to optimize the output current and voltage waveform to its maximum value.

V. RESULTS

A. *Simulation Result with Different Control Algorithms*

In this work at three phase voltage source inverter has been model as an active power filter in series with a passive filter with an objective to reduce the distortion level of the output voltage being fed into the great and also reduce THD in input voltage to the linear and nonlinear loads. The model has been created using two algorithm and finally the validation is done by comparing the distortion level in the voltage waveform being produced after the modeling of the two algorithms in MATLAB and SIMULINK environment. In this work particularly a hybrid model of power filter called hybrid active power filter is being. HAPF provides better performance and cost effective solutions as compared to passive and active filters. Various strategies with extraction and estimation techniques have been implemented in HAPF.

The discrete mode sampling time is kept to be $Ts = 5x\,10^{-6}$. The AC output voltages is then sent to the load. The model can further be integrated with the grid system. In order to overcome the poor and unacceptable performance of the conventional solutions during unsymmetrical loads, an innovative control strategy is anticipated.

- The proposed system presents control strategies of a shunt active power buffer using two algorithms RLS and modified RLS respectively.
- The system is being simulated for 0.5 second for simulation purpose in MATLAB/SIMULINK environment.
- The gate signals provided to the IGBTs drawn after treating the error signals through a control algorithms algorithm.
- The model is made to drive a nonlinear load model with minimum distortion in the voltage waveform.
- The result from the model are traced from 0.03 seconds onwards in order to get best possible result. When the model starts in beginning it shows transient characteristics.

The Result analysis of the model has been arranged in the following manner:

1. Case 1: Hybrid active power filter modeling using PQ algorithm
2. Case2: Hybrid active power filter modeling using RLS algorithm
3. Case3: Hybrid active power filter modeling using PQ_ RLS algorithm

The table below describes the system parameters of the source that has been feeding the load via power filters.

Table 2 : System Parameters:	
Voltage Source Inverter	
Phase to phase voltage (Volts)	400
Frequency (Hertz)	50
Source resistance (ohms)	0.001
Source Inductance (H)	1×10^{-8}
Power Filter	
Capacitor Initial voltage (Volts)	65
Capacitor initial capacitance (F)	470×10^{-8}

The model in Fig. 5 shows the system under test. The model has been created in MATLAB having three phase voltage source as its main supply. The end consists of linear and nonlinear loads. The system under test has approximately 320 volts voltage in the transmission line. The power filer is designed for the same line using different algorithms. The three algorithms have been taken being PQ, RLS and PQ_RLS control.

The power filter in model shown in figure 5 comprises of all the elements as discussed. For the sake of comparison everything other than power filter is similar in all the three cases as discussed above.

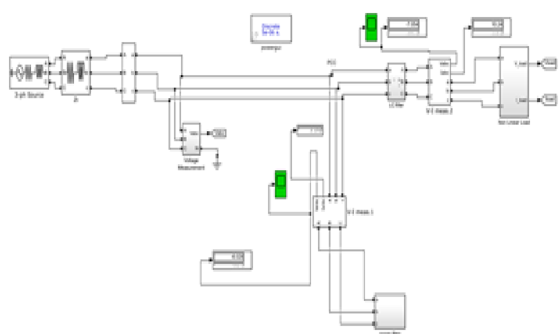

Fig. 5 MATLAB/SIMULINK Model of System under test with Power Filter having different Algorithms

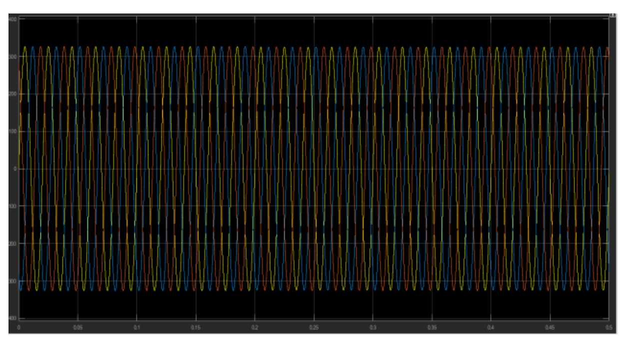

Fig. 6 Source Voltage Output From the three phase voltage source

The fig. 6 shows the voltage output from the three phase voltage source. After proper analysis of the system with the power filter and its control algorithm the bet power filter is used in the hybrid renewable energy system.

B. CASE 1: Model Using PQ algorithm

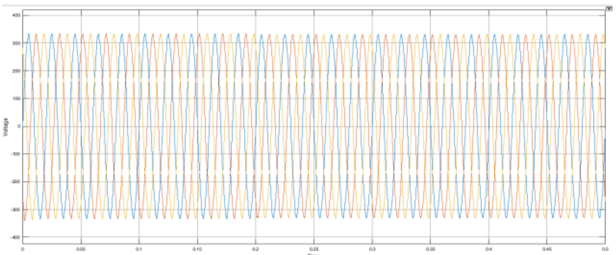

Fig. 7 Voltage input to the nonlinear load from system with P&Q control

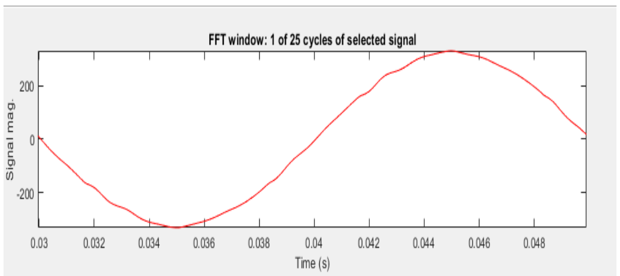

Fig. 8 FFT analysis of Voltage input to the non linear load from system with P&Q control

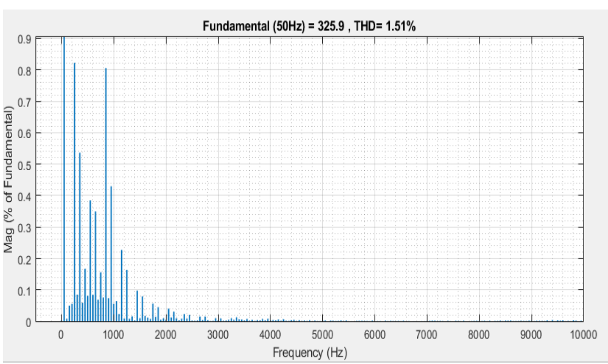

Fig. 9 THD inVoltage input to the nonlinear load from system with P&Q control

The system under test is modeled with the power filter having PQ control algorithm the analysis of voltage available at the nonlinear is studied. The above graphs depict the FFT analysis of the voltage available at the nonlinear load terminal and the THD in it is found to be 2.32 %.

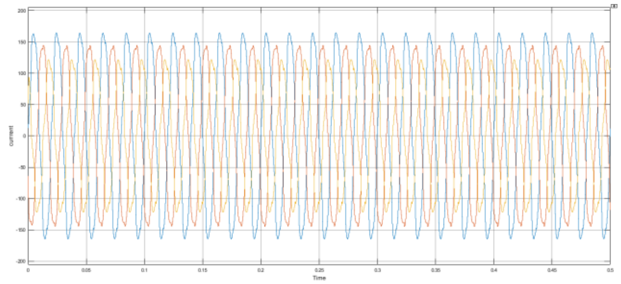

Fig. 10. Current in the system having power filter with PQ algorithm

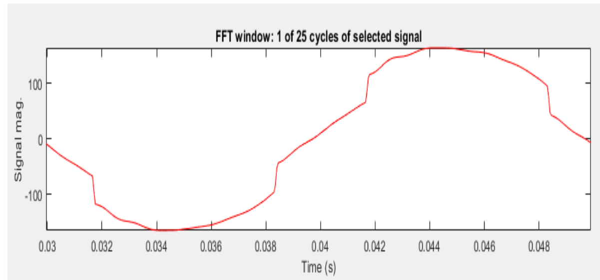

Fig. 11 FFT analysis Current in the system having power filter with PQ algorithm

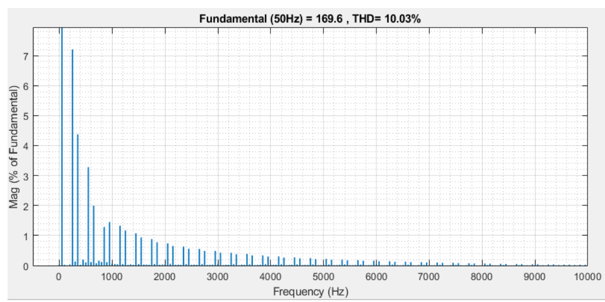

Fig. 12 THD in Current output from the system having power filter with PQ algorithm

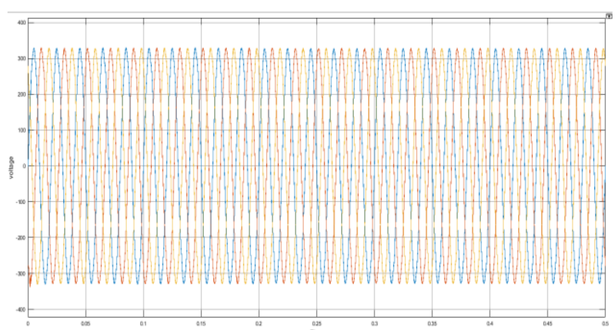

Fig. 13 Voltage output from the power filter with P and Q control

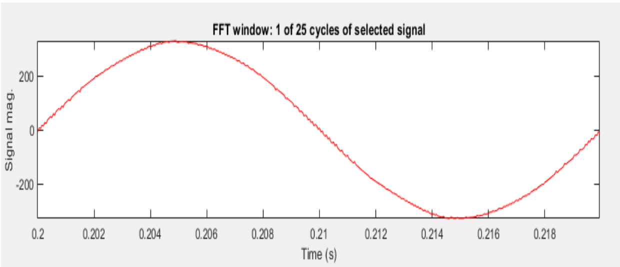

Fig. 14 FFT analysis of Voltage output from the power filter with P and Q control

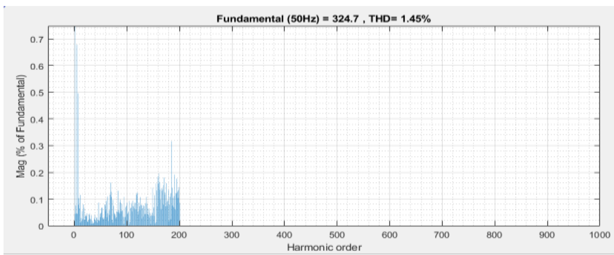

Fig. 15 THD in Voltage output from the power filter with P and Q control

The system under test with power filter having PQ control is studied for voltage output from the power filter with the respective controls (PQ control). The graphs above shows FFT analysis of the voltage output from the power filter and THD level is calculated which was found to be 1.60%

C. CASE 2: Model Using RLS algorithm.

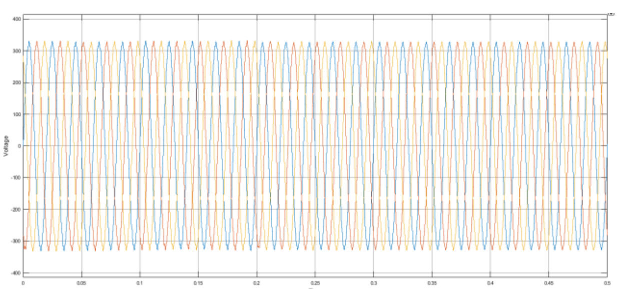

Fig 16 Voltage input to the non linear load from system with RLS control

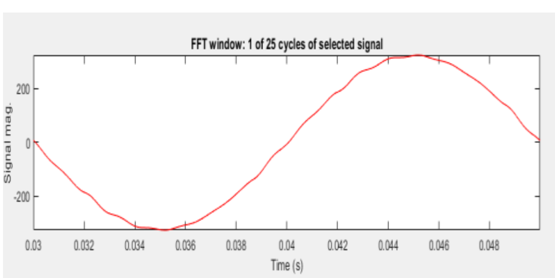

Fig. 17 FFT analysis of Voltage input to the nonlinear load from system with RLS control

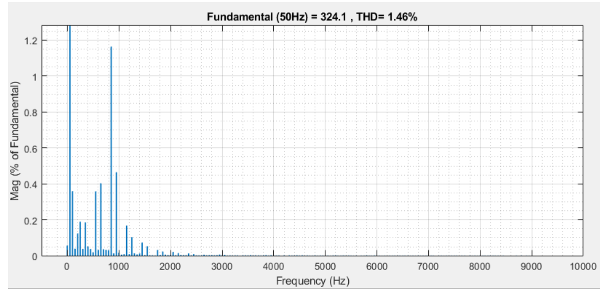

Fig. 18 THD in Voltage input to the non linear load from system with RLS control

The system under test is modeled with power filter having RLS control algorithm the analysis of voltage available at the nonlinear is studied. The above graphs depict the FFT analysis of the voltage available at the nonlinear load terminal and therefore the THD in it is found to be 2.19 %.

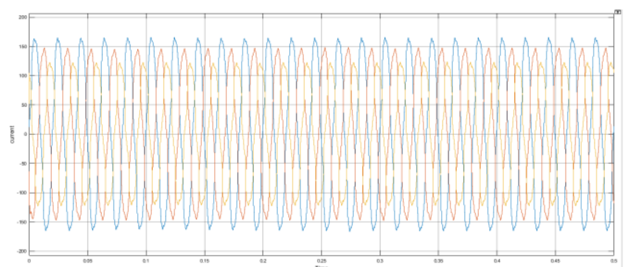

Fig. 19 Current in the system having power filter with RLS algorithm

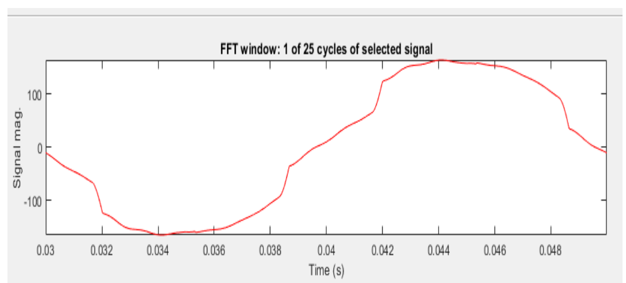

Fig. 20 FFT analysis of Current in the system having power filter with RLS algorithm

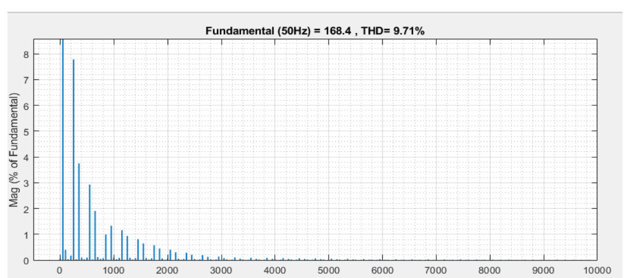

Fig. 21 THD of Current output in the system having power filter with RLS algorithm

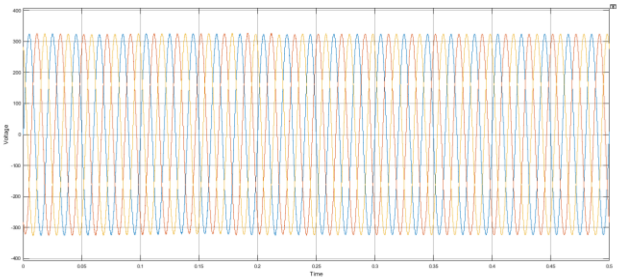

Fig. 22 Voltage output from the power filter with RLS control

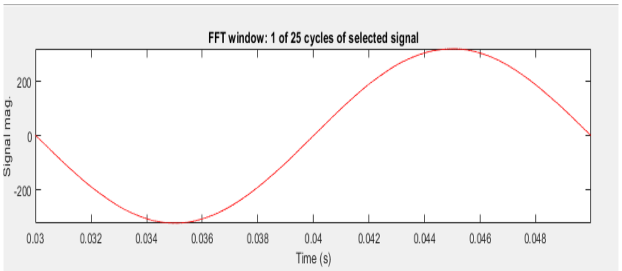

Fig. 23 FFT analysis of Voltage output from the power filter with RLS Control

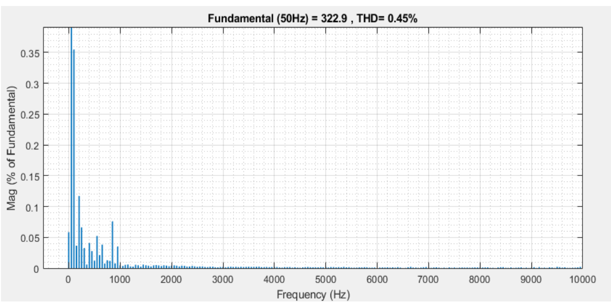

Fig. 24 THD in Voltage output from the power filter with RLS control

The system under test with power filter having RLS control is studied for voltage output from the power filter with the respective controls (RLS control). The graphs above shows FFT analysis of the voltage output from the power filter and THD level is calculated which was found to be 0.45%

D. *CASE 3: Model Using PQ_RLS algorithm*

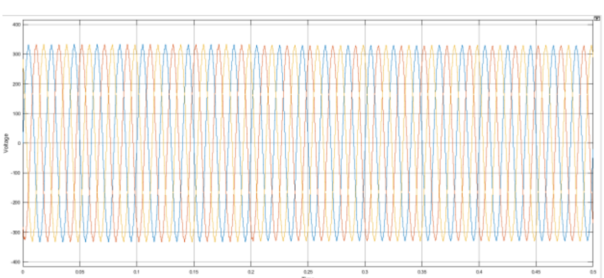

Fig. 25 Voltage input to the nonlinear load from system with PQ_RLS control

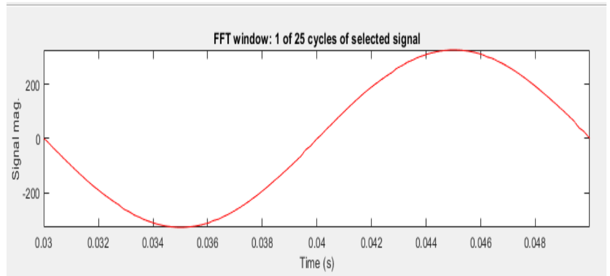

Fig. 26 FFT analysis of Voltage input to the nonlinear load from system with PQ_RLS Control

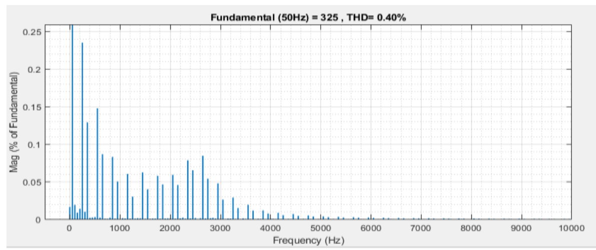

Fig. 27 THD in Voltage input to the nonlinear load from system with PQ_RLS control

The system under test is modeled with power filter having PQ_RLS control algorithm the analysis of voltage available at the nonlinear is studied. The above graphs depict the FFT analysis of the voltage available at the nonlinear load terminal and therefore the THD in it is found to be 2.18 %.

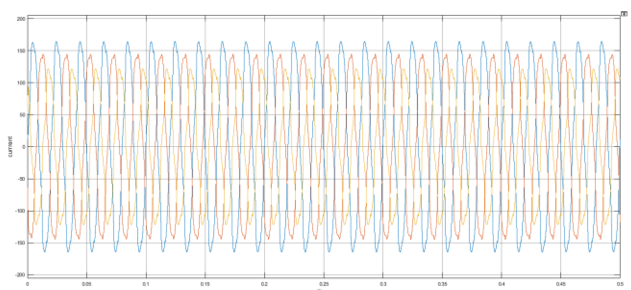

Fig. 28 Current in the system having power filter with PQ_RLS algorithm

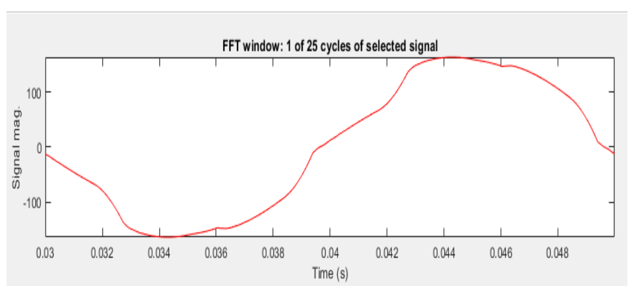

Fig. 29 FFT analysis of Current output in the system having power filter with RLS algorithm

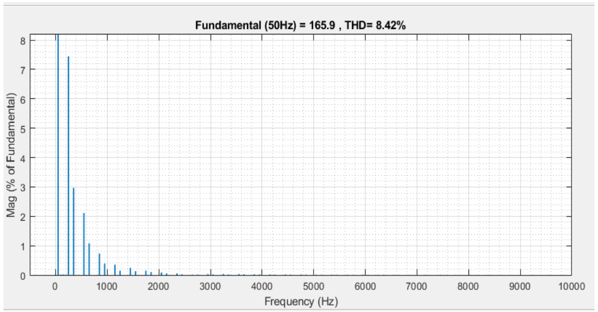

Fig. 30 THD of Current output in the system having power filter with PQ_RLS algorithm

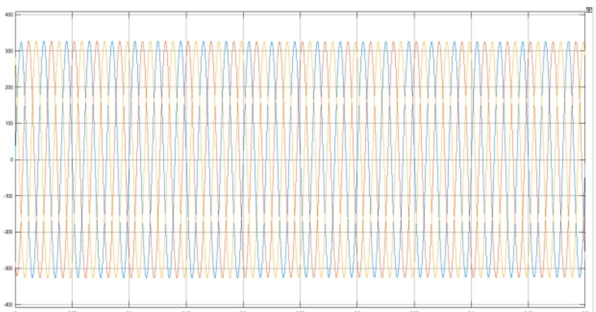

Fig. 31 Voltage output from the power filter with PQ_RLS Control

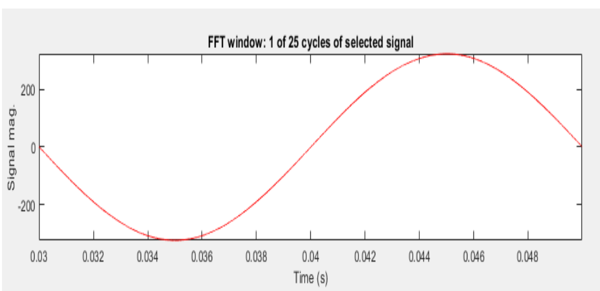

Fig. 32 FFT analysis of Voltage output from the power filter with PQ_RLS Control

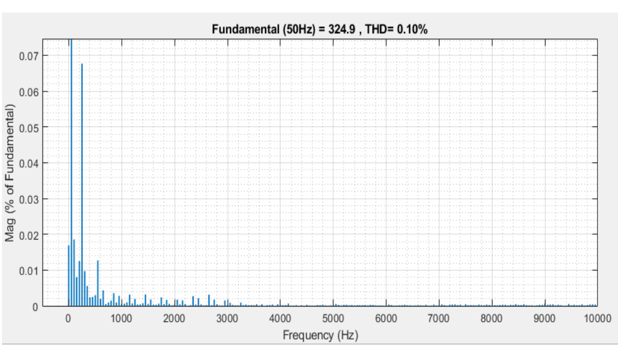

Fig. 33 THD in Voltage output from the power filter with PQ_RLS Control

The system under test with power filter having PQ_RLS control is studied for voltage output from the power filter with the respective controls (PQ_RLS control). The graphs above shows FFT analysis of the voltage output from the power filter and THD level is calculated which was found to be 0.17%

E. Validation

The THD analysis of two waveforms has been done in this work. One at the voltage input to the nonlinear load and other of the voltage output from the power filter after using three types of algorithms. This concludes that the proposed algorithm Having PQ_RLS has been proved more effective in reducing the distortion level. This algorithm is found to be suitable for implementing with hybrid renewable energy system.

Table 5.2: Comparative analysis of THD values in voltage waveforms using different control

	THD in voltage input to the load	THD in output voltage from power filter
Power filter with P&Q algorithm	1.51%	1.45 %
Power filter with RLS algorithm	1.46%	0.45%
Power filter with PQ_RLS algorithm	0.40%	0.10%

The THD analysis of current waveform is also done. This concludes that the proposed algorithm Having PQ_RLS has been proved more effective in reducing the distortion level in case of current at the load terminal also.

Table 5.3: THD in current at the load terminal

Power filter with P&Q algorithm	10.03%
Power filter with RLS algorithm	9.71%
Power filter with PQ_RLS algorithm	8.42%

F. Integration of Grid with Hybrid Renewable Energy System

From the discussion in the previous chapters it is being concluded that the PQ_RLS algorithm has most effective output results in terms of voltage and hence can prove to be an effective choice of filter when it is used in renewable energy system.

The device is meant to filter out the harmonics in the voltage output from the hybrid system and make it drive the nonlinear load models. This work is hence meant to drive the solar/wind based hybrid energy system and find out the output power parameters at the load terminal (nonlinear) and make the PQ_RLS algorithm based power filter. This system was simulated for 1 second to study the output in a detailed manner

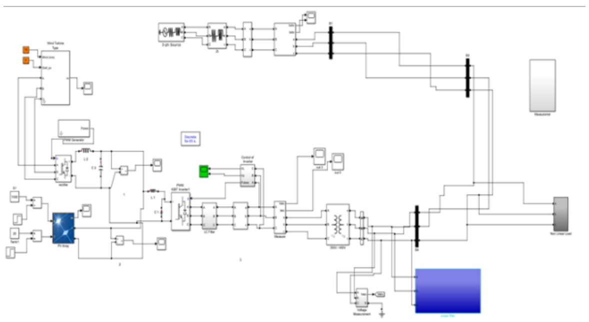

Fig. 34 MATLAB/SIMULINK model of hybrid system with PQ_RLS based power filter

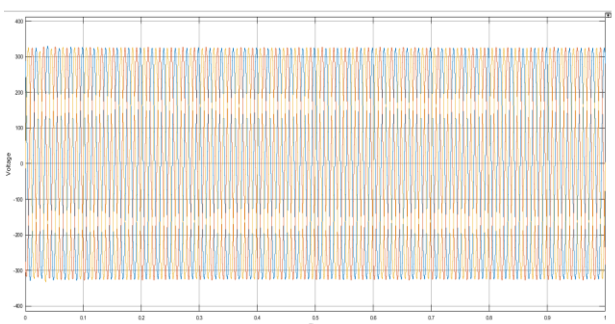

Fig. 35 Voltage Output from the Hybrid System

The voltage output from the system is same as required by the nonlinear load which is approximately 310Volts.

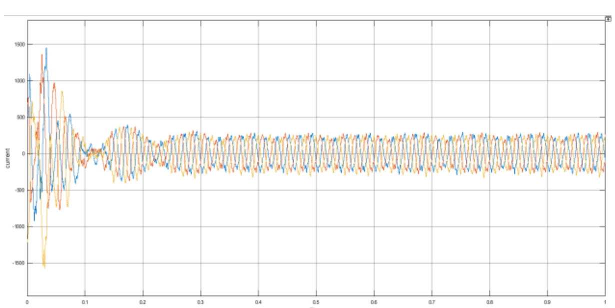

Fig. 36 Current Output from the Hybrid System

The current output from the system at the nonlinear load terminal is approximately 200 Amperes which stabilizer after 0.2 seconds of inverter conversion and control. This current is then passed through our designed power filter before feeding it to the load.

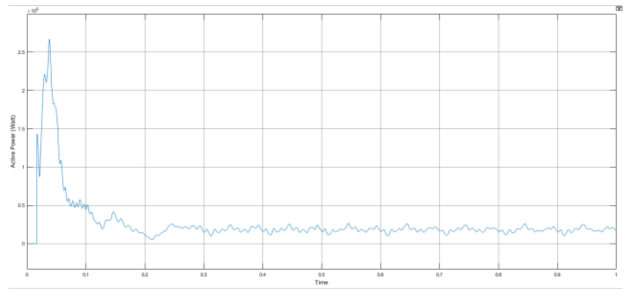

Fig. 37 Active Power output from the Hybrid System

The active power output from the system at the nonlinear load terminal is approximately 25KW as depicted in the graph above.

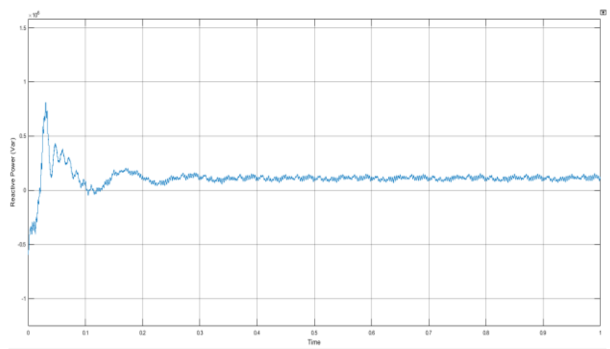

Fig. 38 Reactive Output from the Hybrid System

The reactive power output from the system at the nonlinear load terminal is approximately 20 k VAR as depicted in the graph above.

VI. Conclusion And Future Scope

A. *Summary*

In this work a power filter has been designed using different algorithms with an objective to reduce the Total Harmonic Distortion in the voltage output waveforms. The following major points we concluded from the above analysis:

- The total harmonic distortion in the voltage output waveform being fed to the load using only PQ_RLS algorithm is found to be 2.18 %.
- In case of the output voltage from the power buffer using PQ_RLS algorithm the THD level is 0.17 %.
- the distortion level in the output voltage waveforms in both the cases being fed to the load when compared, it is found that RLS algorithm in combination with PQ algorithm is more effective in reducing the distortion as compared to standard RLS method or PQ method
- The distortion level has been considerably reduced in order to get a smooth voltage waveform that would be able to drive the load, both linear and nonlinear more effectively

and efficiently also when it is integrated with the hybrid renewable energy system.

B. Suggestion for future work

Energy quality can be improved by using a more efficient power filter and algorithm in a networked system. The work can be expanded to improve the quality of the network powered by renewable energy sources. By improving the signal quality of the output voltage, it can be further integrated into the network.

The modulation technique is simple and easy to implement. Using real facts can make the UPS more robust and easier. With the advent of more powerful DPS, the computational complexity and the memory usage needs of the algorithms will decrease and more sophisticated and efficient algorithms can be implemented. It is therefore certainly true that the field of adaptive filtering will remain a long-open field for scientific research and commercial applications.

C. Concluding Remark

As technology advances, the demand for exponential electricity increases. Many consumer devices constantly demand quality performance for their operation. The performance of the devices depends to a large extent on the quality of the power supply. However, the quality of the end user's energy is influenced by various external and internal factors. They are like fluctuations of voltage and frequency, faults, faults, etc. These energy quality problems reduce the life and efficiency of the equipment. Therefore, these problems should be mitigated to improve the performance of the consumer equipment and the overall performance of the system. Finally, the author wishes that this thesis serves the interests of other students who are interested in power electronics especially in power quality improvement using hybrid filter governed by various control algorithms and provides encouragement towards more advanced senior project or master's thesis research.

REFERENCES

[1] A. Ghosh and G. Ledwich, 'Power Quality Enhancement using Custom Power Devices', Springer International Edition, Delhi, 2009.

[2] J. Schlabbach, D. Blume and T. Stephanblome, 'Voltage Quality in Electrical Power Systems', IEE Press Series on Power Engineering and Energy, 2001.

[3] Francisco De La Rosa, 'Harmonics and Power Systems', CRC Press, New York, 2006.

[4] Jos Arrillaga and Neville R.Watson, 'Power System Harmonics', John Wiley and Sons Ltd, England, 2003.

[5] Chakrabortty, S. D., &Zaveri, N. (2015). Power Conditioning by Shunt Active Filter. International Journal for Innovative Research in Science and Technology, 2(6), 105-110

[6] J. Mindykowski, T. Tarasiuk and P. Rupnik, "Problems of passive filters application in system with varying frequency", in Proc. of 9th International Conference on Electrical Power Quality and Utilisation, pp.1-4, 2007.

[7] L-C. Lao, X-L. Jiang and Z-W. Shu,"Applications of intelligent tuning technology in passive power filters", in Proc. of China International Conference on Electricity Distribution, pp.1-9, 2010.

[8] A. Capasso, R. Lamedica and A. Prudenzi, "Estimation of net harmonic currents due to dispersed nonlinear loads within residential areas", in Proc. of 8th International Conference On Harmonics and Quality of Power Proceedings, Vol. 2, pp.700-705, 1998.

[9] B. Singh, V. Verma, A. Chandra and K. Al-Haddad, "Hybrid filters for power quality improvement", IEEE Proc.-Gener. Transm. Distrib., Vol. 152, No. 3, pp. 365-378, May 2005.

[10] S. Bhattacharya, P-T. Cheng and D.M. Divan, "Hybrid solutions for improving passive filter performance in high power applications", IEEE Transactions on Industry Applications, Vol. 33, No. 3, pp. 732-747, May/Jun 1997.

[11] Vishal Verma and BhimSingh,"Design and implementation of a current-controlled parallel hybrid power filter", IEEE Transactions on Industry Applications, Vol.45, No.5, pp.1910-1917, September/October 2009.

[12] B. Singh, V. Verma and V. Garg, "Passive hybrid filter for varying rectifier loads", in Proc. of International Conference on Power Electronics and Drives Systems, Vol. 2, pp. 1306- 1311, 2005