Harmonicsreduction Technique of 48 Pulse Converter with Pi Controller for Electric Vehicle Fast Charger

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Abstract:- Total Harmonic reduction is a present day scenario where the demand and supply needs to full fill with much efficiency. The demand for the power electronic devices for the power quality created a supply with maximum harmonic reduction as the applications are being increased in day by day world. The charging station for the electric cars needed much less harmonics as it needs to convert DC to charge the batteries. Different types of filters are implemented but these filters have more stress on the architectural point and increase the overall cost of the station. A shunt filter along with PI controller is implemented in this paper. The shunt hybrid filter is applied for high power applications with 48 pulse AC/DC converter. The 48 pulse converter is implemented with the combination of the eight six pulse rectifier in parallel and are connected with four three phase transformers. The phase shift for different transformers is achieved by using star delta connection. The main focus of this article is to decrease the Harmonics like 3rd,5th,7th and 13th . This is more economical than any other alternate rectifier and will be concisely explained and verified and simulated in Matlab and Simulink.

Keywords:- *48-pulse converter, 3 phase transformer, PI controller, Fast charger ,Electric vehicle, harmonics.*

I. INTRODUCTION

The 24-pulse converter rated up to several thousands of horsepower generally used as a front-end ac-to-dc power converter for dc drives[1].The high contents of 48-pulse related input current harmonics could combine into nearby telephone circuits and cause mis operation of protective relaying and circuit breakers. To avoid such undesirable harmonic effects, tuned passive filters[2][3] have been used on the ac side of the converter. However, passive filters cause their own harmonic problems[4],including delayed system response following disturbances and suffer from the resonance problem with undetermined system impedances, It is easy and efficient way to enhance the power quality [5][6].Active power filters might be aanswer to these problems, but the initial cost of the equipment makes it hard to put them into practical use, particularly in high-power applications. Multiple connection of thyristor bridges rises the pulse number of the converter and decreases low-order harmonic contents without increasing high-order harmonics. With parallel or series connection of two bridges, the 12-pulse converter removes the fifth and seventh harmonics in the input current. To further increase the pulse number, multiple connection of bridges and the correspondingphase-shifting transformers[7]are essential, but this raises the cost and size of the equipment [8]. Numerous multi pulse techniques based on parallel or series connection have been proposed [9]–[12]. With the present day situation electrical vehicles are been uplifting with the current fossil fuel vehicles[13]. With the increase in the electrical vehicles the carbon foot print will be decreased[14]. With the increase demand in electrical vehicles[15] the enhancement of the industry has also been in long run with contrast to the above mentioned electrical vehicles had a huge disadvantage of the constrained durations and long charging timings. The implementation for the fast charging techniques are been underway with the current implementation of fast charging systems. But with the fast charging comes with various consequences like battery overheating and quick discharge[16].This paper focus on the fast charging techniques with increasing the power quality and increases the fast charging system up to 80percent less charging time. The power converter implementation is done with reactive compensated 48 pulse thyristors. These thyristors are controlled by the Pulse Width Modulation technique[17][18]. The pulses are been varied with the capacity of the battery for the electrical vehicles. The amount of the charging current varies based on the state of charge of battery[19].The charging current is fed to the DC-DC conversion for the reduction of ripples and then the charging current is fed to the EV battery. Other writings have shown the similar configurations while with different ac-dc converter stages [20]–[22].With the implementation of the multiple pulse converters the amount of charging time is significantly reduced .

II. BLOCK DIAGRAM

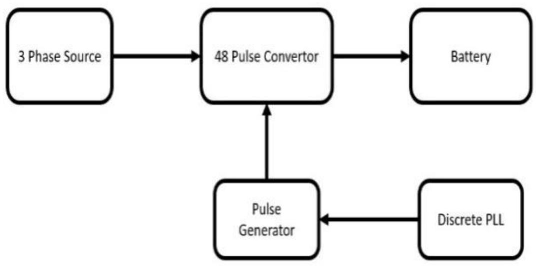

Fig 1:-pBlock Diagram

2.1 Three Phase Source

The balanced voltages in three phase system are

$E_a=E_m \sin(wt)$ (1)
$E_b=E_m \sin(wt-120)$ (2)
$E_c=E_m \sin(wt+120)$(3)

The 3ph Source block employs a balanced 3ph voltage source with an inner R-L impedance. The three voltage sources are connected in Y with a neutral connection that can be internally grounded .Also source internal resistance and inductance by directly entering R and L values or indirectly by specifying the source inductive short-circuit level and X/R ratio.

$\mathbf{P = VI\ Cos}\ \emptyset$ (4)

V - voltage of 1ph, i.e. V_{ph}
I - current of 1ph, i.e. I_{ph}
Cosϕ- power factor of circuit.
Power in three phase system is

$\mathbf{P = 3\ Vph\ Iph\ Cos}\emptyset$ (5)

III. CONVERTER TOPOLOGY 48 PULSE

The forty eight multi pulse converter obtained from joining eight six multi pulse rectifier in equivalent, these rectifier are related with four 3 phase transformers. The vibe of post eight multi pulse converter essentially focuses on Harmonics, diode rectifiers is used for AC/DC conversion. Regardless of the way that its diminishes the low harmonic, in any case the AC yield voltage from transformer would have 48n±1. At any rate this 48 multi pulse converter is commonly incredible than some other electrical rectifiers and was checked and energized by using MATLAB and SIMULINK programming. 48 multi pulse converter action, working of stage moving transformers by delta to star and delta to delta. A 12-pulse rectifier is obtained by interfacing two 6-pulse rectifiers dealt with from two 3-phase systems stacked by 15º. The 48-pulse rectifier topology is associated with four 12-multi pulse rectifier structures which means joining of eight 6-pulse rectifiers from eight 3-phase systems moved by both 15 º and 30º.Four 12pulse converter, Phase move by 7.5 degree from one another, can give a 48-pulse converter. Its voltage would have 48n± 1 ,eg; 47th, 49th, 95th, 97th Harmonics, with extents of 1/47th, 1/49th, 1/95th, 1/97th, correspondingly.48-pulse with eight six-multi pulse one lot of transformers of one 24-pulse converter stage moved from the other by 7.5 degree, or one set moved by +3.75 degree and the other by - 3.75 degree. Fig.2 illustrates the general design of 48-pulse dc converter. The rectifier has eight indistinguishable units of 6-pulse diode rectifiers by a stage moving transformer.

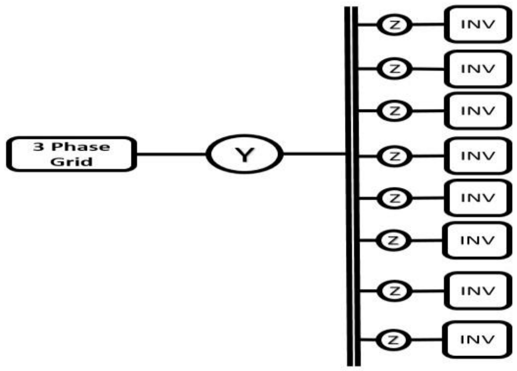

Fig 2:- 48-pulse ac-dc converter configuration

For48-pulse ac-dc converter the needed phase displacement amongst two adjacent secondary winding voltages is 7.5º and the typical values of δ are -26.25º,-18.75º, -11.25º, -3.75º, 3.75º, 11.25º, 18.75º and 26.25º

A. Calculation of Form and RippleFactor

In Fig 3 shows the effect of form factor and ripple factor. For design of FF and RF, RMS and Mean value block, by this block find the RMS and average value of output voltage. This values are used for calculating the Form factor and Ripple Factor of the output voltage, by the formula given in equations 1&2

FF= RMS value/ Mean Value (6)

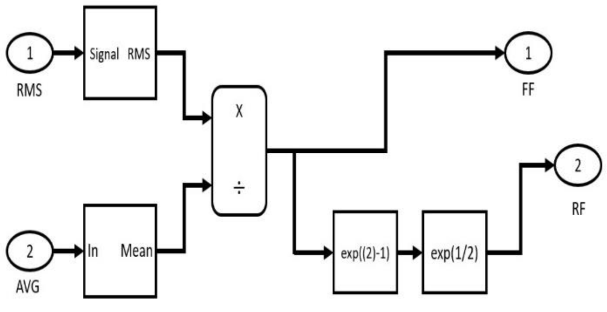

Fig 3:- Modelling for ripple factor & form factor

$RF = \sqrt{FF^2} - 1(7)$

Total Power 4.8KV power triangle V cos $\boldsymbol{\theta}$
RMS valve 3.84KV, Mean Valve 2.4KV
Form factor 1.6 ripple factor 1.24

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B. Phase Locked Loop

The PLL is a feedback technique used in motor speed control. The simple PLL can be analog or digital.

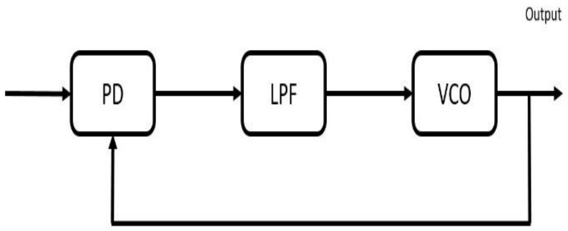

Fig 4:- Basic Phase Locked Loop.

The main components of a PLL are Phase Detector (PD), Loop pass filter (LPF), Voltage controlled oscillator (VCO). These elements are connected with feedback framework as shown in Figure 3. The reference signal is periodic eg;sine wave (or square wave) which is contrasted and the yield of VCO utilizing a phase detector. The yield of stage identifier is then low pass with a control sign to drive a voltage controlled oscillator inherently non-linear. The major source of non-linearity is the phase detector. using a little sign supposition and the way that the multiplication operator is continuous, then the basic PLL can be estimated by a linear second order system similar to a position servo.

C. PLL Analysis

Input signal of PLL is sine wave
r (t)=Asin(w_rt+θ_r)(8)
output signal for the VCO is assumed to be
y(t)=cos(w_yt+θ_y)(9)

The phase detector is a multiplier & output from the phase detector is the product of reference and VCO signals.
e(t)=KAsin(ω_rt+θ_r)cos(ω_yt+θ_y)(10)

This can be expanded
e(t)=$\frac{KA}{2}\left[\left((sin\omega_r + \omega_y)t + \theta_r + \theta_y\right) + \sin\left((\omega_r - \omega_y)t + \theta_r - \theta_y\right)\right]$ (11)

This first term on right of expression in high frequency term is filtered by low pass loop filter. assuming$\omega_r \approx \omega_y$ then output from multiplier can be estimated by:

$$e(t) = K_m[\theta_r - \theta_y] \quad (12)$$

The error signal is a gain multiplied by phase difference between reference signal and the signal from VCO. Usually the LPF is a first order low pass filter.

$$F(s) = \frac{K_f}{\tau_f s+1}(13)$$

And phase is integral of angular velocity the VCO is modelled as

$$VCO(s) = \frac{K_0}{s}(14)$$

Combining these transfer functions provides the loop gain

$$\boldsymbol{L(s)} = \frac{\boldsymbol{K_t}}{\boldsymbol{s(\tau_f s+1)}} \quad (15)$$

$$K_t = K_m K_f K_0$$

Can be recognized as the transfer function of a position servo. The closed loop dynamics are

$$\boldsymbol{T(s)} = \frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2} \text{where } \omega_n = \sqrt{\frac{K_t}{\tau}} \text{ and } \zeta=\frac{1}{2\sqrt{\tau K_t}}(16)$$

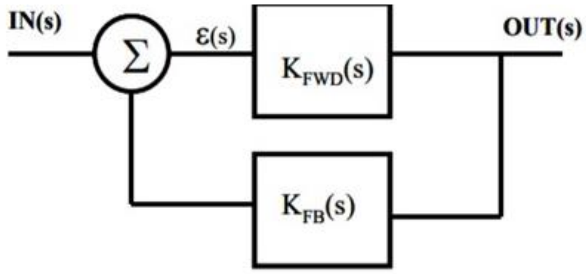

Fig 5:- PLL Feedback system

Loop gain:$T(s) = K_{FWD}(s)K_{FB}(s)$ (17)

Transfer Function:$\frac{OUT(s)}{IN(s)} = H(s) = \frac{K_{FWD}(s)}{1+T(s)}$(18)

loop gain described as a polynomial

$$\boldsymbol{T(s)} = \frac{K'(s+a)(s+b)\ldots}{s^n(s+a)(s+b)\ldots}(19)$$

Order = order of polynomial in the denominator
Type= n

Phase Error = $\boldsymbol{\varepsilon(s)} = \frac{IN(s)}{1+T(s)}$(20)

Steady State Order =$\boldsymbol{\varepsilon_{SS=\lim_{s\to 0}[s\varepsilon(s)]=\lim_{t\to\infty}\varepsilon(t)}}$

SS error is a feature of feedback control systems. This is the error left over in loop at the phase detector output when all transients have died out. Once again, a large loop T(s) leads to small phase error.

D. Effect of harmonics

Harmonics gives a scientific investigation of multi direction to a current or voltage waveform.

➢ *Calculating THD*

THD is the ratio of root mean square (RMS) voltage of all the harmonic frequencies over the RMS voltage of the fundamental frequency Equation21 shows the mathematical definition of THD.

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} v_{n\_rms}^2}}{V_{fund\_rms}} \quad (21)$$

$V_{n\text{-rms}}$ is - RMS voltage of the nth harmonic.
$V_{fund\text{-rms}}$- RMS voltage of the fundamental frequency.

The amplitudes of harmonics are required to compute the THD, Fourier analysis can be applied to help decide THD. The fourier series representation of the 50percent duty cycle square wave as follows.

$$v_{square}(t) = \frac{4}{\pi}\sum_{n=1,3,5,..}^{\infty}\frac{\sin(2n\pi ft)}{n} \quad (22)$$

Assuming a square wave has a lot of harmonic distortion was based on visually examining the square wave in the time and the frequency domain. A square wave actually has about 48.3% total harmonic distortion meaning that the RMS of the harmonics is about 48.3% of the RMS of the fundamental frequency.

➢ *Measuring Total Harmonic Distortion*

THD is determined to find the RMS value of fundamental frequency and all the harmonics.

$$THD = \frac{V_{RMS\_Without\_Fundamental}}{V_{RMS\_Fundamental}} \quad (23)$$

This technique is simple to get measurements. The noise included in measurement to get a measurement of THD plus noise. The complex signal includes all repeating waveforms which are not sinusoidal. The 2ndharmonic has double frequency of main frequency, thus, nth harmonics have frequency equals to (n*f). where (f) is main source frequency, n =1,2,3,.....,∞ Harmonics are separate and even components, when signal has difference between positive half and negative half, even components will appear (2nd,4th,..) and some odd components exist as well. f (t) of any signalwithcycle of 2π is expressed as

$$f(t) = a_0 + \sum_{n=1,2,...}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t) (24)$$

Where a_0 is the DC level of main signal,($a_n\cos n\omega t$+$b_n\sin n\omega t$) is the nth component for the signal $a_0, a_n and b_n$ calculated using the formulas (25-27)

$$a_0 = \frac{1}{2\pi}\int_{2\pi}^{0} v_t d\omega t \quad (25)$$

$$a_n = \frac{1}{\pi}\int_{0}^{2\pi} v_t \cos n\omega t\, d\omega t (26)$$

$$b_n = \frac{1}{\pi}\int_{0}^{2\pi} v_t \sin n\omega t\, d\omega t (27)$$

Formula (24) could be given in (28)

$$f(t) = a_0 + \sum_{n=1,2,3...}^{\infty} c_n \sin(n\omega t + \emptyset_n) (28)$$

Where $c_n = \sqrt{a_n^2 + b_n^2}\emptyset_n = \tan^{-1}\frac{a_n}{b_n} c_n \& \emptyset_n$ is amplitude and angle of nth element of the signal

➢ *Causes & Results of Harmonics:*

- cause high temperatures during switching in every electrical equipment connected.
- high switching loss creates nonlinear switching and faults in the load connected.
- The harmonics effects in overheating of the electrical equipment.
- voltage distortions and current distortions commonly takes place which impact the overall decrease in the voltage and power of the system.
- Creates interference in rest of the communication cables.

IV. DESIGN

A. Designing of The Rectifier Topology

The rectifier topology is intended for a DC yield voltage of 600V.The four combined arrangement diode extensions deliver a yield voltage of 600V, thus, the DC voltage gave by each one extension = 600/4 = 150V. The DC yield voltage of a 3-phase diode extension is given by, Vm = Peak voltage input voltage and the respective is Vrms voltage is provided as follows

V_0 =(3/pi)*Vm
Vrms= Vm
So, Vrms = 3.84 KV

So, the line voltages of every one of the four secondary windings to be 3.84 KV.

B. Phase Shift Transformer

The primary winding of transformers are connected in zigzag, while secondary windings of transformer are connected in series to converter. According to the winding arrangements, the transformers can be classified into star/zigzag and delta/zigzag configuration, where the primary winding can be connected in wye or delta and the secondary winding is normally in zigzag connection. Both configurations can be equally used into rectifiers.

Primary in delta connected:
Line voltage on primary side = Phase voltage on Primary side.
Transformation Ratio (K) = Secondary Phase Voltage / Primary Phase Voltage .
Secondary Phase Voltage = K x Primary Phase Voltage.
Secondary in Star connected
Line voltage on Secondary side = √3 x Phase voltage on Secondary side.
Line voltage on Secondary side = √3 x K x Primary Phase Voltage.
Line voltage on Secondary side = √3 x K x Primary Line Voltage.
There is +30 Degree or -30 Degree Phase Shift among Secondary Phase Voltage to Primary Phase Voltage

C. State of Charge, SOC

The state of charge, SOC is an indication of amount of electricity left over in the battery.

$$SOC = \frac{Q_{Remaining}}{Q_{Nominal}} \quad (29)$$

D. Selection of Battery

Batteries for electric vehicles have complex charging/discharging attributes and have

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comparativedamageable features, It is essential to determineprecise battery models for effective design of charging station. Batteries used for electric vehicle are lead acid, Ni-Cd, Ni-Mh, Li-ion etc. Amongst these lithium-ion is the best choice for electric vehicle. The nominal voltage, ampere hour, capacity, life, specific energy, energy density, charging cycle, internal resistance, cost etc are the reasons to be considered whenchoosing a battery . Energy density and life cycle is nearly 2.5 times than of lead acid battery.

E. Selection of Battery Charger Unit

DC-DC Buck converter is used for charging of electric vehicle. The buck converter converts a high voltage to low voltage and efficient power conversion extents battery life, reduce heat etc. The unit contains a single IGBT which performs buck mode of operation and the inductor and capacitor acts as a low pass filter. low pass filter smoothest the IGBT switching action and produces smooth dc voltage.

F. PI-controller

This control the output power represented as I_{max} and control the DC power and voltage. The error in PI controller is symbolized as error (e) which passes through the controller in a steady state as in DC voltage. The transfer function H(s) is defined as

$$H(s) = K_p + \frac{K_1}{s} \quad (30)$$

$$Output(I_{max}) = e * K_p + K_1 \int edt \quad (31)$$

KP - proportional constant decides the dynamic response of voltage control.
KI- integration constant decides settling time.

G. Multi-Pulse Methods

The increase in number of output voltage within a particular time interval with eventual increase in number of pulse to trigger source voltage is multi pulse method. Multi pulse method is usually implemented in high power applications with three phase transformers and heavy power electronic systems. The amount of pulses is based on the type of application and level of harmonic reduction in resultant supply. The multi pulse method designed in this paper consist of triggering pulses from 6, 12, 18, 24, 30, 36, 48 pulses. These pulses are connected to thyristor in circuit with series and parallel combination of bridges.

V. SIMULATION DESIGN REQUIREMENTS

The idea of this system is to decrease the harmonics to end where we could able to achieve the pure DC for charging batteries at any given time and also best utilize of the system while controlling the pulses with the state of charge. The circuit consisting of the supply from distribution station to the phase transformer and then supplied AC and is converted to DC with IGBT by fuzzy logic controller and PI controller. In this charging system the complete charged battery is controlled by SOC from the battery. The supply of 400KV AC is fed from the distribution station is then its converted by the phase transformer using Delta/Star transformer which converts AC to pulsated DC which further converts it into the DC in later stages. This conversion is used by using with IGBT by PI controller as the pulses can be varied from six pulses to 48 pulses with the variable inductor and variable capacitor in parallel to the battery for reducing the leakage current from the battery. From the battery SOC is measured which acts as the feedback for the controller and the pulses are reduced until the battery is completely charged. The charging system is capable of charging the many different schemas like level-1, level-2 and level -3.The controller connected after the battery for ideal switching and the switching is done using discrete PLL with balancing of the temperature and also reducing the total harmonic distortionwith multi-level current control. The EV battery needs to be protected from the sudden changes of current and voltages which affects the battery performance. To avoid such scenarios the battery is connected with the IGBT which acts as the current control with the circuit current flow. This state of protection needed to keep the battery intact and maintain its performance with the variation of currents. The control strategy of the converter is based on the PI controller and the pulses are been controlled with Discrete PLL

- *Simulation Results*

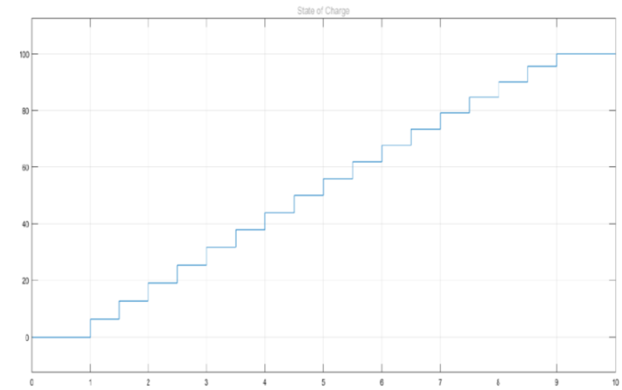

Fig 6:- State of charge

State of charge is the level of charge of an electrical battery related to the capacity. When the EV is plug in the State of Charge (SOC) is calculated and the graphical representation is displayed. The sequential steps are related to the multi-level charging strategy of charging battery.

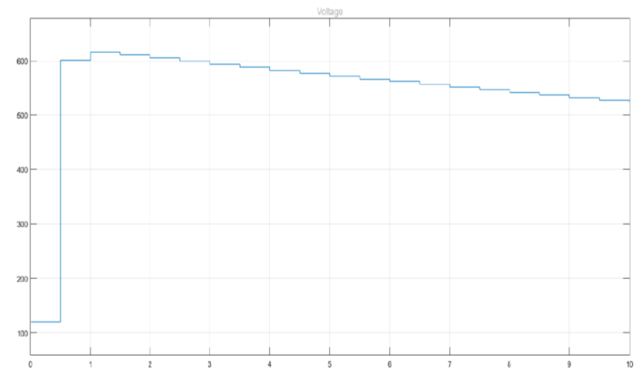

Fig 7:- Battery voltage.

A electrical battery voltage is considered as many hundreds of small individual cells arranged in series and parallel combination to achieve a desired voltage. This voltage higher which allows more power transfer with less load. Here the voltage initially increases but decreases gradually as the voltage isproportionalto temperature and temperature increases creates as permanent damage to the EV battery.

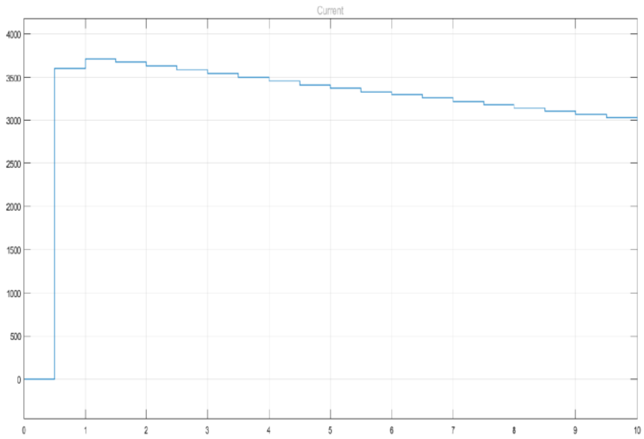

Fig 8:- Battery Current

Same as the voltage graph the current graph initially increase but then decreases. Battery Management System is controlled inside the EV as well as the charging station. The amount of current is high when compared to the current it delivers There are standards for the charging stations. Here as per the Indian standards the charging current is in the range of level-3.

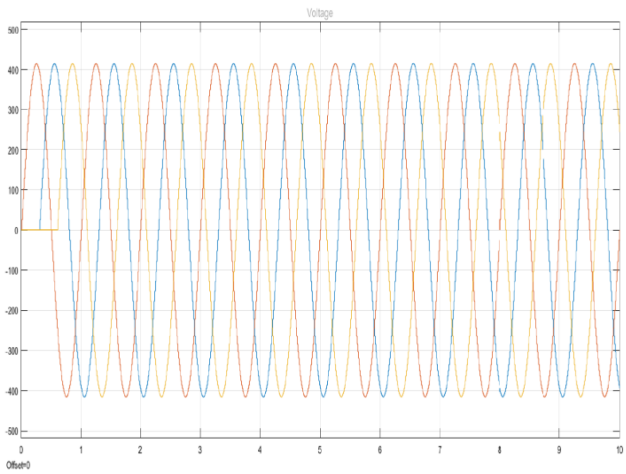

Fig 9:- Supply voltage

The supply power is in three phase supply with 50 Hz Frequency. The phase angle between three phases is of 120 degrees as part. The supply is from the main grid.

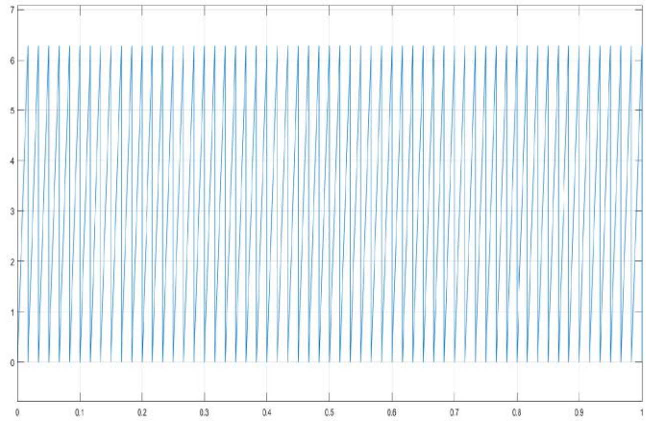

Fig 10:- Switching wave of single Quadrant

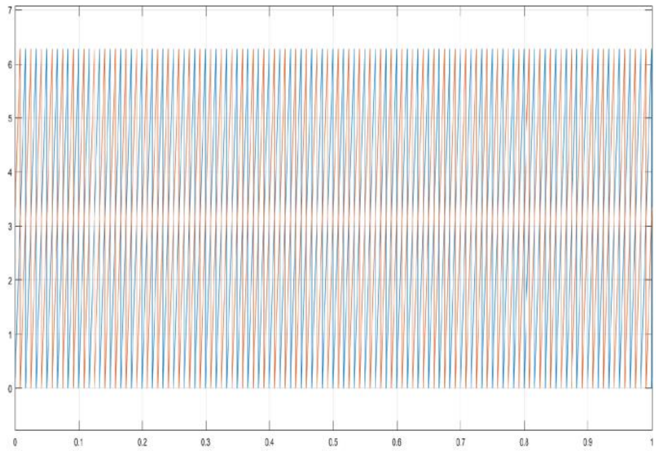

Fig11:- Switching Wave for All Four Quadrants (Q_1, Q_2, Q_3 and Q_4)

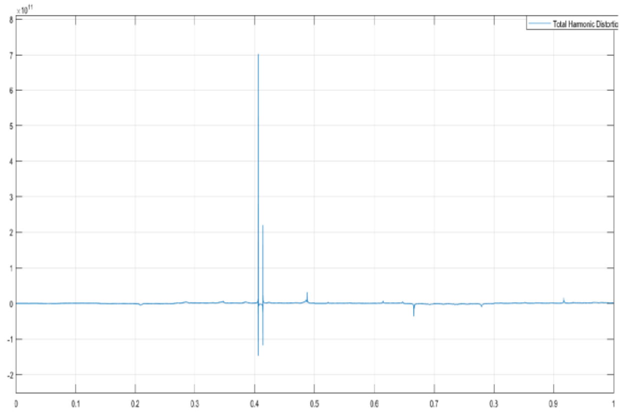

Fig 12:- THD Analysis of 48 Pulse

The total harmonic reduction is the calculation of the harmonic distortion present in a signal and is the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Here the total harmonic reduction is reduced to much extent so that only a single harmonic is represented in the total harmonic distortion calculation.

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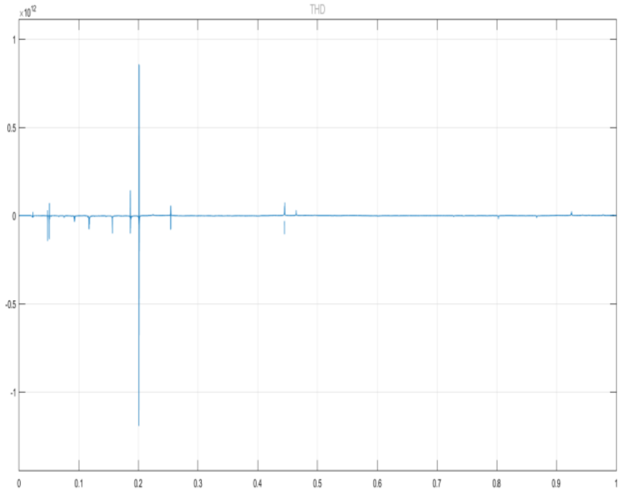

Fig 13:- THD Analysis of 36 Pulse

Here the total harmonic reduction is reduced much extent so that two a dual harmonic is represented in the total harmonic distortion calculation

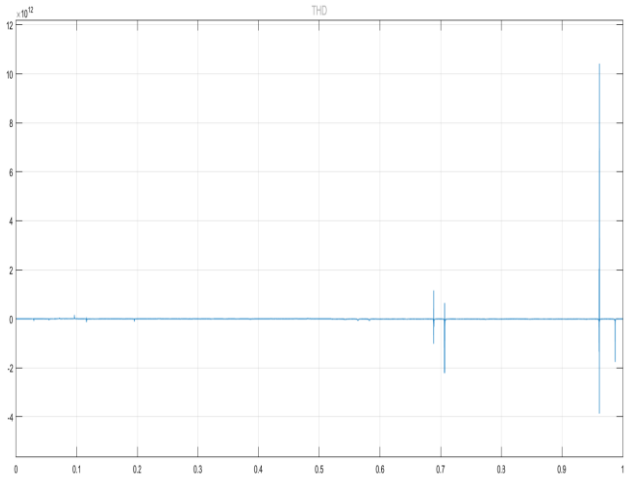

Fig 14:- THD Analysis of 24 Pulse

Here the total harmonic reduction is reduced much extent a quadrant harmonic is represented in the total harmonic distortion calculation.

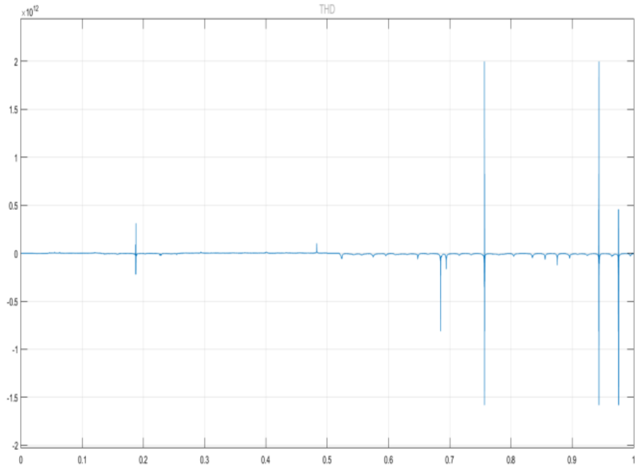

Fig 15:- THD Analysis of 18 Pulse

Here the total harmonic reduction is reduced much extent so that six a six harmonic is represented in the total harmonic distortion calculation.

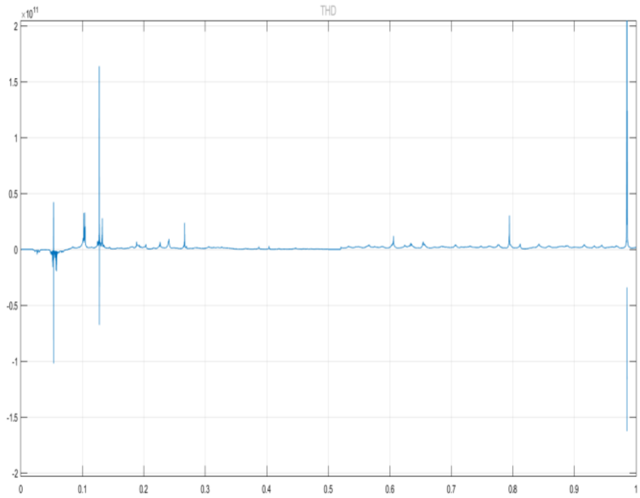

Fig 16:- THD Analysis of 12 Pulse

Here the total harmonic reduction is reduced much extent so that many harmonics is represented in the total harmonic distortion calculation.

VI. CONCLUSION

The waveforms of the voltage and current are been distorted as with the presence of the harmonics. Different filters have been implemented with the combining of the passive and active filters. With the proposed architecture the combined Hybrid filter provides a potential to the voltage and current. The complete harmonic reduction is carried out by the Hybrid power filter with interfacing with PI controller. The complete model is validated using the Matlab/Simulink. In this paper the complete architecture is designed using 48 pulse AC/DC converter with phase shift transformersWith minimum architecture and less switching strategy the design is implemented with variable voltage and power applications and with large applications to be considered and could able to deliver clean DC power with any harmonics for the improvement of the system and its appliance performance.

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