IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 10, Issue 4, April 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.122

9940 572 462 6381 907 438 ijareeie@gmail.com www.ijareeie.com

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

Power Quality Elaboration Using Active Power Filter of Electrical Distribution System with Renewable Power Generation

Neha Rahul Wankar[1], Vaishali Malekar[2], Radharaman Shaha[3]

PG Student, Dept. of EE, Tulsiramji Gaikwad Patil College of Engg. & Tech., Nagpur, India[1]

Assistant Professor, Dept. of EE, Tulsiramji Gaikwad Patil College of Engg. & Tech., Nagpur, India [2]

HOD, Dept. of EE, Tulsiramji Gaikwad Patil College of Engg. & Tech., Nagpur, India [3]

ABSTRACT: In this modern world use of non-linear load is increases rapidly. Every daily need equipment use of non-linear load is existence. Non-linear loads affect the power quality of the power systems. An active power filter executes with four- leg voltage source inverter (4L-VSI) is demonstrated. This system also mitigates unbalance current generated by non-linear load as well as allows the current harmonic components compensation. A simple mathematical model of active power filter presented with a prediction control algorithm with derivation of power system impedance. The performance of active filter compensation technique presented here with the simulation results.

KEYWORDS: Power Quality, Active Power Filter, Current Control, Current Compensation, Harmonics, Predictive Control, Non-linear load, Four-leg Converter

I.INTRODUCTION

Today's generation people adopt a renewable power generation system for their domestic and industrial use. In villages popularity of micro grids are also increases rapidly [1]. If use of more renewable power it means that it get affects the power quality due to the nature of its non-linearity, since high –power static PWM converter is must be connected to the wind generators and solar power plants with respect to the grid [2]-[3]. A voltage and current distortion will occur in the power system due to the non-uniform nature of renewable power generation systems also directly affects the voltage regulation of the respective power system. These new challenges in the power systems need a proper compensation technique for the stable operation of distribution system. Due to development of modern industry more and more non-linear loads are connected due to which harmonic pollution is generated.

In this paper prediction control algorithm is designed and implement. Traditionally PI controller is specially designed for the linear model. Prediction current control method quickly spring up the current reference signal with maintaining consistent DC voltage and functioning awkwardly on transitory as well as typical operating surrounding. Mathematical model of three-phase four-leg voltage-source inverter (4L-VSI) is presented in this paper with prediction control method [4]-[6].Principle procedure along with the modeling operation of preferred current reference generator with complete confession implemented in active power filter is presented. Finally, in the simulation active power filter performance with effective current compensation and control method demonstrated [7].

II. PROPOSED SYSTEM

Fig.1 shows the block diagram of renewable power generation system with active power filter. The output of renewable power generation is given to the distribution substation. Various types of loads are connected i.e small industries, domestic loads to the distribution substation. Dc/ac static PWM converters are use for voltage alternation on Solar power generation side. These converters excerpt the ultimate power from sun by maximum power point tracking (MPPT). The consumer side electrical energy consumption and utilization is unreliable and irregular it may be a single phase or three phase, linear or non-linear and, balanced or unbalanced [8]-[9]. Solar power generation is typically used to generate power. An active filter is connected in between the power distribution system and various types of loads.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

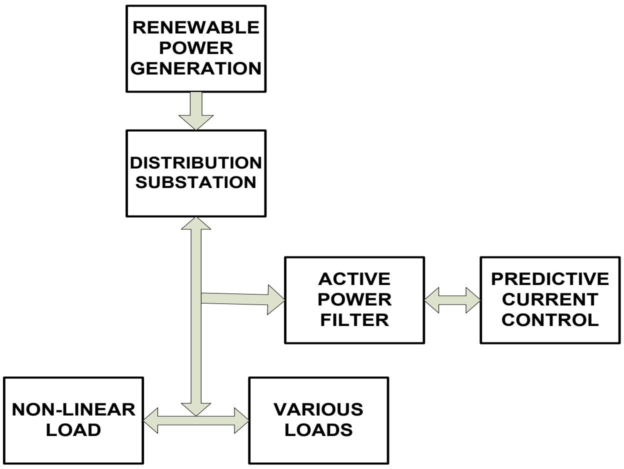


Fig.1. Proposed systems block diagram

III. FOUR LEG INVERTER CONFIGURATION

Fig.2. shows the structure of active power filter executed in proposed system. In between distribution point and the consumer premises a shunt active power filter is connected with 4L-VSI topology to compensation of current harmonics and current unbalance. Active power filter is a composition of four-leg PWM inverter, electrolyte capacitor and the first-order output ripple filter. In the circuit clearly exposed power system equivalent impedance Z_s, converter output ripple filter impedance Z_f and load impedance Z_L

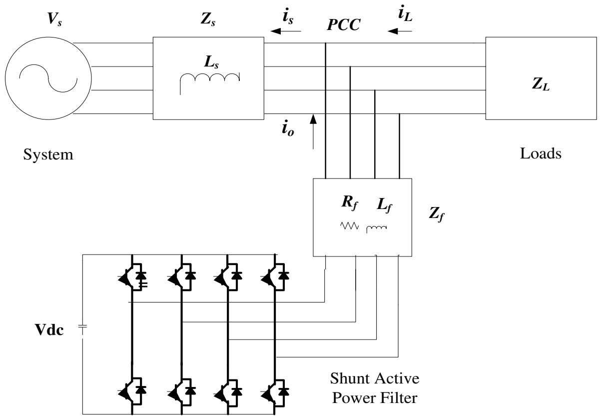


Fig.2. Equivalent circuit diagram of the proposed shunt active power filter

The four- leg PWM inverter (4LVSI) configuration is shown in fig. 3. The fourth leg of this converter is linked with the neutral bus and this is equivalent as conventional three- phase converter.

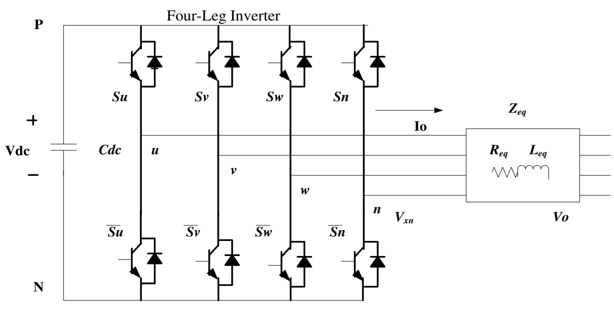


Fig.3. Four-leg PWM- VSI topology

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

The fourth leg of the converter raises switching states from 8 to 16, with additional developing current control affability and output voltage quality and it is suitable for the compensation of current unbalance [10].

Consider x be the any leg of the inverter to attain the voltage of any leg obtained from the neutral point (n) in the terms of switching states can be as follows,

$$V_{xn} = S_x - s_n v_{dc} \qquad (1)$$

$x = u,v,w,n$ (voltage in any leg of the converter)

From the equivalent circuit shown in fig. 2 mathematical model of the filters is

$$V_o = V_{xn} - R_{eq} i_o - L_{eq} \frac{di_o}{dt} \qquad (2)$$

Where ,

$R_{eq} = R_f$ and $L_{eq} = L_s + L_f$

R_{eq} & L_{eq} are the output parameter of the active filter expressed in terms respect to output terminal Z_{eq} as thevenins impedance

$$Z_{eq} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f \approx Z_s + Z_f \qquad (3)$$

For this model it is assume that $Z_L >> Z_s$ in the system equivalent impedance resistive part of the system is neglected. Series connection of ripple filter impedance Z_f and combination of parallel arrangement between Z_s and Z_L we can determine the venins equivalent impedance.

IV. PREDICTIVE CURRENT CONTROL SCHEME

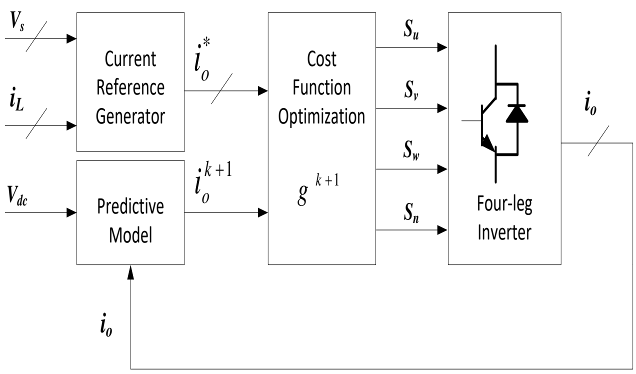


Fig.4. Block diagram of digital predictive current control

Prospective digital predictive current control arrangement is shown in fig.4. This scheme is implemented with a embedded function because basically it is a optimization algorithm. For the prediction of variables which we have to control in system, predictive control method is very effective and this is the main characteristics. This controller is assembles and implements this information for further operation to select the most favorable switching states and this is efficiently applied to the 4L-VSI. This control algorithm is predicted and studies the future behavior. Fig.4. shows the implementation of this control scheme in three main blocks. It generates a current required to active power filter operation for compensation.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

(A) Current Reference Generator: In this case, system voltages, load currents and the dc-voltage of the four leg-voltage source inverter are measures and calculated from the signal neutral output current and neutral load current. This block construct and designed to development of the required current reference that is apply for undesirable load current components compensation.

(B) Prediction Model: Output converter current is predicted by this converter model. In this scheme the controller performs in discrete time domain, both the system model and the controller is expressed in a terms of discrete time rule [11]. A recursive matrix equation is applied to this prediction system to know the discrete time domain. At kTs we have to know the converter switching states and variable to be controlled at the given sampling time. At any instant $[k+1]T_s$ the next states will be desirable the future behavior prediction and forecasting of the converter operation. Because of the first-order description of the state equations that shows and presents in model (1)-(2), this paper shows a enough and accurate first order resemblance model has been considered.

$$\frac{d_x}{d_t} \approx \frac{x[k+1]-x[k]}{T_s} \quad (4)$$

$$\frac{d_{io}(K)}{d_t} = \frac{i_o[k+1]-i_o[k]}{T_s}$$

$$T_s\left[\frac{d_{io}(K)}{dt}\right] = i_o[k+1]-i_o[k]$$

$$T_s\left[\frac{d_{io}(K)}{dt}\right] + i_o[k] = i_o[k+1] \quad (5)$$

From Equation (2) rewritten as ,

$$V_o = V_{xn} - R_{eq} i_o - L_{eq}\frac{di_o}{dt}$$

$$\frac{d_{io}[k]}{dt} = \frac{V_{xn}[k]-V_o[k]-R_{io}[k]}{L_{eq}} \quad (6)$$

From (5) and (6) the 16 possible output current predicted values can be obtained as

$$I_o[k+1] = \frac{T_s}{L_{eq}}(v_{xn}[k]-v_o[k]) + \left(1-\frac{R_{eq}T_s}{L_{eq}}\right) \quad (7)$$

The 4L-VSI converter output voltage V_{xn} and the input voltage value V_o are required to forecast the respective output current i_o at the instant (k+1) as shown in equation (7). This algorithm will calculate all Predicted 16 values associated with all the combination that can achieve the state variable. While the elimination of current harmonics, current unbalance in the system prediction current control algorithm precisely predict the future behavior of the system model and do implementation of current compensation very smartly.

(C) Cost Function Optimization: In the power converter application our robust method is predictive control algorithm. To obtain the 16 possible optimal switching states and this values obtained for the $I_o[k+1]$. By use of cost function g obtained 16 possible values compared with the reference signal, as per following mathematical model:

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

$$g[k+1] = (i^*_{ou}[k+1] - i_{ou}[k+1])^2 + (i^*_{ov}[k+1] - i_{ov}[k+1])^2 + (i^*_{ow}[k+1] - i_{ow}[k+1])^2 + (i^*_{on}[k+1] - i_{on}[k+1])^2 \quad (8)$$

g = 0 condition satisfied when the output current (i_o) of the converter model is equivalent to the respective reference current (i_o^*). To minimize the cost function voltage vector VxN is preferred and it will employ and apply to the next sampling condition. The minimum amount of cost function g is taken into explanation and select from the 16 possible function values all along each switching states. During the operation of converter in the k+1 state the algorithm preferred the applicable switching state and it creates the appropriate minimal value.

V. CURRENT REFERENCE DEVELOPEMENT

Active power filter current reference signal is obtained by the dq-based current reference generator scheme. For fast and rapid specific signal tracking proficiency this scheme will execute very effective work. Voltage fluctuation is neglected and avoid by this characteristic for improvement of better compensation performance [12]. In fig.5 it is clearly mentioned that from load current obtained the corresponding current reference signal.
Current reference generation technique calculates and identifies the current reference signal useful for the current requirement of converter for the effective compensation to the current harmonics and current imbalance. The relationship between active power filter apparent power demand with respect to the load is determined by the displacement power factor ($\sin\phi_{(L)}$) and the maximum total harmonic distortion of the load as shown in following equation

$$\frac{S_{APF}}{S_L} = \frac{\sqrt{\sin\phi_{(L)} + THD_{(L)}{}^2}}{\sqrt{1 + THD_{(L)}{}^2}} \quad (9)$$

Where the value of $THD_{(L)}$ define and indicates that highest compensable harmonic current and also specify the highest acceptable value of reference current.

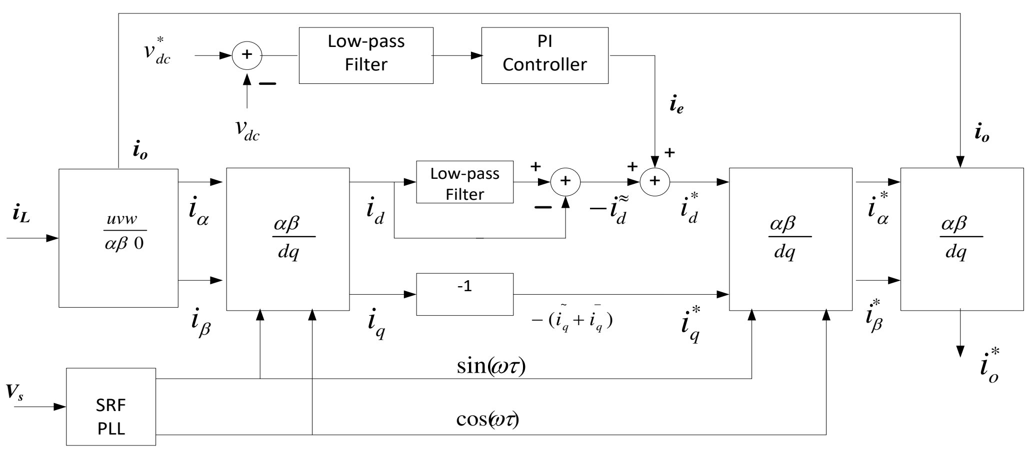


Fig.5. dq-based current reference generator

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

The dq-based reference generation system operation is rotating reference frame; that's why, the obtained and measured current have been multiply to the sin (wt) and cos(wt) signals. By applying the dq-transformation, d current elements integrate and combined with the respective phase-to-neutral system voltage and q current component with phase-shifted by an angle 90^0. Main objective of synchronous reference frame (SRF) PLL to acquire the sin (wt) and cos(wt) synchronized reference signals [13]. Major problem of the power system is voltage is severely distorted to overcome this problem SRF-PLL is employed it generates a pure sinusoidal waveform. Elimination of tracking error is occurs, since SRF-PLL are employed to avoid and elimination phase voltage unbalance, harmonics components and off load conditions occurs due to the measurement error and the non-linear load.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin wt & \cos wt \\ -\cos wt & \sin wt \end{bmatrix} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} iL_u \\ iL_v \\ iL_w \end{bmatrix} \quad (10)$$

Connection among the real currents iL_x (t) ($x=u,v,w$) and the identified dq components (i_d and i_q) presents clearly in equation (10). To the generation of harmonic reference components $-i_d$ a low-pass filter is hired to excerpt the dc component of the phase – currents i_d. By appropriate phase shifting the comparable ac and dc component of i_q with an angle 180^0 we get reactive reference components of the phase-currents. In order to control dc voltage constant conversion of inverter reference signal is needed with the help of this it is possible to maintain the dc voltage constant [12]-[13].

$$\begin{bmatrix} i_{ou}^* \\ i_{ov}^* \\ i_{ow}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin wt & -\cos wt \\ 0 & \cos wt & \sin wt \end{bmatrix} \begin{bmatrix} i_o \\ i_d^* \\ i_q^* \end{bmatrix} \quad (11)$$

From equation (11) it is conclude that after applying the inverse park and Clark transformation, the resulting signals i_d^* and i_q^* are getting in three-phase system. The LPF cut of frequency used in this paper is 20Hz.

The phase currents with phase shifting by 180^0 obtained in equation (12). This defines the current that flowing through the neutral of the load is compensating by to inject the same instantaneous value with the help of phase currents.

$$i_{on}^* = -(i_{Lu} + i_{Lv} + i_{Lw}) \quad (12)$$

The dq-based current reference scheme is admit the operation of linear controller in the dc-voltage control loop implementation. This is the major advantage of this proposed reference generator scheme. In the operation and determining the dq-based reference generator scheme the second harmonic component is generated automatically under balance as well as transient operating conditions. This is negligible disadvantage of this control scheme.

Mathematical analysis of Total harmonic distortion (THD) obtained from,

$$THD = \sqrt{\frac{I_{or}^2 - I_{o1}^2}{I_{o1}}} \quad (13)$$

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

$$I_{or} = \sqrt{\frac{1}{T}\int_{0}^{T} I^{2} dt} \tag{14}$$

Where, I_{or} total average RMS value and I_{o1} RMS value of fundamental component. After calculating the mathematical analysis of total harmonic distortion this values verified with FFT analysis from the MATLAB/Simulink.

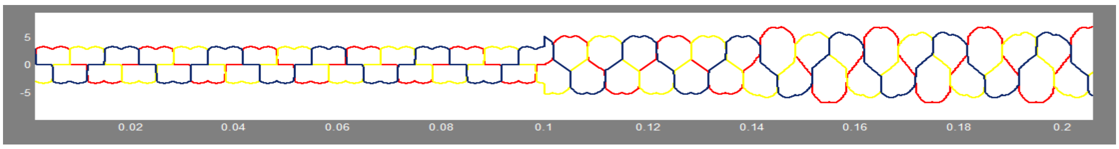
VI. RESULT AND DISCUSSION

A simulation model is developed in a MATLAB/ Simulink with parameters shown in Table-1. The main objective of proposed system is to verify the harmonic current in the system and as per required reference value the current compensation will provide. This system is developed in discrete time domain and simulation is performed on time 20us. Non-linear load use on this system is six-pulse rectifier.

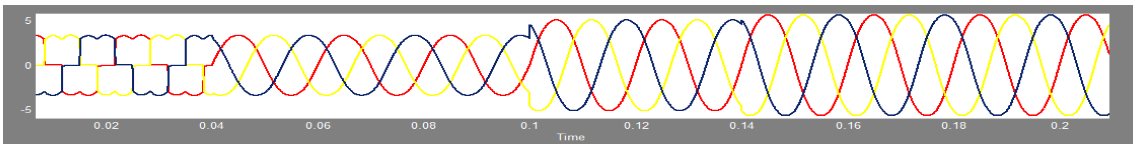
TABLE I : SYSTEM PARAMETERS

Variable	Description	Value
V_s	Source voltage	240V
f	System frequency	50Hz
v_{dc}	dc-voltage	172V
C_{dc}	Dc capacitor	2200uf (2.0 pu)
L_f	Filter inductor	5.0mH (0.5pu)
R_f	Internal resistance	0.66Ω
T_s	Sampling time	20us

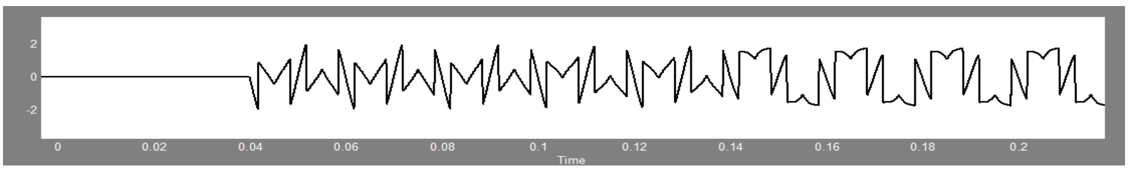
(a) Phase to neutral source voltage



(b) System currents before compensation



(c) System currents after compensation

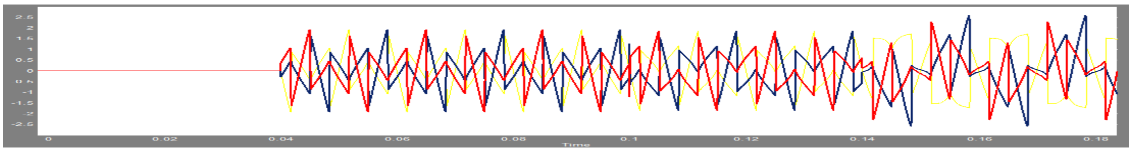


(d) Single phase active filter output current

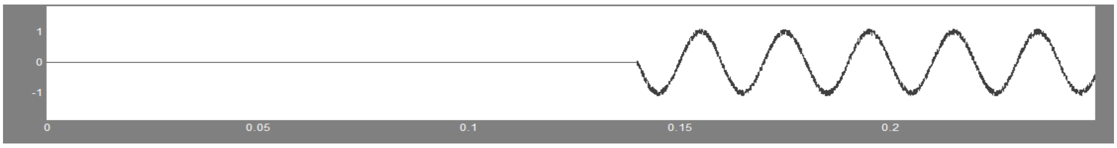
| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

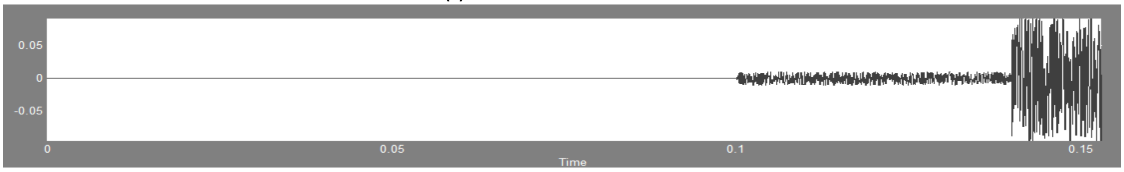
DOI:10.15662/IJAREEIE.2021.1004031



(e) Three phase active filter output current



(f) Load to neutral current

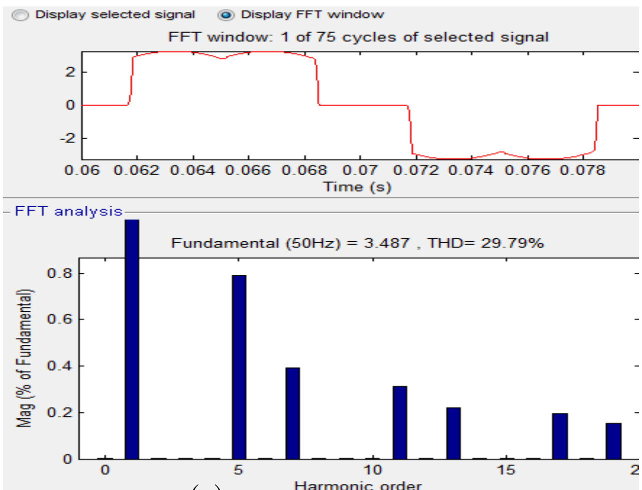


(g) source to neutral current

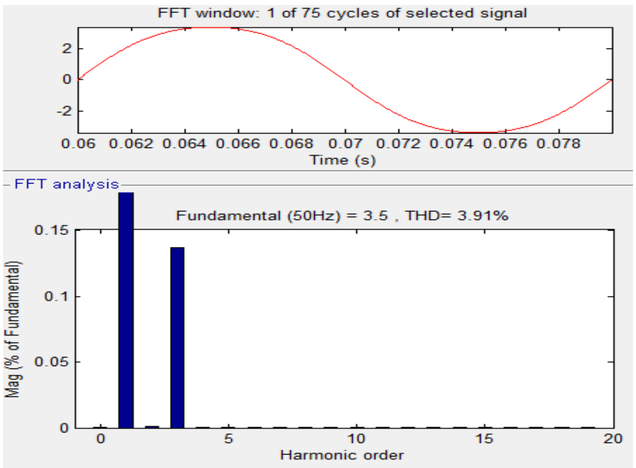
(h) DC voltage converter

Fig.7. Simulation Waveforms of the represented control scheme

The simulation results are shown in fig.7. Phase to neutral source voltage shown in fig.7(a). It is purely sinusoidal. The active power filter start compensates current on time 0.04sec which is set in MATLAB. In this time it compensates the current harmonics, current unbalance. In fig.7(b). shows a effect of current harmonics to the system currents. After compensation the current harmonics get reduced as shown in the fig.7(c). Single- Phase active power filter compensation current shown in fig.7(d). Three-Phase active power filter output current shown in fig.7(e). Neutral currents are also important part of this control algorithm fig.7(f) shows the load to neutral current and fig.7(g) illustrated the source to neutral current. To verify the effectiveness of this control method various load added in load side. The current waveform remains sinusoidal on various load changes also. Simulation results shows how this system is effectively work to eliminate the current unbalance and harmonics. After all this processes fig.7(h). shows that DC- voltage is constant in total active power filter operation.



(a) THD before Compensation



(b) THD Compensation

Fig.8. THD Comparison of proposed system

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 4, April 2021||

DOI:10.15662/IJAREEIE.2021.1004031

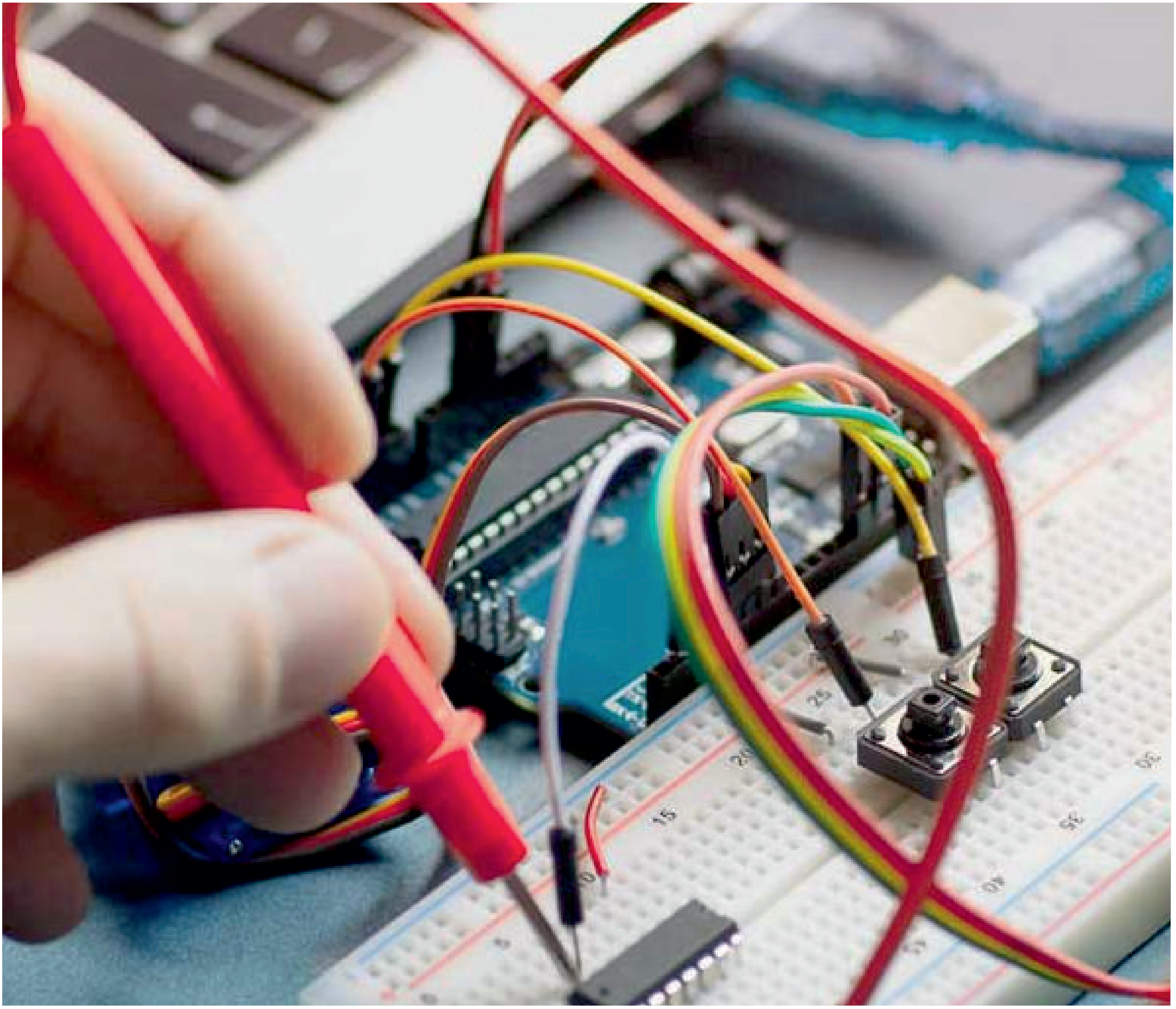
Fig.8(a). shows that THD without active power filter compensation is 29.79% which is dangerous for the system components. By using active power filter compensation with predictive current control method THD is reduced to 3.91% as shown in fig.8(b).

VII. CONCLUSION

This control scheme is improved and developed dynamic current harmonic elimination and compensation for the renewable power generation as well as distribution systems. It improves the current quality with distortion-less current. This improved control scheme associated with the simplicity, modelling and for the implementation and utilization in any power system. Main function of this prediction control algorithm is to give effective, simple and robust solution for the active power filter performance. Simulation results show the proposed predictive algorithm is suitable and effective for the active power filter operation as compared to the traditional controllers. Stable and robust solution is obtained with compensation effectiveness of proposed shunt active power filter.

REFERENCES

[1] M. Aredes, J. Hafner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *IEEE Trans. Power Electron.*, vol. 12, no. 2, pp. 311–318, Mar. 1997.
[2] S. Naidu and D. Fernandes, "Dynamic voltage restorer based on a four-leg voltage source converter," *Gener. Transm. Distrib., IET*, vol. 3, no. 5, pp. 437–447, May 2009.
[3] N. Prabhakar and M. Mishra, "Dynamic hysteresis current control to minimize switching for three-phase four-leg VSI topology to compensate nonlinear load," *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 1935– 1942, Aug. 2010.
[4] R. de Araujo Ribeiro, C. de Azevedo, and R. de Sousa, "A robust adap-tive control strategy of active power filters for power-factor correction, harmonic compensation, and balancing of nonlinear loads," *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 718–730, Feb. 2012.
[5] D. Quevedo, R. Aguilera, M. Perez, P. Cortes, and R. Lizana, "Model predictive control of an AFE rectifier with dynamic references," *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3128–3136, Jul. 2012.
[6] V. Khadkikar and A. Chandra, "A novel structure for three-phase four-wire distribution system utilizing unified power quality conditioner (UPQC)," *IEEE Trans. Ind. Appl.*, vol. 45, no. 5, pp. 1897–1902, Sep./Oct. 2009.
[7] A. Pigazo, V. M. Moreno, and E. J. Estebanez, "A recursive park trans-formation to improve the performance of synchronous reference frame controllers in shunt active power filters," *IEEE Trans. Power Electron.*, vol. 24, no. 9, pp. 2065–2075, Sep. 2009.
[8] M. Aredes, H. Akagi, E. H. Watanabe, E. V. Salgado, and L. F. Encarnacao, "Comparisons between the *p–q* and *p–q–r* theories in three-phase four-wire systems," *IEEE Trans. Power Electron.*, vol. 24, no. 4, pp. 924–933, Sep. 2009.
[9] A. Luo, Z. Shuai, W. Zhu, and Z. J. Shen, "Combined system for har-monic suppression and reactive power compensation," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 418–428, Feb. 2009.
[10] T. Geyer, "Computationally efficient model predictive direct torque con-trol," *IEEE Trans. Power Electron.*, vol. 26, no. 10, pp. 2804–2816, Oct. 2011.
[11] M. I. M. Montero, E. R. Cadaval, and F. B. Gonzalez, "Comparison of control strategies for shunt active power filters in three-phase four-wire systems," *IEEE Trans. Power Electron.*, vol. 22, no. 1, pp. 229–236, Jan. 2007.
[12] L. Czarnecki, "On some misinterpretations of the instantaneous reactive power p-q theory," *IEEE Trans. Power Electron.*, vol. 19, no. 3, pp. 828– 836, May 2004.
[13] M. Rivera, J. Rodriguez, B. Wu, J. Espinoza, and C. Rojas, "Current control for an indirect matrix converter with filter resonance mitigation,"*IEEE Trans. Ind. Electron.*, vol. 59, no. 1, pp. 71–79, Jan. 2012.



INNO SPACE

SJIF Scientific Journal Impact Factor

Impact Factor: 7.122

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर NISCAIR

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering