

Four-leg active power filter control with SUI-PI controller

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ABSTRACT

Four-leg active power filter is considered one of the greatest vital active filters that are frequently used in industrial applications, especially those that need to be controlled in each individual phase. Also, to control the neutral current that created because of a lot of unbalanced and non-linear loads. In this paper, the used active filter was controlled by a proposed control method which can achieve simplicity and intelligence at the same time. The novelty of this paper is using the proposed controller with Four-leg active power filter. This controller relies on instantaneous reactive power theory, which used to create the required currents that are injected into the network via the used active filter to remove the problems created by unbalanced and non-linear loads. It is also maintained that the current source a pure sinusoidal wave. The system is implemented on MATLAB/Simulink. The simulation results proved the preference of the proposed controller than the conventional proportional-integration controller, where it reduced the percentage of total harmonic distortion for the current source.

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1. INTRODUCTION

In many large industrial facilities, there are many non-linear and unbalanced loads. These loads cause major problems for the feed source of these installations and also increase the neutral current. Thus, it was necessary to search for solutions to these problems. 4-leg active power filter (4-LAPF) was used to overcome these problems, which depended on three-dimensional space vector modulation (3-DSVM), and who is discussed in section 2.

Numerous renewable power sources are applied to power grids, and this affects badly on power quality for users [1]. Now a days more loads are electronic devices. These devices may increase unstable cause and bad signals (harmonics) to network. Current harmonics make numerous harms in supply systems and the devices of consumers like overheating, wicked process for safety equipment, and also converters bad working which decrease their efficiency. Further may cause destruct for neutral line because of heating. Also, extra reactive power rises harms of stability in the grid [2]. The conventional solutions for these problems were the conventional passive filters which have low cost and simple design. But they have more side effects as huge size and the problems of resonance. The APFs can solve these difficulties specially the 4-wire APFs which could control neutral current, reactive power, purification and balancing the source current, and control their harmonics simultaneously [3]. So, 4-wires APFs are considered as a suitable solution than the conventional passive filters. So, in next section a short comparison between the commonly used 4-wire

inverters as APFs are done. Then, for good performance a precise control should be used which is introduced in section 3.

2. FOUR (4) WIRE ACTIVE POWER FILTERS

Four (4)-wire APFs is connected in parallel with loads as obvious in Figure 1 which obvious the simple principle of compensation based on shunt APFs. They are used to inject the compensation currents which is defined based on the load currents harmonics. The 4-wire APFs have three main typologies: i) MPC typology, ii) 3H-bridge typology, and iii) 4-leg typology which described in Figure 2.

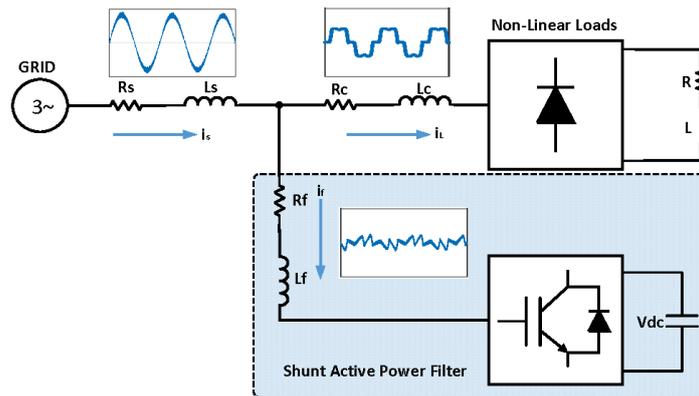


Figure 1. Main simple structure for shunt compensators

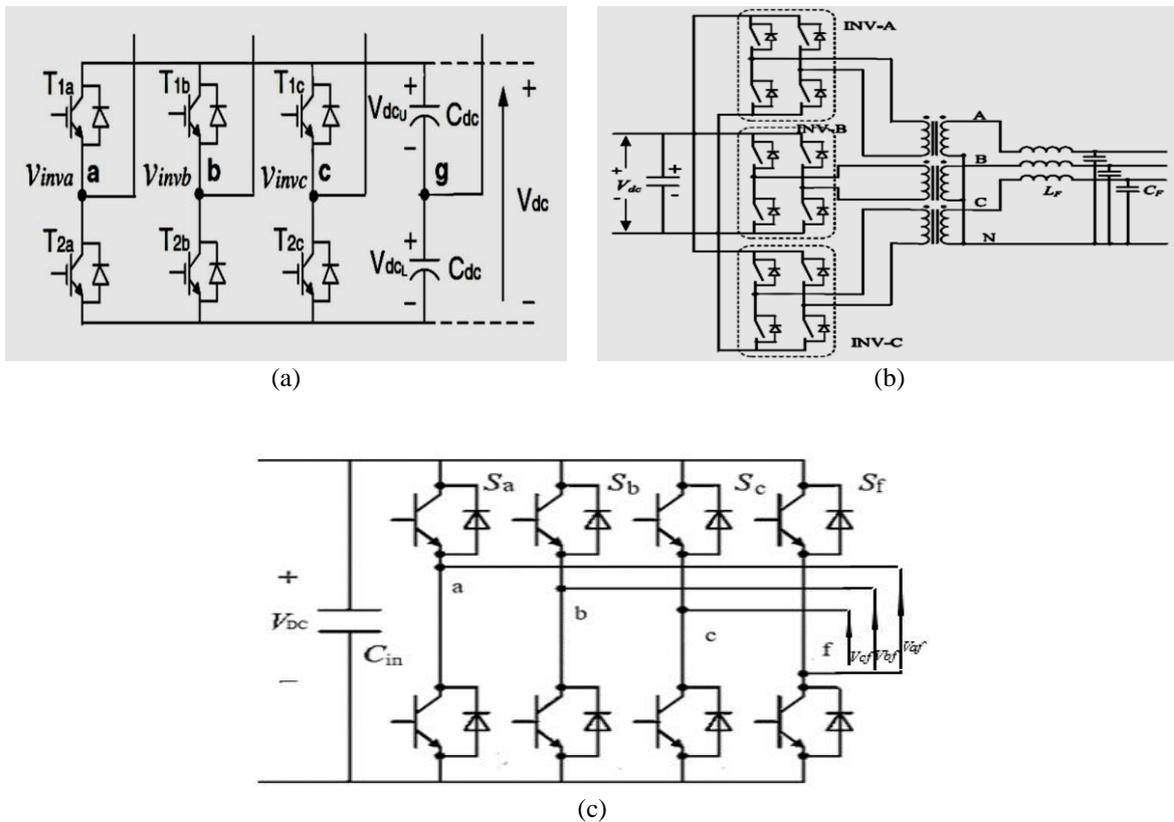


Figure 2. Different three-phase 4-wire typologies; (a) mid-point cap. typology, (b) 3 H-bridge typology and (c) 4-LI typology

As obvious in Figure 2(a) the MPC typology, where the neutral point is connected between the two capacitors. Even though, it has the less numbers of switches, on the other side, it requests a high DC link capacitor than another two typologies. Also, huge and private capacitors are crucial to maintain a low voltage ripples mainly when there is extraordinary neutral current. The second typology (three H-bridge inverter) obvious in Figure 2(b). The problem of this typology, that it has a greater number of switches than the other two typologies and needs for isolation transformers. The four-leg inverter (4LI) displayed in Figure 2(c) has not involves an extraordinary voltage as the MPC one, and has no additional link capacitor. Also, neither need for isolation transformer nor a greater number of switches as in three H-bridge typologies. Also has small weight and size comparing to this typology. But this typology requests devices with a high switching rating especially in the fourth leg comparing to the other typologies [4]. In this paper for capturing the neutral current created from the unbalanced/nonlinear loads in 4-wire systems and to enhance the power quality in the grid a 4LI based on a 3D-SVM is used. A 4LI modelling based on a 3D-SVM scheme is proposed in [5].

3. CONTROL TECHNIQUES FOR 4-LAPF

There are many more control techniques used for 4-LAPFs whether in a-b-c or α - β - γ structure based on instantaneous reactive power (IRP) theory or the dq0 control technique [6]. The further vital and habitually used is IRP theory which is applied well for regulatory and designing three-phase APF structures as in [6] and for 4-wire structures as in [7]. IRP theory used to form the reference currents values and shapes that ought to inject into the network via the 4LI to treat the difficulties created from the unbalanced and non-linear loads. These calculated by IRP theory are compared to actual currents of compensator.

The produced error may be treated by more controllers as Hysteresis current controller, and conventional PI-controller based on 3-DSVM as in [8], Result of the growth of the proportional integral derivative (PID) controller. There are further than four hundred tuning rules have been established. Open loop [9, 10], and closed loop step method [11], step or impulse responses identification method [12]. Parameter estimations graphically of an identified higher command process [13]. Also, the process identification method in discrete time [14, 15]. Moreover, Modern intelligent techniques as Fuzzy [16-20] and neural [21] are used for dipping the procedure parameter dependency for controller design and refining the controller response. They are considered as simple tools for the governing of complicated processes. Adaptive control also advanced and applied to develop the PID response based on decreasing the effect of the method parameter variant through control process [22].

Over the last decade, to adapt the PID response, a great deal of attention has been paid to using intelligent techniques [23]. Hybrid controllers have also been used to develop the PID response. In this paper a proposed technique based on the simplified universal intelligent (SUI) PI-controller [24] is presented and applied for 4-LAPF as an application then the results are compared with conventional PI-controller to display its effectively.

3.1. The proposed controller

The used SUI PI-controller considers as a traditional PI in addition a general PID constant, which leads to no need for precise design and also not require modeling for the controlled system. Constants of SUI controller are the absolute values of errors and their integration only for PI-controller. So, the offered controller has several advantages like: more simplicity, easy in implementation, very little error, quick response, very small steady state error, and no requirement for modelling the system to implement this controller. But on the other side the problem of determining the gains of controller done by trial-and-error method.

The controller proposed is seen as a universal controller. It is superior to other controllers and does not need either the process nature or the design process for controller. The used controller technique is established based on the multi degree of freedom controller (MDOF) idea [25, 26]. Current controller is implemented to ensure the injected current to the grid by 4LI equal the reference current produced by IRP theory. The reference current is compared to the real current produced by 4LI. The output of this controller is the reference voltage applied to 3-DSVM to produce the suitable patterns for the 4LI switches. Commonly, the controller PID composes of three portions as in (1), (2) and (3) respectively:

$$\text{The first part controller: } P = Kp * \text{error} \quad (1)$$

$$\text{The second part controller: } I = Ki * \int \text{error} \quad (2)$$

$$\text{The third part controller: } D = Kd * d(\text{error})/dt \quad (3)$$

Let [26]:

$$Kp = ABS(error) \quad (4)$$

$$Ki = ABS(\int error . dt) \quad (5)$$

$$Kd = ABS(d(error)/dt) \quad (6)$$

By substituting the previous values of (4), (5), and (6) at (1), (2), and (3) the adapted PI-controller (C_m) could be identified as:

$$Cm = C * M * error + \frac{C}{M} * (1 - error) \quad (7)$$

$$\text{Which can simplify as: } Cm = C * error * \left(M - \frac{1}{M}\right) \quad (8)$$

$$\text{For } M \gg 1 \text{ then } Cm = C * error * M \quad (9)$$

Where; C is the controller output and is M the SUI PI controller gain.

The output of the proposed controller given in (9) is applied to control both the currents and the capacitor voltage of 4LI.

4. SIMULATION RESULTS

Figure 3 (a) obvious the central scheme of the system. The controller block includes the known and proposed PI-controller techniques, and the IRP theory that is obvious in Figure 3(b) used for creating the reference currents based on the currents of load and the voltage source. The reference current is compared with the actual currents produced by the 4LI based on 3-DSVM then the error is treated by the conventional and the proposed techniques which create the reference voltage as obvious in Figure 3(c). Also the 4LI capacitor voltage is controlled by both control techniques. The load in this system is implemented to be unbalanced and nonlinear load as obvious in Figure 4. The results of simulation for the system based on A) conventional PI-controller and B) proposed controller are presented in next section. The results are displayed below without using of the 4-LAPF and after using it, at time $t=0.044$ sec., Also, after load changing, at $t=0.11$ sec. In this time the switch obvious in Figure 4 is switched ON which, change load suddenly to display sure the ability of the proposed technique at transient cases. Load component values are obvious in Figure 4.

4.1. Conventional PI-controller results

Figure 5 displays the 4LI capacitor voltage which follow the reference voltage value ($V_{dc}=900$ V). But the ripple is a little high and large settling time when it zoomed as obvious in Figure 5. Figure 6(a) displays the nonlinear and unbalanced load current I_L . The current I_C produced by 4LI compensator and injected to the network at point of common coupling (PCC) at time $(t)=0.044$ sec. is displayed in Figure 6(b) which, repair the current of the source I_S to be balanced and sine wave as obvious in Figure 7(a). The network voltages V_S is displayed in Figure 7(b). The fourth leg current of 4LI (I_{nc}) that is injected to the network at the PCC is displayed in Figure 8(a) to remove the neutral current I_{nL} produced because of the unbalance in the load, displayed in Figure 8(b) at PCC, so could repair network neutral current I_{ns} , displayed in Figure 8(c), nearly deleted. The load is changed randomly at $t = 0.11$ sec. to create a sudden change for the load value to display the enactment of 4LI as a shunt compensator at this condition. Moreover, to confirm the stability and the balancing of, phase b voltage and current are displayed in Figure 9 that verifies that both of them sine waves and in phase.

4.2. Proposed controller results

Figure 10 displays the 4LI capacitor voltage which follow the reference voltage. But the ripple is a slight high and small settling time when it zoomed as obvious in Figure 10. Figure 11(a) displays the nonlinear and unbalanced load current I_L . The current I_C produced by 4LI compensator and applied to the network at PCC at time $t=0.044$ sec. is displayed in Figure 11(b) which, repair the current of the source I_S to be balanced and sine wave as obvious in Figure 12(a). The network voltages V_S is displayed in Figure 12(b). The fourth leg current of 4LI (I_{nc}) that is injected to the network at the PCC is displayed in Figure 13(a) to eliminate the neutral current I_{nL} produced because of the unbalance in the load, displayed in Figure 13(b) at

PCC, so could repair network neutral current I_{ns} , displayed in Figure 13(c), nearly deleted. The load is changed randomly at $t=0.11$ sec. to create a sudden change for the load value to display the enactment of 4LI as a shunt compensator at this condition. Moreover, to confirm the stability and the balancing, phase b voltage and current are displayed in Figure 14 that verifies that both of them sine waves and in phase.

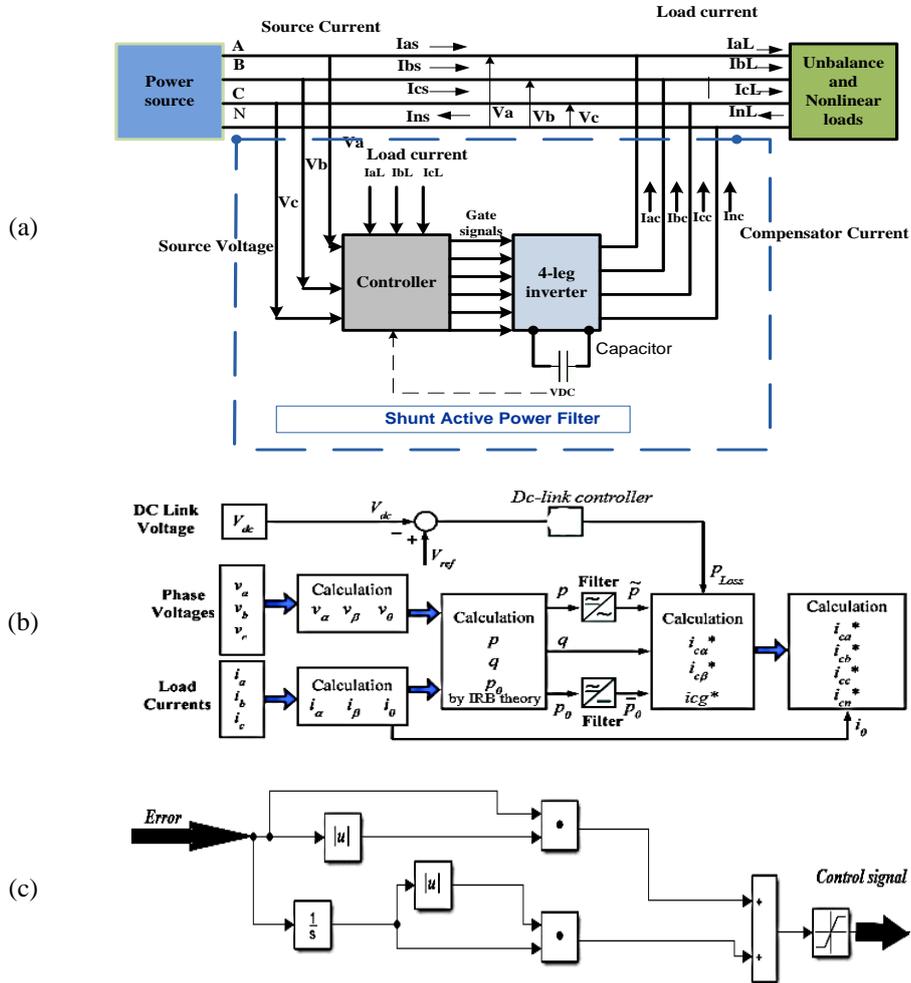


Figure 3. These is: (a) system implementation in MATLAB, (b) IRB theory, and (c) SUI PI controller

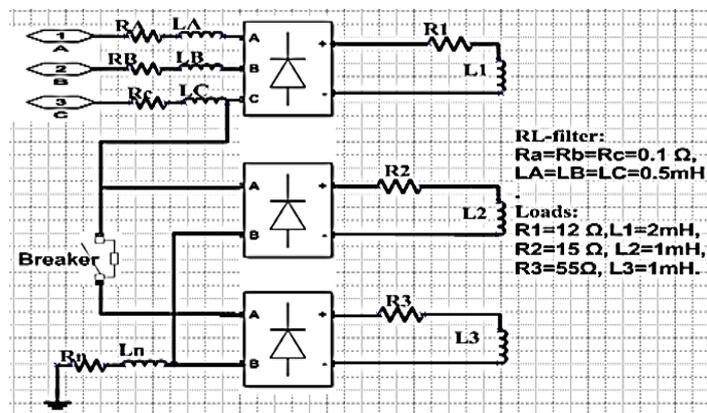


Figure 4. The load of the system

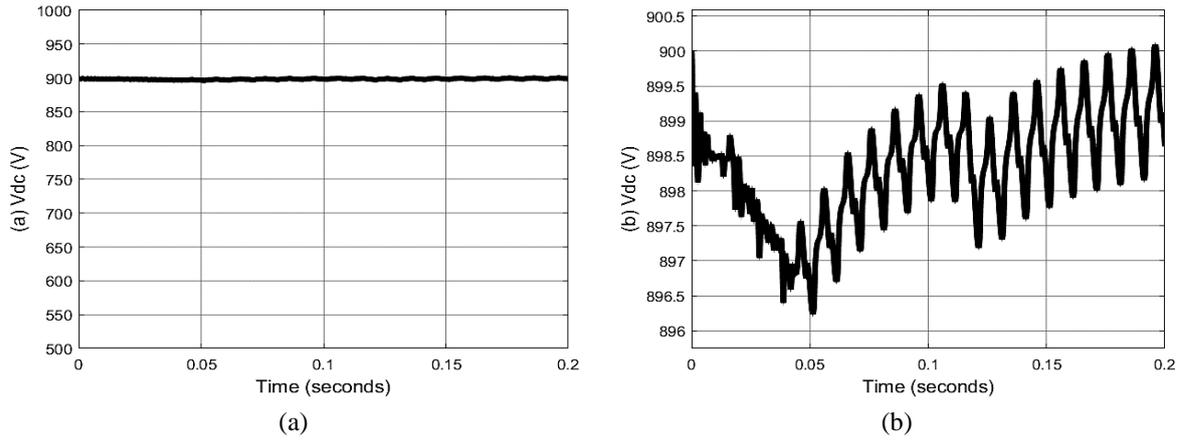


Figure 5. These is: (a) 4LI capacitor voltage, and (b) Zoomed 4LI capacitor voltage

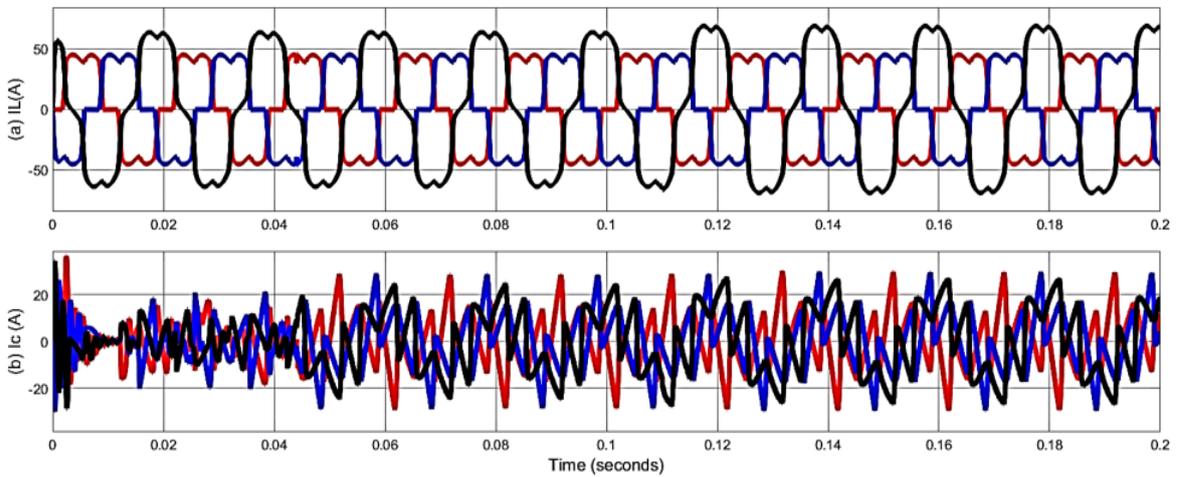


Figure 6. These is: (a) the current of the load (I_L), (b) 4LI current

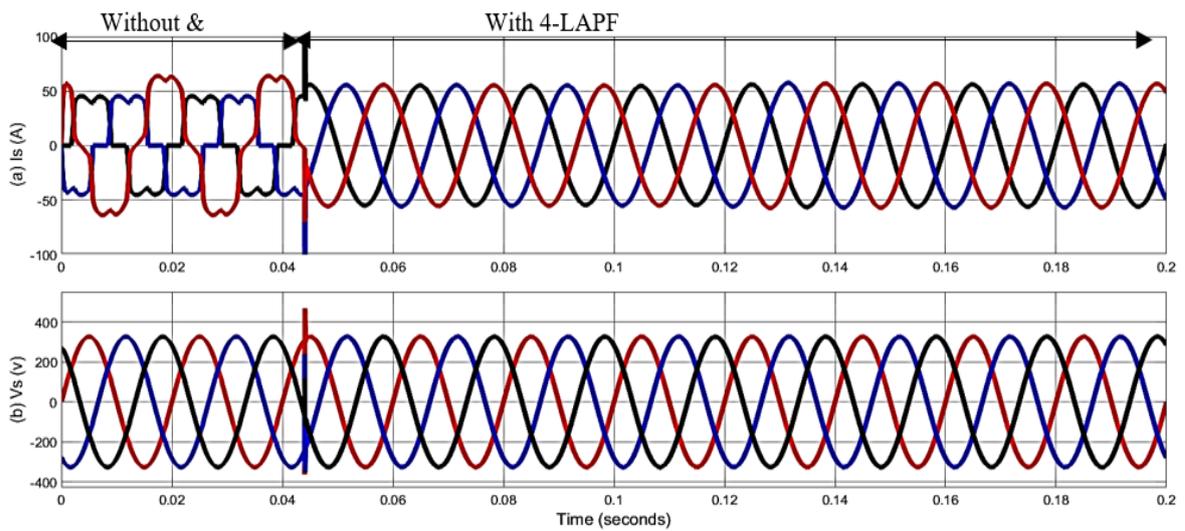


Figure 7. These is: (a) network current, (b) network voltage

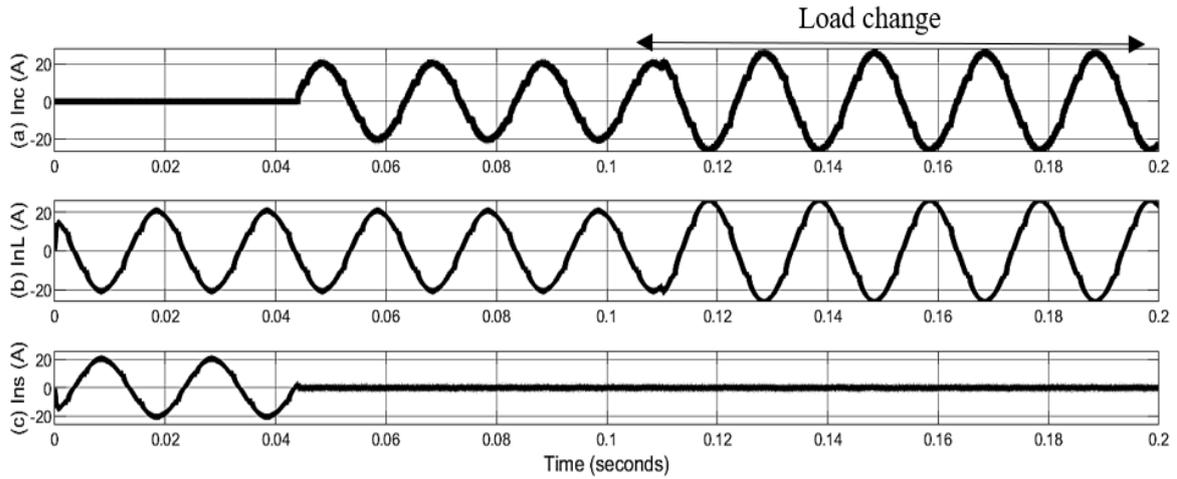


Figure 8. The neutral currents of (a) 4LI, (b) load, and (c) network

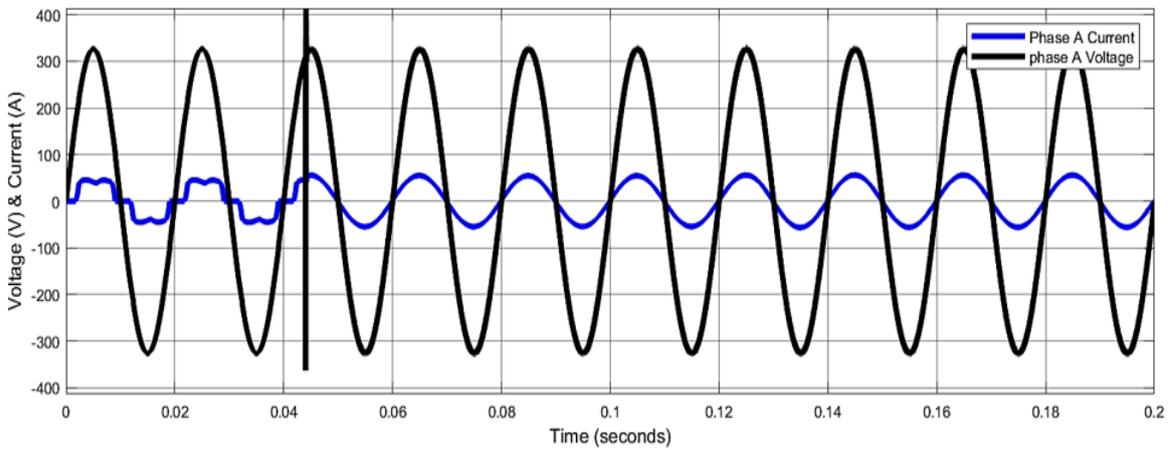


Figure 9. One phase V & I

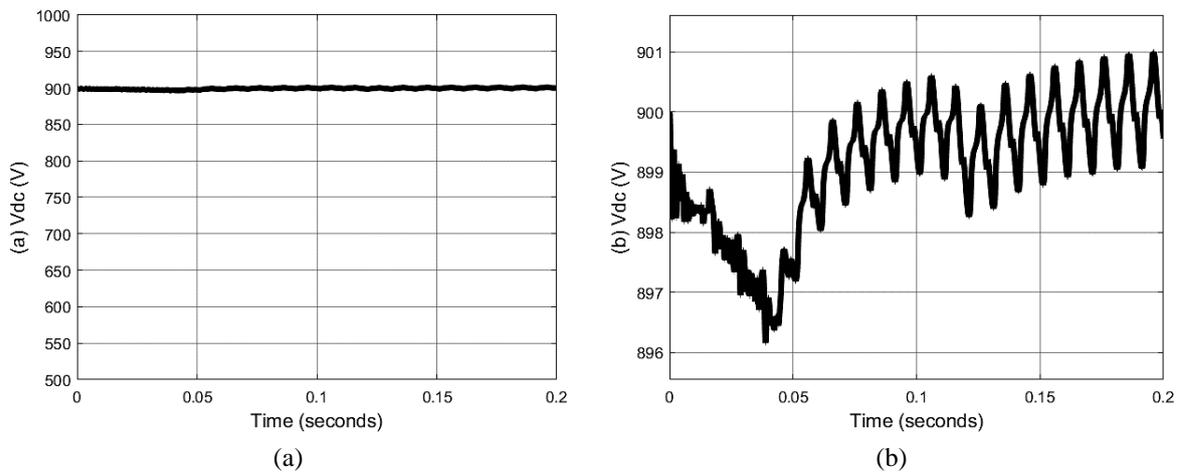


Figure 10. These is: (a) 4LI capacitor voltage, (b) Zoomed 4LI capacitor voltage

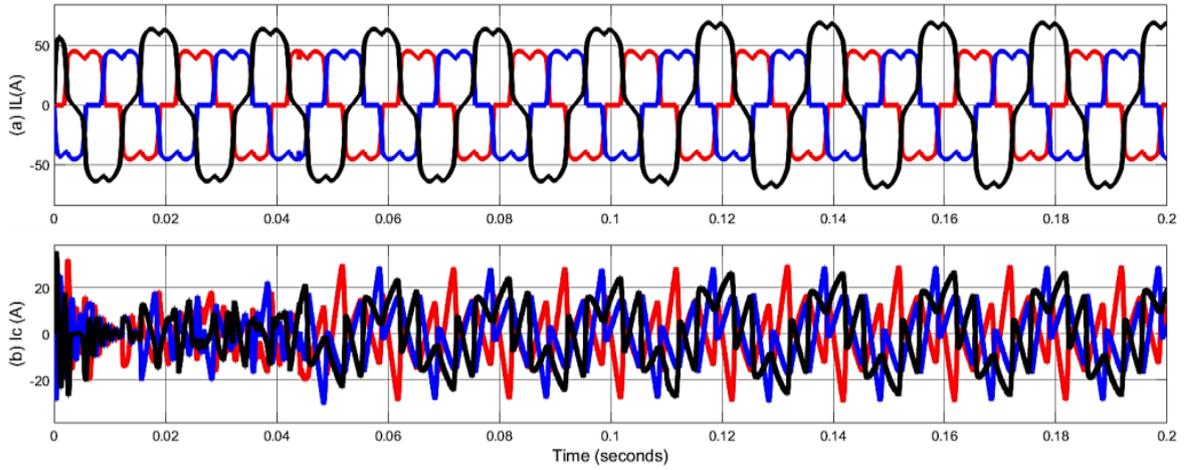


Figure 11. These is: (a) The current of the load (i_L), and (b) 4LI current

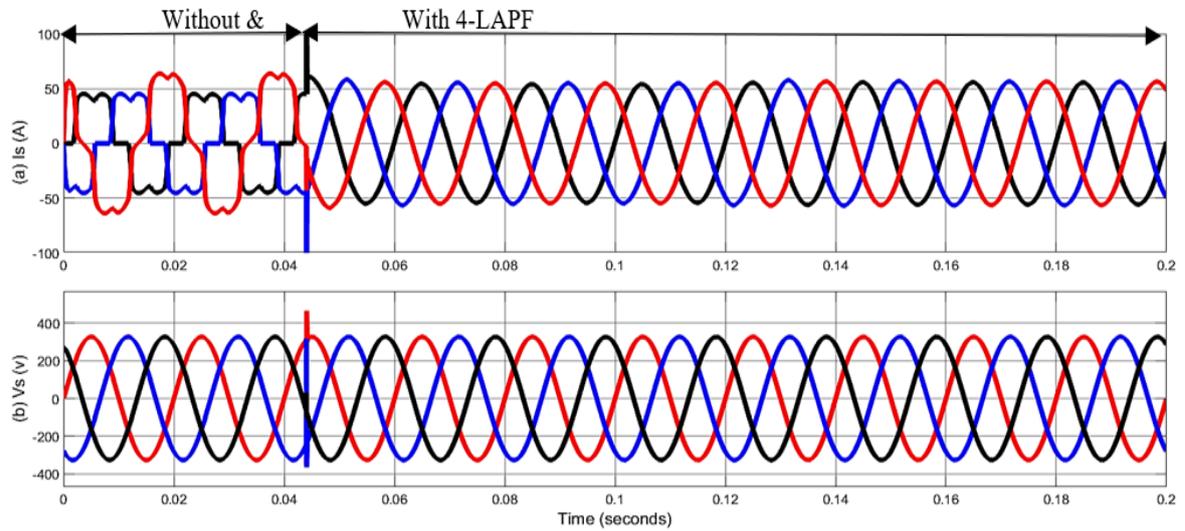


Figure 12. These is: (a) Network current, and (b) Network voltage

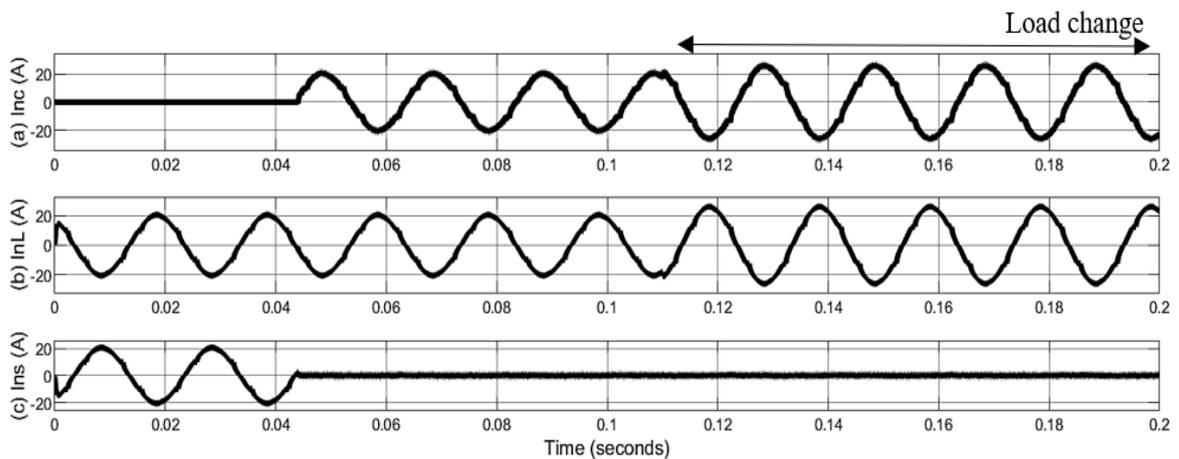


Figure 13. The neutral currents of (a) 4LI, (b) Load, and (c) Network

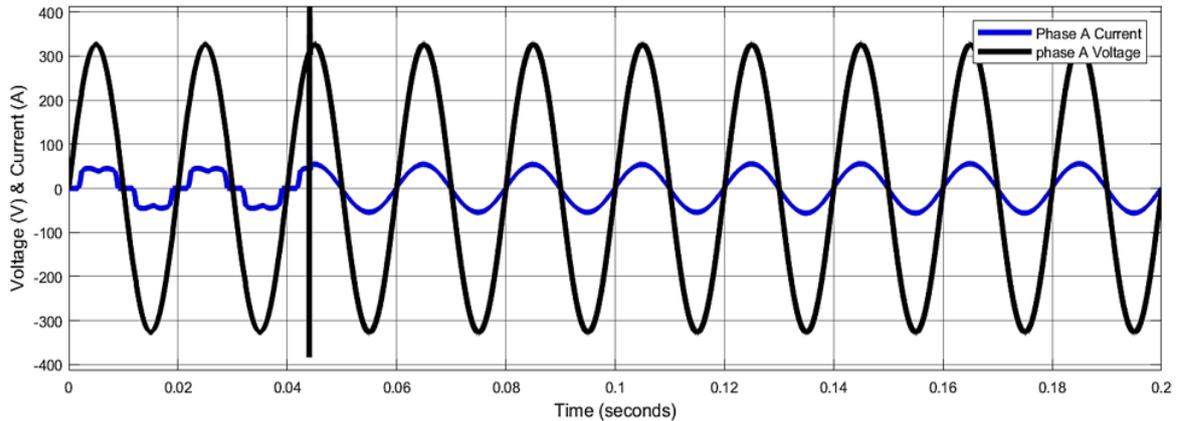


Figure 14. One phase V & I

The previous results say that, 4-LI as active power filter based on IRP theory has capability to deal with harmonics in currents, problems of the reactive power, also the harmonics of the neutral current whether used old known PI-controller or the proposed controller. Hence, the THD factor considered as a comparing factor among them. The THD of the old known controller is (2.0%) and for the proposed controller is (1.57%). These values are within range based on IEEE reference [27], as displayed in Figures 15(a) and (b), correspondingly. Likewise, the THD of the proposed technique is lesser than the conventional technique that let it extra favored to use besides the advantages of the proposed controller and the drawbacks of the old controller stated overhead in section 3.1.

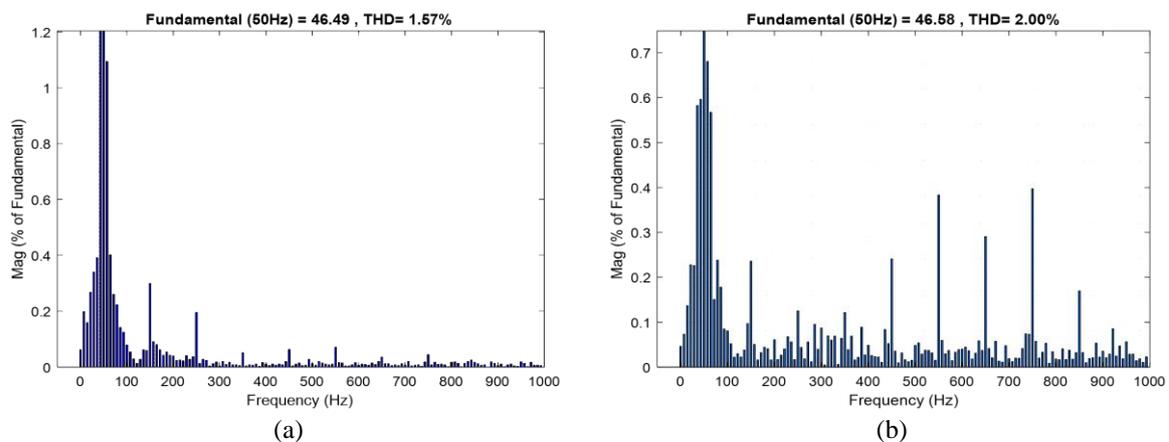


Figure 15. THD of the source current based on (a) Proposed controller, and (b) Conventional controller

5. CONCLUSION

In the paper, a shunt active filter depends on 4LI and IRP theory has been presented. After using the active filter, the network current is enhanced and become sinusoidal. Also, could control the current of neutral. Thus, this active filter can reduce the unbalanced loads problem and develop the quality of power in the grid. A good general enhancement has realized depends on the conventional and the proposed controllers. But the proposed controller results have a less THD of the source current than the conventional one. The results of simulation prove that the following objects had been efficiently realized using the 4-LAPF based on the proposed controller which has many advantages as mentioned above in section 3.1. These advantages help to good deal with unbalanced/nonlinear loads effectively, clarifying the current of the source from the harmonics and make it balanced, control the source neutral current, and displays an effective dealing in both normal and suddenly change cases. Also, a good control in the 4LI capacitor voltage by decreasing the settling time and good follow for desired voltage value. All these leads to enhance the quality of power.

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