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HARMONIC COMPENSATION BY IMPLEMENTING HYBRID ACTIVE POWER FILTER

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ABSTRACT

Hybrid active power filters are mainly used to achieve better effect and to improve the performance of passive filters which are tuned. This paper deals with a particular conditioner which removes the tuning of passive filter. This conditioner is known as smart impedance. In this method tuning is achieved by electronically. By using smart impedance method phase locked loop system is avoided. Harmonic currents with multiple frequencies also compensated. To achieve perfect harmonic tuning proportional resonant controller is incorporated in the system. This topology handles the displacement power factor in effective manner.

Keywords: Hybrid active filter, smart impedance, proportional resonant controller.

I. INTRODUCTION

Industrial sector is facing the problem like power quality issue due to use of non-linear loads. Also such non-linear load causes the harmonics which results into the increase in the current in given system. Harmonic mitigation can be either done by utilizing passive filter solutions or by active filter solutions [1], [2]. Nowadays passive filters are replacing with the active filters. This is because passive filter suffers from certain limitations resulting into low efficiency. Quality factor, tuned factor and source equivalent impedance decides the efficiency of passive filters . [3], [4].

Figure 1 shows the working block diagram of smart impedance topology. Hybrid active power filters can be use in the system where passive filters are present previously. This improves the physical limitations of passive filters and high cost of active power filters. [5], [6].

It should be noted that all the topologies such as active resistance and active inductance together with active or smart impedance are already present. Although the topologies are presented previously the working of smart impedance is differ from hybrid active power filter. This is because for fundamental and various harmonic frequencies, the proposed design of filter offers different equivalent impedances. The working of proposed topology is not limited only for extension of tuned passive filter. Required components of this given topology are power converter as a active filter, coupling transformer and capacitor bank. Here capacitor bank is used as tuned passive filter. So that by proper controlling multiple numbers of harmonic frequencies can be filtered out without any presence of inductor and passive filter tuning [7].

Smart impedance presents null impedance for preferred harmonic frequencies, offering an excellent quick for the burden modern harmonics. On the alternative hand, it turns into endless impedance for supply harmonic voltages blockading the polluted currents which arises from voltage supply disturbance.

This paper consisting of section 2 having the conceptual basics of smart impedance, section 3 having control of proposed topology, section 4 containing the result and related conclusions are discussed in section 5.

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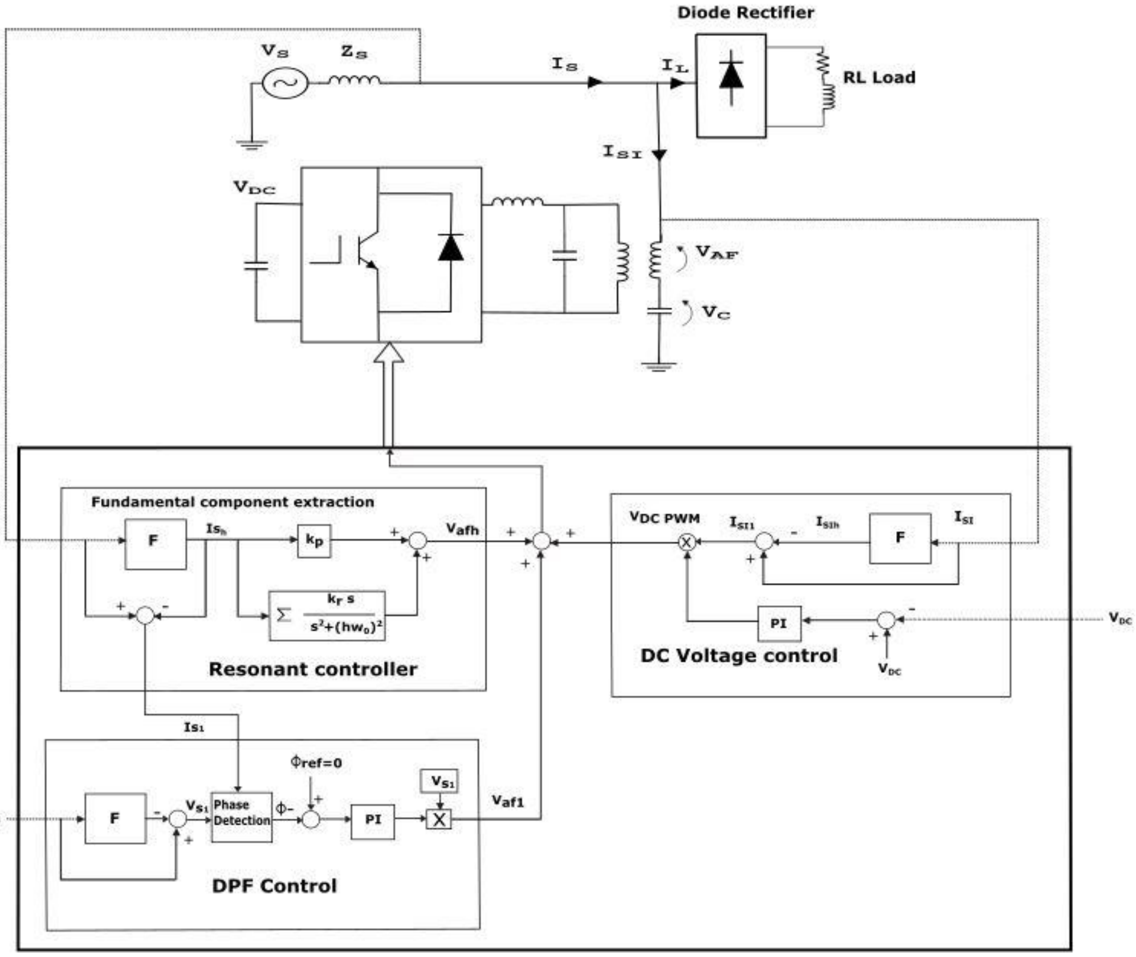

Figure 1. Block Diagram of Smart Impedance

II. METHODOLOGY

Basics of Smart Impedance:

Fig. 2 shows the equivalent circuit of single phase smart impedance harmonic compensator. Assuming a source voltage as a pure sine wave i.e. Vsh=0.

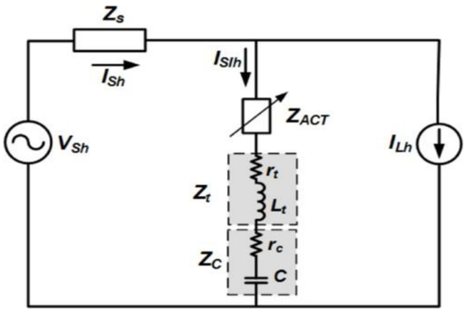

Figure 2: Single phase equivalent harmonic circuit of smart impedance.

With the help of above circuit diagram, source having harmonic current named as I_{sh} is expressed as

$$I_{sh} = \frac{Z_t+Zc+Z_{ACT}}{Z_s+Z_t+Zc+Z_{ACT}} I_{Lh} \quad (1)$$

Where

Z_s = source impedance,

Zc = coupling transformer impedance,

Z_{ACT} = active impedance produced by active filter,

I_{Lh} = load harmonic current.

For ideal system $Z_t + Zc + Z_{ACT}=0$. Hence I_{Lh} will flow through filter rather than source. So that Z_{ACT} is controlled as

$$Z_{ACT} = -(Z_t + Zc) \qquad (2)$$

Presently, for chosen frequency (ω), the dynamic impedance ought to be acclimated to electronically tune the keen impedance

$$\omega = \frac{1}{\sqrt{(La+Lt)C}} \qquad (3)$$

Note that $Z_t = r_t + j\omega L_t$ is impedance of coupling transformer and $Zc = rc + \frac{1}{j\omega C}$ is impedance of capacitor.

From the equation (3), it is clear that desired harmonics can be eliminate by creating different active inductances and also multiple tuning frequencies at a time can be achieved. [8], [9].

Here the problem of residual resistance arises due to active resistance (ra). This problem can be eliminated by

$$ra = -(r_t + rc) \qquad (4)$$

In this way residual resistance is eliminated and proper tuning can be achieved. So that hybrid branch becomes a perfect close path for contaminated load current and contaminated voltage becomes zero. Harmonic current (I_{sh}) arising in source voltage due to V_{sh} is given as

$$I_{sh} = \frac{V_{sh}}{Z_s+Z_t+Zc+Z_{ACT}} \qquad (5)$$

Capacitor bank should be isolate from harmonics of supply voltage and resonance can be avoided between supply and passive circuit. This can be achieve only when the hybrid branch provides infinite impedance to V_{sh}.

I_{sh} will be null for both conditions under ideal compensation. Therefore the net impedance for smart branch for every harmonics (Z_{SIh}) should be

$$\{Z_{SIh} = \infty, \quad \text{for } V_{sh},$$

$$\{Z_{SIh} = 0, \quad \text{for } I_{Lh}. \qquad (6)$$

The active filter is able to generate voltage which required to supply targated voltage to inflict voltage V_{afh}

$$\dot{V}_{afh} = \dot{V}_{sh} + (\dot{Z}t + \dot{Z}c)\,\dot{I}_{Lh} \qquad (7)$$

Infinite branch impedance arises due to the term V_{sh} as it doesn't allow contaminated current to flow from source to filter branch. And the term $(Z_t + Zc)I_{Lh}$ removes harmonic voltage drop present in hybrid branch owing to harmonics presented in I_L. i.e. zero impedance is provided to harmonics. These two impedances makes the given system as smart impedance.

III. CONTROL STRATEGY

Compensation of harmonics -

Proposed control calculation given in this paper is anticipated on Proportional Resonant regulator (P + Resonant) which is that numerical change of the coordinated edge with PI regulator [10].

Expression for controller is given as:

$$C(s) = k_p + \frac{kr\, s}{s^2+\omega^2} \qquad (8)$$

where

k_p= proportional gain,

k_r= resonant gain,

ω= frequency of resonance

Sinusoidal reference with zero steady-state error is provided by resonance frequency at high gain. An equal attributes PI regulator presents for dc reference so that reference change and PLL synchronization calculation can be evaded. This is because the reference current signal is tracked from the error signal. With the help of notch filter from the source current harmonic contents in source I_{sh} is achieved. Transfer function for this extraction is given as:

$$H(s) = \frac{s^2+\omega_0^2}{s^2+2\omega_c s+\omega_0^2} \qquad (9)$$

where

ω_c = bandwidth of notch filter,

ω_0= frequency of rsonance

Here ω_0 is 376.8 [rad/s] as a fundamental frequency and ω_c is 31.4 [rad/s]. In this topology the harmonic current produced due to load flows through the smart impedance branch. Also harmonics due to source voltage gets blocked. Resonance among harmonic filter and source impedances is avoided because resonance damping is provided by harmonic source current feedback. Several harmonics frequencies are mitigated with multiple controllers connected in parallel, at a time:

$$C(s)= k_p + \sum_{h=3}^{21} \frac{k_r s}{s^2+(h\omega_0)^2} \quad (10)$$

Tuning of smart impedance is done by generating voltage reference V_{afh}. . And this voltage is generated by adding all P + Resonant regulators for each frequency. Tuning of this type of controller is done by various methods.[12], [13], [14]. Zero order hold method is used for discretization by P + Resonant controller.

Compensation of displacement power factor -

By using eq. (9), V_S the source voltage component and I_S the source current component at fundamental frequency is achieved. Phase difference between these two components is obtained from zero-crossing method. Amplitude of active filter voltage V_{af} is controlled by phase error signal which is given to capacitor in series Voltage across capacitor bank at fundamental frequency is:

$$V_C = V_S - V_{af} \quad (11)$$

Since the phase difference between V_C and V_S is not much. This is due to the fact the voltage drop at essential frequency is low. Hence V_S is incorporated as Displacement Power Factor control reference rather than V_C.

Control of dc link :

It is required to keep voltage of dc link at reference value. This aim is achieved by operating the active filter as pulse width modulation rectifier. To do that the voltage is taken throughout the coupling transformer which ought to be actually in stage with the current of capacitor bank at essential frequency. In this way dc link voltage becomes stable. Also this approach supplies the filter losses. Generation of reference for dc link control is obtained with Phase Locked Loop (PLL) algorithm. [15], [16]. The proposed topology is free from PLL. With the assist of notch filter, essential frequency sinusoidal reference is accomplished from the current of hybrid filter.

IV. RESULTS AND DISCUSSION

Analyse of results of the proposed topology without as well as with hybrid active filter MATLAB/Simulink is used. For a single phase system R-L load having resistor of 5 ohm and inductance of 0.001H is connected with diode rectifier. This load is connected with hybrid active power filter. Simulation results of this non-linear load containing system are discussed as below.

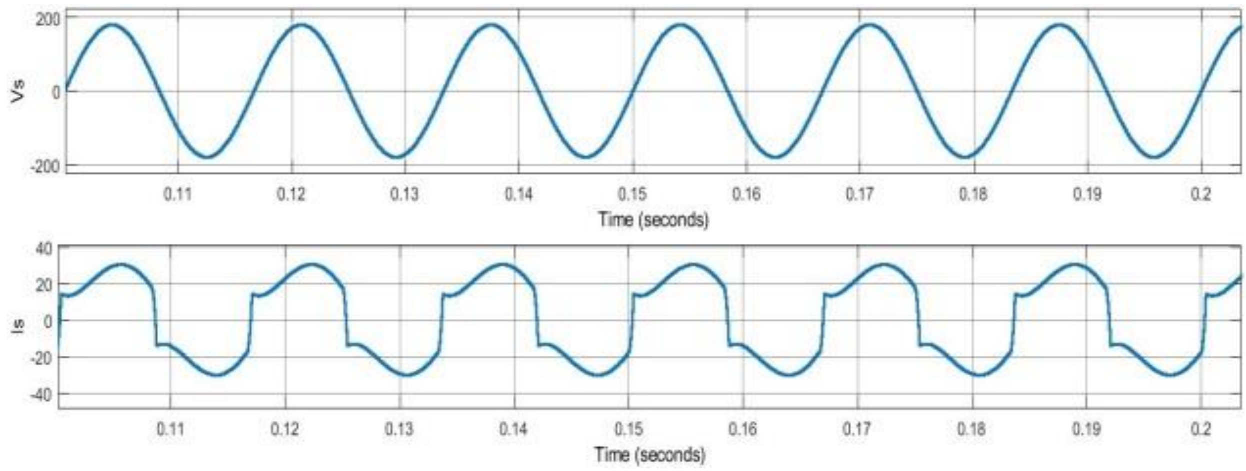

Figure 3(a): Source voltage and source current without filter.

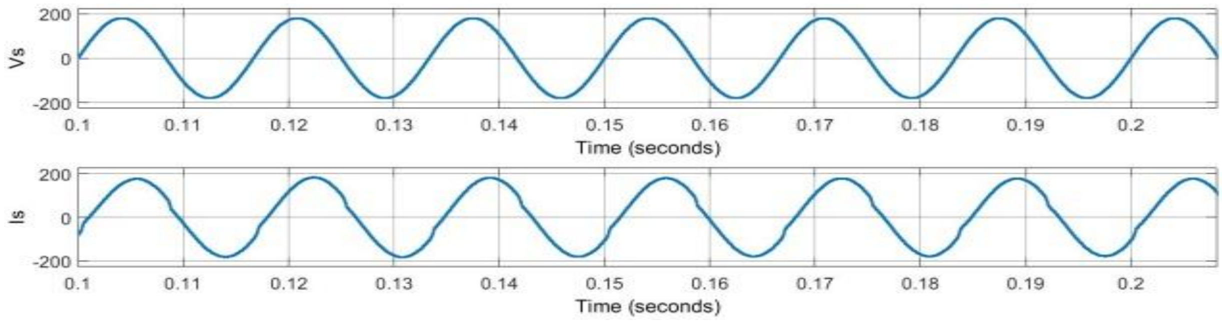

Figure 3(b): source voltage and source current with filter

Figure 3(a) shows the output waveform of source voltage and source current without filter. Due to the presence of distortion the source current get disturbed. It is clearly seen that current is not sinusoidal in nature. Figure 3(b) shows that the distorted source current is improved at much better level. This is achieved when Hybrid filter is incorporated in given system. Obtained waveform is nearly sinusoidal in nature.

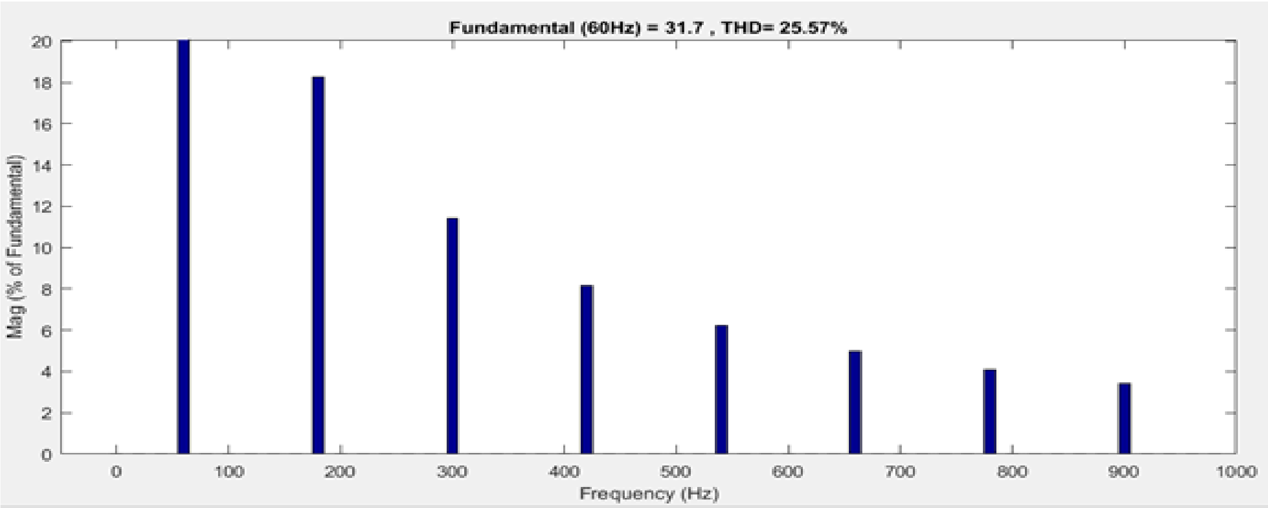

Figure 4(a): THD analysis without filter

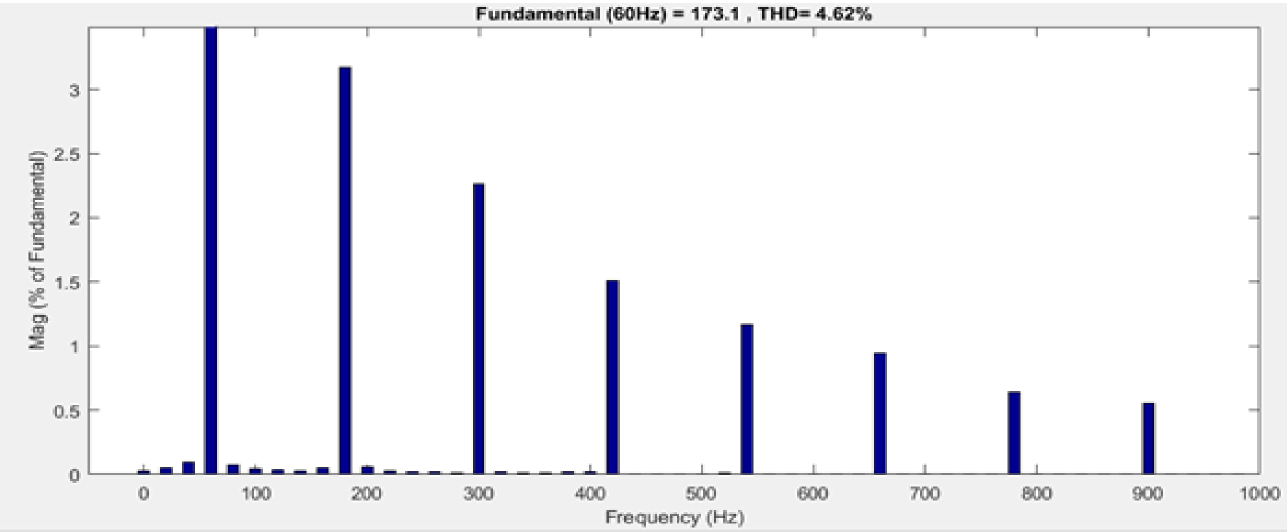

Figure 4(b): THD analysis with filter

Figure 4(a) and (b) representing the total harmonic distortion (THD) without and with filter respectively. Absence of filter allows the more harmonics in system making the high THD. THD without conditioner is 25.57% which is clearly seen in Figure 4 (a). When smart impedance branch comes into the picture, then this THD drops to 4.62%. By observing Figure 4 (b) it will be clear.

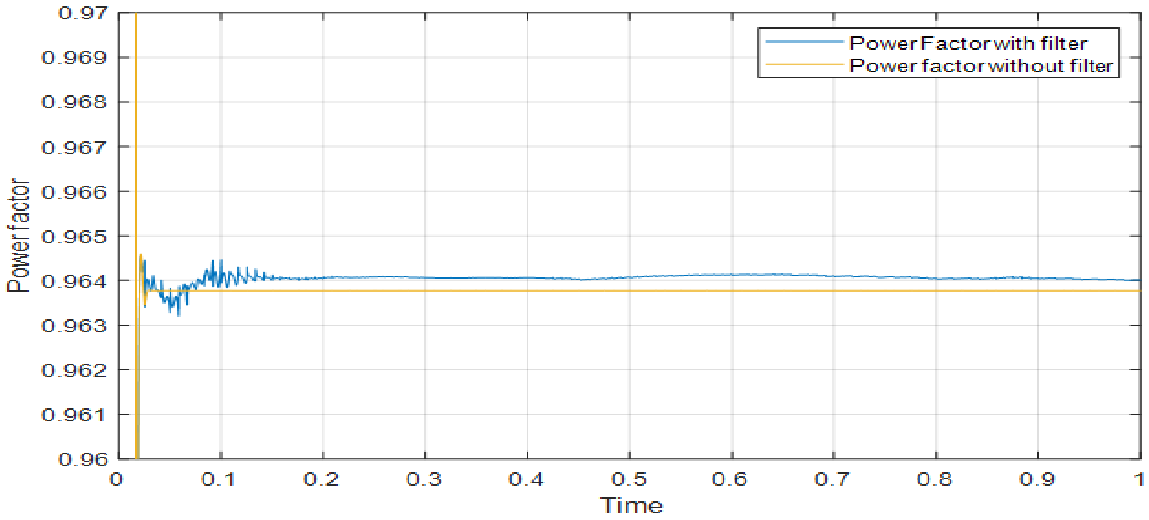

Figure 5: Power factor with and without filter

Figure 5 represents the two power factors in same graph. One when smart impedance branch is absent and second when smart impedance branch is present.By comparing these two signals it is clearly seen that there is little difference in between them. Power factor with filter branch is quite improved in nature than that of power factor without filter branch. In number it is improved by 0.001 as shown.

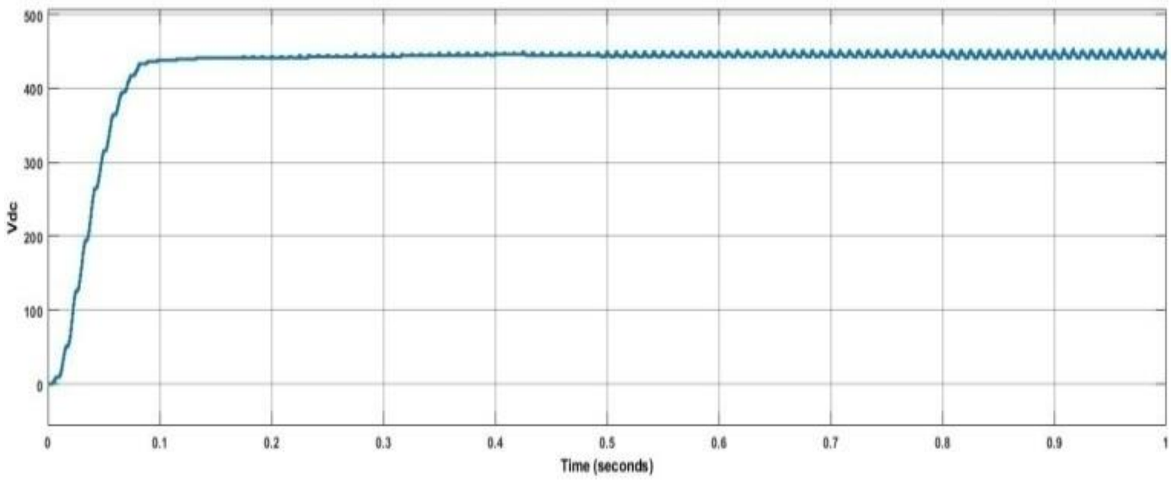

Figure 6 : Dc link of capacitor voltage V_{dc}

Voltage at dc link of capacitor is trying to keep constant in nature. To keep this voltage at constant level active filter from hybrid branch acts as pulse width modulation rectifier. For this purpose feeding voltage must be in phase with current of capacitor bank at vital frequency making sure to keep the stable voltage across dc link by the real power.

V. CONCLUSION

Smart impedance topology uses the P + Resonant controller for tuning purpose. So the system becomes free from PLL. Tuning of multiple frequencies is possible with this topology. Another advantageous feature of this technology is that it can be install in any capacitor bank. The need of passive filter tuning is completely absent. This is because the tuning is achieved by electronically. Along with the harmonic compensation the proposed topology is able to compensate displacement power factor. This can be easily incorporated in three phase system also.

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