A New Multilevel Inverter Based Parallel Active Power Filter

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Abstract- Developments in the field of power electronics have increased the use of non-linear loads. The increase in the use of these loads causes power quality to decrease and problems to appear in transmission and distribution systems. The adverse effect of passive harmonic filters and the up-growing use of modern sensitive loads in the production process have made active power filters an important area of interest in eliminating current and voltage harmonics. In this study, a multilevel inverter topology for parallel active power filter applications has been proposed. The principle of operation for the proposed multilevel inverter topology is explained in detail. The harmonic components of the grid current which has a high total harmonic distortion (THD) value, are eliminated by the proposed multilevel inverter providing a reduced number of switching elements. The generation of switching signals for parallel active power filter application is also expressed with generalized formulas. All required operating states of multilevel inverter topology are given in detail to obtain reference filter current with harmonic components. In addition, the simulation studies carried out for different number of level modules and different values of harmonic distortion are presented. The obtained results show that the proposed multilevel inverter topology is suitable for parallel active power filter applications.

Keywords Active power filter, multilevel inverter, total harmonic distortion, power quality.

1. Introduction

The widespread use of nonlinear loads such as arc and ladle furnaces, motor drivers, switched-mode power supplies, rectifiers and dc/dc converters has increased due to advances in the field of power electronics. Such loads cause power quality problems in transmission and distribution systems. Current and voltage harmonics as a problem of power quality become more considerable in parallel with the increasing use of modern sensitive loads in the production process [1].

Due to the ever-increasing power quality problems, active filtering solutions are of interest for harmonic suppression since the conventional passive filters have adverse effects such that they are affected by the grid impedance and can filter only for the specified harmonic component.

Active power filters, which can be applied to solve many problems such as filtering harmonics, reactive power compensation, resonance suppression and voltage regulation, are mainly classified into two groups according to the grid connection modes; parallel and series active power filters. Parallel active power filters are used to eliminate problems created by non-linear loads acting as harmonic current sources, while series active power filters connected to the system via a transformer provide voltage regulation by eliminating voltage harmonics.

The operation principle of the active power filters is based on the generation of the reference current and/or voltage waveforms obtained by a set of control techniques from the sampled load current and/or voltage with the help of controlled semiconductor power switches [1]. Based on this operation, it can be said that active power filters consist of three main parts as shown in Fig.1; harmonic detection unit, control unit and inverter unit. Generally, the harmonic detection unit and the control unit are defined together. The harmonic detection unit detects the harmonics from the

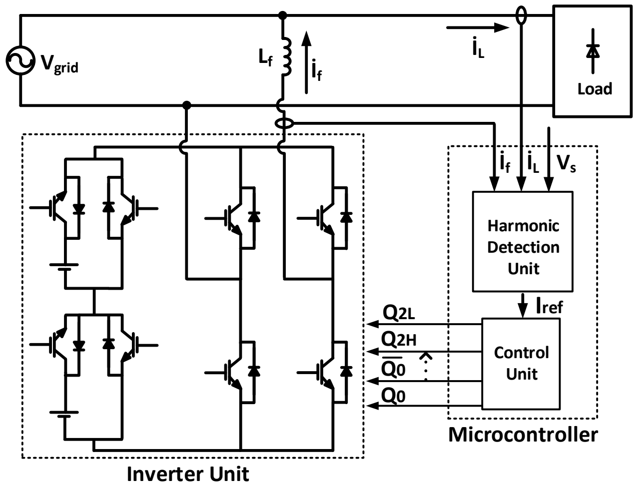


Fig. 1. The principle scheme of parallel active power filter with main parts

sampled load current and/or voltage by means of an algorithm thus determining the reference signal. Algorithms developed for the determination of harmonics are carried out in this unit. These algorithms are generally divided into two groups as frequency and time domain based methods. The frequency domain methods used to determine harmonics in active power filters are Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT) and Sliding-Discrete Fourier Transform (S-DFT).

The time domain methods applied for the same purpose are instantaneous power theory (p-q theory), artificial neural network based techniques, constant reference (αβ) transformation, synchronous reference (dq) transformation and hybrid (αβ/dq) transformation [2-3].

At the input of the current and/or voltage control unit, there is the reference signal determined at the harmonic detection unit while the switching signals of the inverter unit are found at the output. The contribution of this unit to the operating principle of the active power filter is the generation of switching signals for controlled semiconductor power switches. For this purpose, it is seen that different control techniques such as Pulse Width Modulation (PWM), Sinusoidal PWM, hysteresis control and recently used "dead-beat" control are used in the literature.

The inverter unit is the part where the filter output voltage (V_{AB}) is obtained according to the reference voltage. The switching signals from the control unit are used to generate the filter output voltage of the inverter. In the literature, many studies have been carried out with different inverter units to reduce the complexity of the control method by reducing the number of semiconductor power switches [4]. When many features such as switching frequency, dv/dt voltage stress on switching elements, efficiency, electromagnetic interference, harmonic distortion and output filter requirement are taken into consideration, multilevel inverter topologies are often preferred for active power filter applications [5-7]. In the literature, although there are studies on active power filters with diode-clamped and flying-capacitor inverters, it has been determined that the most common multilevel topology in active power filter applications is the cascaded H-bridge inverter, The reasons for the preference of the cascaded H-bridge inverter are that it is suitable for high voltage and high power applications, the dv/dt voltage stress on the switching elements is reduced and the THD value of the output voltage is lower [8-11].

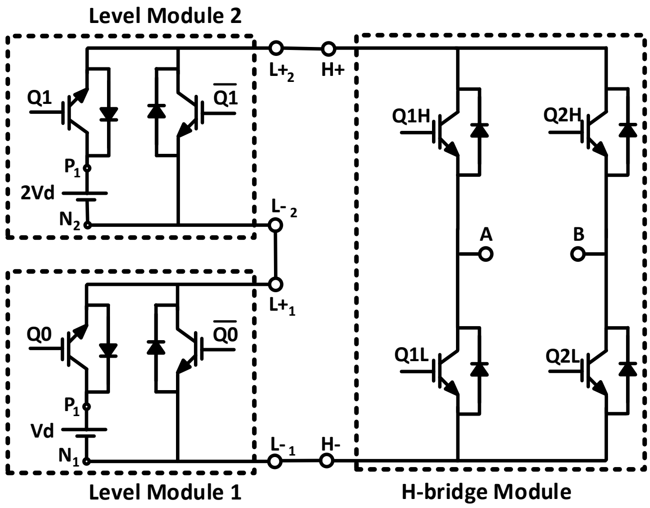


Fig. 2. The principle scheme for 7-level half-bridge cascaded inverter

Multilevel inverters can produce output voltage with sinusoidal form as well as output voltage with desired harmonics. In this way, multilevel inverters are used for active power filter applications [11]. In this study, a half-bridge cascaded multilevel inverter topology is proposed. The switching algorithm developed for the proposed multilevel inverter based parallel active power filter is also introduced. The switching signals to obtain the required output waveform and the other results of the filtering process are demonstrated by simulation studies. The results of the carried out simulation studies confirm that the developed strategy works properly.

2. Half-Bridge Cascaded Multilevel Inverter

Figure 2 shows the principle scheme of the 7-level half-bridge cascaded inverter to be used for parallel active power filter application. The inverter is basically composed of two different parts, the level module (LM) and the H-bridge module (HM) [12]. The required level of the inverter can be acquired by changing the number of LM. To expand the system and increase the output voltage levels of the inverter, more LMs connected in series are used.

LM comprises a dc source and two semiconductor switching elements. The voltage of dc source V_d in LM 1 is related to the required maximum value of the output voltage and the level of the inverter.

The voltage of dc sources in other LMs are scaled in power of 2. The maximum level of the inverter n can be computed as

$$n = 2^{(m+1)} - 1 \tag{1}$$

where m is the number of LMs used in the inverter.

HM shown in Fig. 2 is a conventional H-bridge inverter. HM is the constant part of the multi-level inverter. In order to increase the number of levels, HM is connected to the series-connected LMs as shown in Fig. 2.

The value of n is the maximum level number of the inverter depending on m calculated by using equation (1). However, any required level can also be acquired by the same number of LMs. For example, a number of level modules of 3, a maximum of 15 levels can be obtained, as well as 9, 11 or 13 levels. By increasing the number of LMs, any required number of level can be easily obtained by the proposed inverter since it has a simple and modular structure.

3. Switching Algorithm

The multilevel inverter used in the proposed active power filter has the capability to generate an output voltage waveform more sinusoidally. Furthermore, the multilevel inverter can produce any voltage with harmonic components. Due to this feature, it acts as a harmonic voltage source. For this purpose, it is first necessary to define the reference voltage signal which contains the desired harmonic components [13]. The reference voltage is defined as in equation (2);

$$V_{ref} = \frac{V_{dc}}{2} + \sum_{h=1}^{\infty} V_h \sin(h\omega t + \varphi_h) \quad (2)$$

The reference voltage signal is present by the harmonic detection unit. A sample reference voltage signal with 3rd and 7th harmonic components is chosen to describe the proposed switching algorithm. The waveform of the sample reference voltage signal is shown in Fig.3, and the mathematical definition of this waveform is given in equation (3).

$$V_{ref} = V_3 \sin(3\omega t + \varphi_3) + V_7 \sin(7\omega t + \varphi_7) \quad (3)$$

Fig.3 depicts the sampling time of the switching signals (Δt). The smaller the sampling time, the more similar the output voltage is to the reference voltage signal. The sampling time depends on the frequency of the fundamental harmonic of the output voltage and the number of level modules.

$$t_{sample} = \Delta t = t_{i+1} - t_i \quad (4)$$

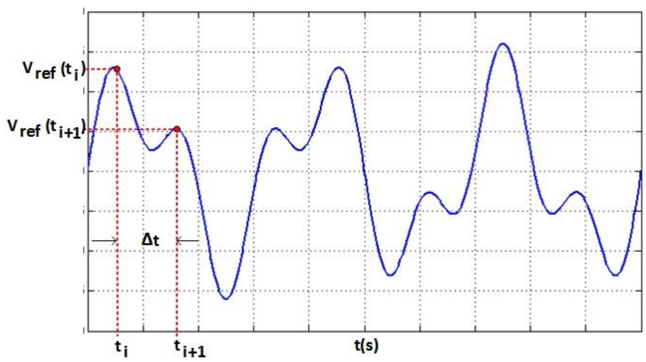


Fig. 3. The waveform of a sample reference voltage signal

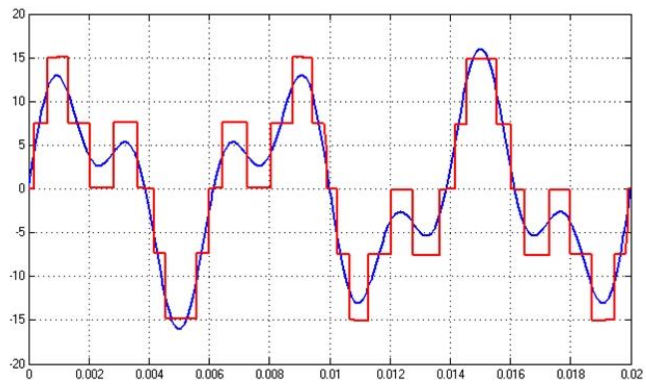
Switching signals are generated for the instantaneous values of the reference voltage signal V_{ref}. The equation for the switching signals used in the system can be generalized according to the number of level modules as follows;

$$Q_{(j-1)}(t) = \begin{cases} j = 1,\ V_{ref}(t) \mod 2 \\ j \succ 1,\ \left(\dfrac{V_{ref}(t) - \left(V_{ref}(t) \mod 2^{(j-1)} \right)}{2^{(j-1)}} \right) \mod 2 \end{cases} \quad (5)$$

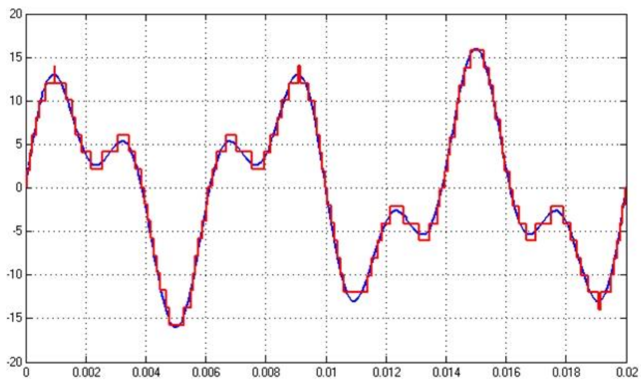
By using equation (5), the switching signals for the switching elements used in LMs are easily obtained. There are two switching elements in each level module, and these switching elements are operated as if they are the inverse of each other.

With the obtained switching signals an output voltage similar to the reference voltage signal given in Fig.3 can be produced as shown in Fig.4.

The waveforms of the inverter output voltage given in Fig.4 can converge to the reference voltage signal by increasing the number of level modules. If the inverter output voltage converges to the reference signal, the harmonic filtering capability of the parallel active power filter increases.

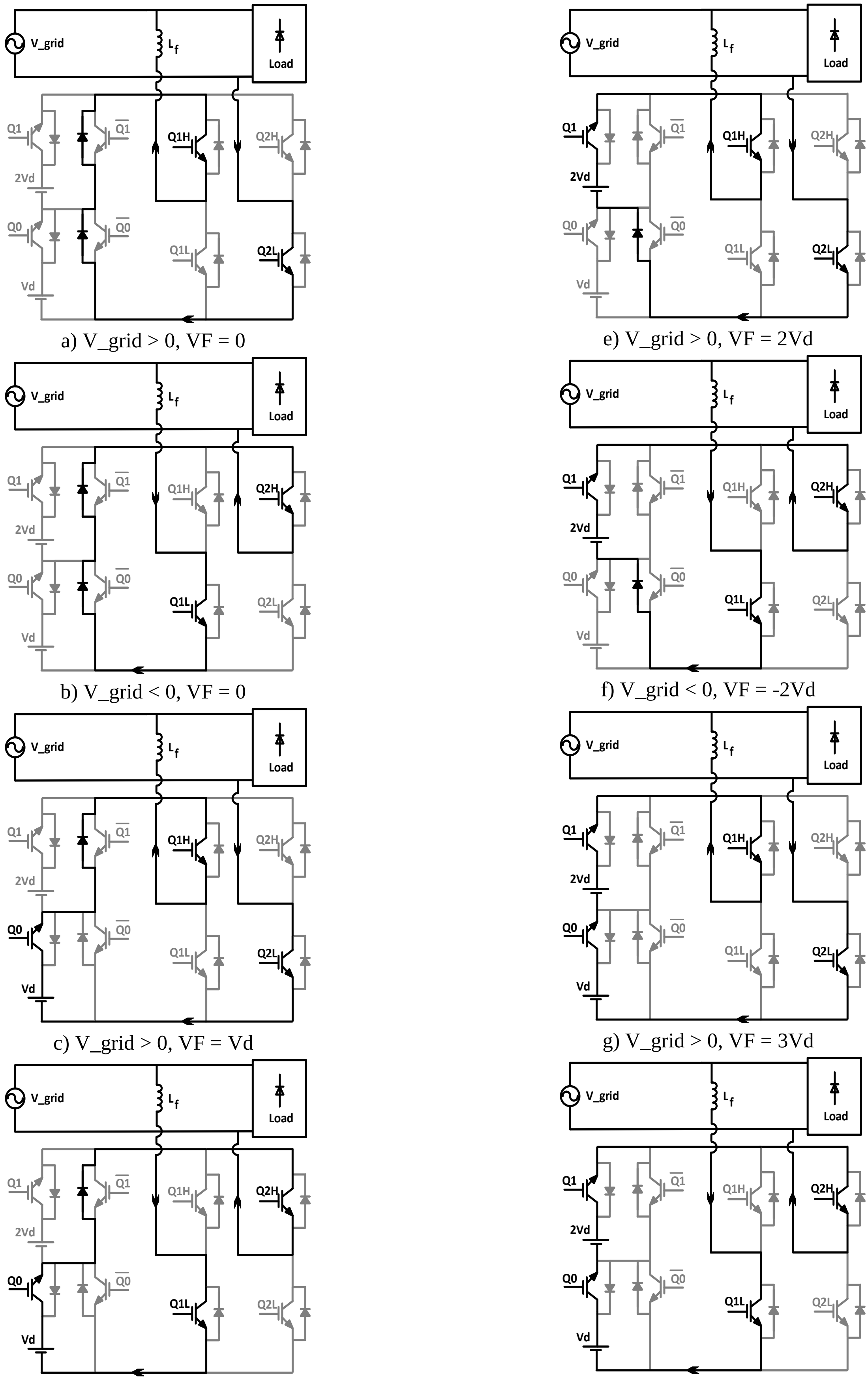


(a) 7-level



(b) 31-level

Fig. 4. The waveforms of reference voltage signal and output voltage of a multilevel inverter



a) V_grid > 0, VF = 0

b) V_grid < 0, VF = 0

c) V_grid > 0, VF = Vd

d) V_grid < 0, VF = -Vd

e) V_grid > 0, VF = 2Vd

f) V_grid < 0, VF = -2Vd

g) V_grid > 0, VF = 3Vd

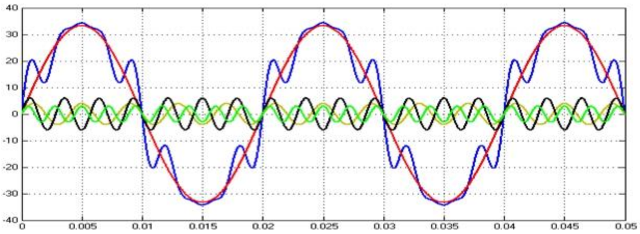
h) V_grid < 0, VF = -3Vd

Fig. 5. The operating states of a 7-level parallel active power filter

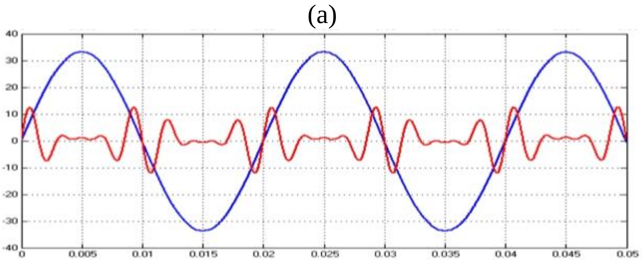
Figure 5 shows the topology of the multilevel inverter with the ability to generate the desired voltage waveform at its output through the proposed switching algorithm, including all operating states of a parallel active power filter application. The results of this application are included in the simulation study.

4. Simulation Study

The switching algorithm proposed for parallel active power filter is applied to inverters with different number of level modules. For this purpose, a distorted grid current with a THD value of 23.43% is filtered by using 31-level inverter. The grid current consists of 5th, 7th, and 9th harmonic components with fundamental harmonic. After filtering, the grid current is nearly sinusoidal with the THD value of 0.30%. The grid current and its harmonic current components, the grid and filter currents after the parallel active power filter is applied, and switching signals are shown in Fig.6a, 6b and 6c, respectively. To demonstrate the effect of level number, in other words the number of level modules, a highly distorted grid current consisting 3rd and 7th harmonic components except fundamental with a THD value of 34.99% is filtered by using 7-level and 31-level inverter based parallel active power filters. The simulation results are shown in Fig.7 and Fig.8. The grid current and its harmonic current components are shown in Fig.7a and Fig.8a; the grid and filter currents after the parallel active power filter is applied are shown in Fig.7b and Fig.8b; and switching signals are shown in Fig.7c and Fig.8c.



(a)



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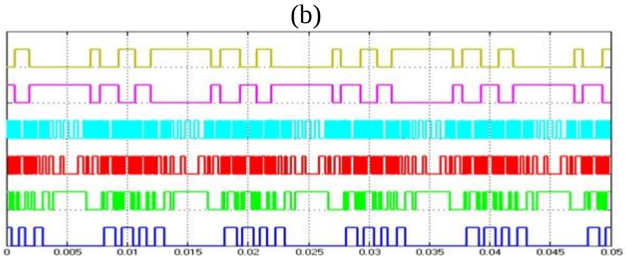
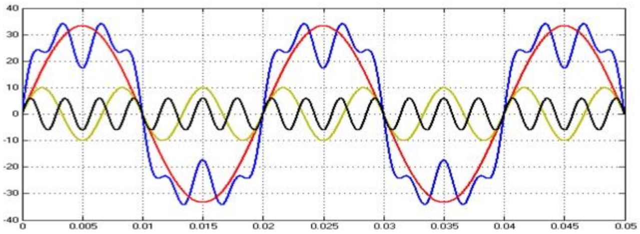
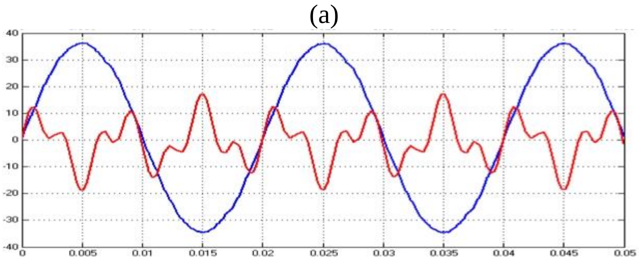


(c)

Fig. 6. The simulation results obtained from 31-level inverter based parallel active power filter, a) grid current with a THD value of 23.43% and harmonic components before filtering, b) grid current and filter current, c) switching signals



(a)



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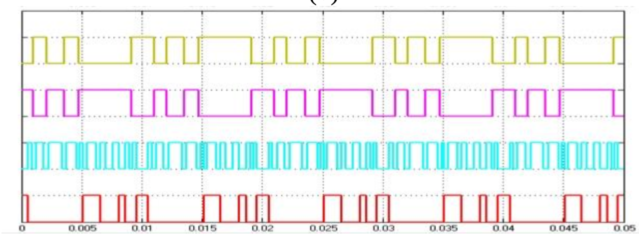
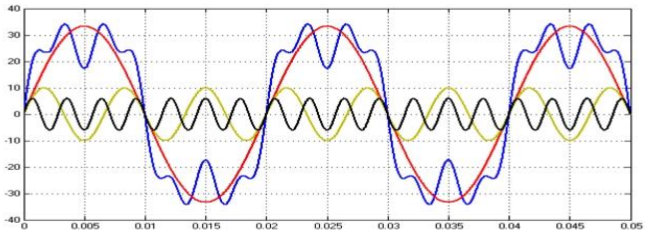
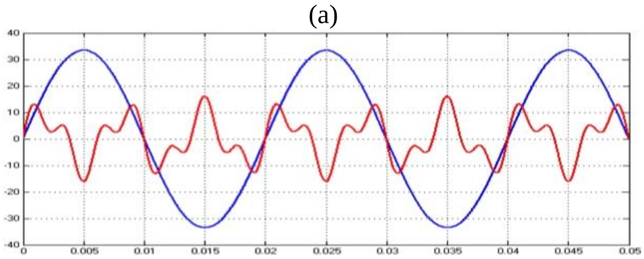


(c)

Fig. 7. The simulation results obtained from 7-level inverter based parallel active power filter, a) grid current with a THD value of 34.99% and harmonic components before filtering, b) grid current and filter current, c) switching signals



(a)



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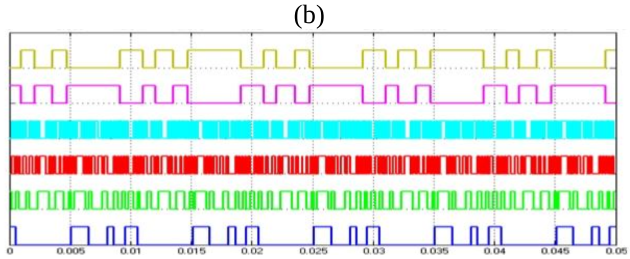

(c)

Fig. 8. The simulation results obtained from 31-level inverter based parallel active power filter, a) grid current with a THD value of 34.99% and harmonic components before filtering, b) grid current and filter current, c) switching signals

According to the simulation results, it is seen that the grid current after filtering becomes approximately sinusoidal.

5. Conclusions

Active power filters are frequently used in solving power quality problems in parallel with the increased use of non-linear loads. In this study, a switching algorithm developed for multilevel inverter based parallel active power filter is introduced. Through the switching algorithm used for the acquisition of switching signals, the total harmonic distortion of 34.99% generated by the third and seventh harmonic current component is reduced to 1.70% using two level modules and 0.27% using four level modules. The results of the simulation studies demonstrate the validity of the control algorithm and the importance of the number of level modules used in the inverter unit.

Acknowledgements

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