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Application of a New Modified PWM Techniqueon Shunt Active Filters

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Abstract-This paper presents a Shunt Active Filter (SAF) based on the Variable Index Pulse Width Modulation (VIPWM) approach. In the proposed method of Pulse Width Modulation (PWM), the triangular wave is derived by integration of the reference signals. This method introduces two basic advantages, the first one is that the triangular signal contains the information of the signal to be obtained in output and the second advantages is that its amplitude is varied in proportion to the amplitude of the reference signal. Therefore, in our proposed PWM method, the modulation index is varied according to the variation of the reference signal, so it is termed as Variable Index Pulse Width Modulation. In order to demonstrate the validity of the proposed method, the obtained simulation results are compared with the results of Space Vector Modulation (SVM) approach. Furthermore, it is shown that in the case of non-sinusoidal voltage, the SAF with the proposed control strategy can provide the filtering action. This method is quite easy to implement and requires lower circuitry. The results show that the proposed method can satisfy the IEEE standard regarding the reduction of harmonics.

١-Introduction

Nonlinear loads such as adjustable speed drives, power supplies for various electronic equipments are the origin the harmonic current using the frequency domain method of compensation in which all harmonic current components are targeted and eliminated. In this paper a novel PWM technique with the property of variable index based on the integral of reference current is suggested and applied on a SAF. To demonstrate its performance and superiority the obtained results are compared with [٢٨] in which the SVM technique based on Hysteresis Current Controller (HCC) is used. The paper is organized as follows: Section ٢ defines the configuration and control system of SAF. The proposed modified PWM technique is introduced in Section ٣. Section ٤ is

paper the frequency domain approach is used. There exist several methods based on the frequency domain in which either few specific frequencies or all frequencies except fundamental frequency are eliminated [۱۹]. As in this paper, the aim is to eliminate the total harmonics from line current by reducing the THD index as much as possible, so the second method has been employed. Therefore, the harmonic current is passed through a band reject filter having the center frequency of ٦٠ Hz. Then this signal is used as a reference signal.

۳-۲ Variable Index PWM

In all previously developed SAFs in which the PWM techniques are used, the reference signal is compared with the triangular signal. It is obvious that the triangular signals have no information. However, in the proposed method the triangular signal is derived from the integral of reference signals so it will be an intelligent signal and has the following advantages.

The obtained triangular wave contains the information related to the output signal and also its amplitude will vary in proportion to the amplitude of the reference signal. In fact, the modulation index is changed regarding to the amplitude of the reference signal, hence it is termed VIPWM. The procedure of this type of modulation for phase a (leg q۱&q٤) in Fig.۲ is described as follows.

devoted to the application of SAF on a sample circuit with a non-linear load considering sinusoidal and non-sinusoidal sources. The simulation results are presented in this section and the necessary comparison has been made to validate its superiority and performance. Conclusions are given in Section ٥.

۲-System configuration

The current error signal is acquired from the difference between the reference current and the feedback current. This current error signal is then fed into SAF and by using the VIPWM the appropriate states for transistors switching are provided.

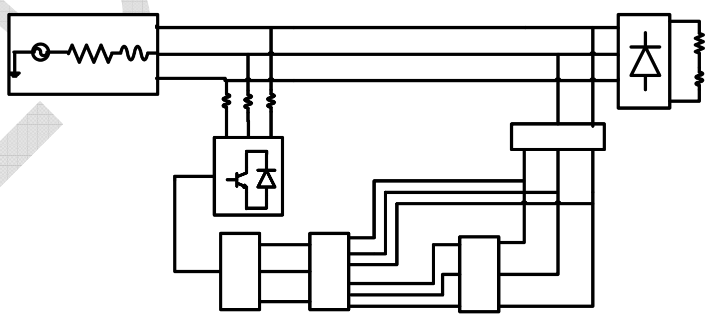


Figure۱-Block diagram of the proposed APF

۳- Proposed Modified PWM

In this section the proposed new PWM technique is described in detail and the principle operation of the control system is elaborated.

۳-۱ Reference Signal

As it was mentioned there are two basic approaches in producing reference signals: time domain and frequency domain. In this

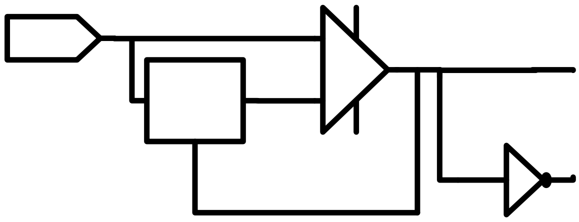


Figure.۳ Configuration of circuitry for transistor driving

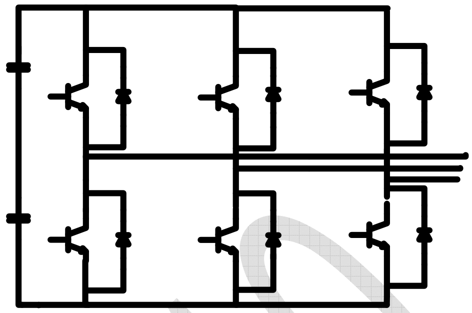
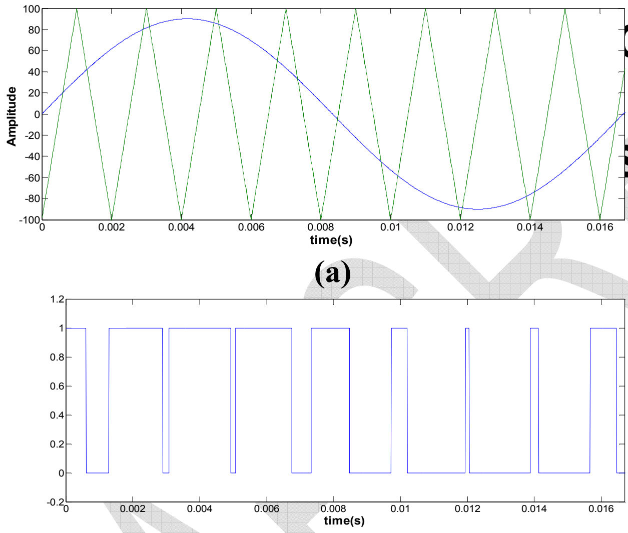


Figure۲-The structure of three phase inverter

The sine wave, triangular wave and the required signal for driving the transistor q۱ corresponding to PWM with a constant modulation index (m=۰٫۹) are shown in Fig.۴. The similar plots for VIPWM are shown in Fig.۵.



(a)

(b)

Figure۴. Modulation with constant index (m=۰٫۹)
(a) Sine wave and triangular wave
(b) Logic signal for driving transistor T۱

For the generation of a triangular signal we need an integrator with reset capability. According to Fig.۳, in the positive half cycle at first, the integral of reference current is performed, then the output of the integrator which is the triangular wave, is compared with the reference current. So long as the reference current is greater than the integrator output, transistor q۱ is on and transistor q۴ is off. When these two signals are equal, the integrator becomes reset and as long as the integrator output is zero, q۱ is off and q۴ is on. When output begins to increase q۱ starts to conduct and q۴ ceases. This process is continued up to the end of the positive half cycle.

However, during the negative half cycle, as long as the integrator output is greater than the reference signal, q۴ conducts and q۱ does not. When two signals are equal, the integrator becomes reset and as long as the integrator output is zero q۱ is on and q۴ is off. When the integrator output decreases from zero T۴ begins to conduct and T۱ ceases.

which the amplitude of the peak current considered to be equal to ($\pm I_a$), i.e. the small variations in peak is neglected. So we have:

$$i_1(t) = a_0 + \sum_{n=1}^{\infty}[a_n \cos(n\omega t) + b_n \sin(n\omega t)]$$

$$a_0 = I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_1(t)d(\omega t) = 0 \qquad (1)$$

$$a_n(t) = \frac{1}{\pi}\int_0^{2\pi} i_l(t)\cos(n\omega t)d(\omega t) = \frac{1}{\pi}\left[\int_{\pi/6}^{5\pi/6} I_a \cos(n\omega t)d(\omega t) - \int_{7\pi/6}^{11\pi/6} I_a \cos(n\omega t)d(\omega t)\right] = 0 \qquad (2)$$

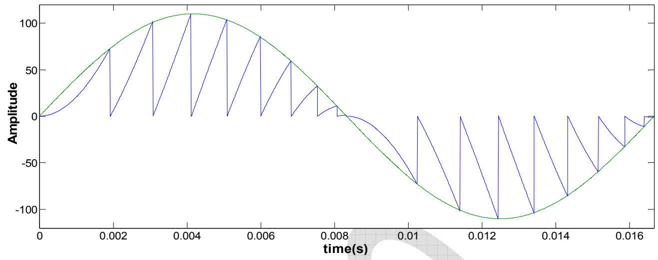
$$b_n(t) = \frac{1}{\pi}\int_0^{2\pi} i_l(t)\sin(n\omega t)d(\omega t) = \frac{1}{\pi}\left[\int_{\pi/6}^{5\pi/6} I_a \cos(n\omega t)d(\omega t) - \int_{7\pi/6}^{11\pi/6} I_a \cos(n\omega t)d(\omega t)\right] \Rightarrow$$

$$b_n(t) = \begin{cases} 0 & if\ n = 2k \\ 0 & if\ n = 3k \\ \frac{4I_a}{n\pi}\sin(\frac{n\pi}{3}) & otherwise \end{cases} \qquad (3)$$

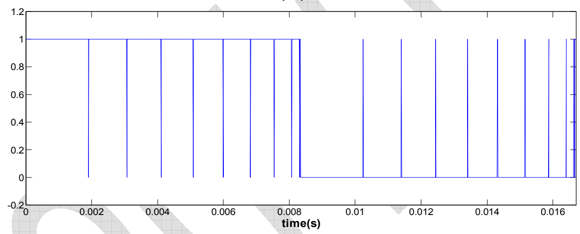
According to relations ۱, ۲ and ۳ the amplitude of ۲nd and ۳rd harmonics and their multiples are zero but there exist other harmonics. The line current frequency spectra is shown in Figure ٦b.

It is clear from this figure that the total harmonic distortion (THD) is equal to ۲۸,٥٦٪ which is quite excessive, so according to IEEE ٥١٩ standard to be reduced.

To do so, a SAF with the proposed control system is employed. The compensator desirable current and its harmonic spectra are shown in Fig.۷a and Fig.۷b respectively. The line current and its harmonic spectra after compensation are also shown in Fig.۸a and Fig.۸b respectively. It can be seen from this figure that the amount of THD is now ٤,٠٣٪, therefore a considerable reduction is provided. To show the superiority of the proposed method, a comparison is made with result of Ref. [۲۸], where the SVM based HCC is used and the obtained THD is equal to ٥,۳۲٪ which still does not satisfy the IEEE٥١٩ standard, while the proposed method of the present paper does.



(a)



(b)

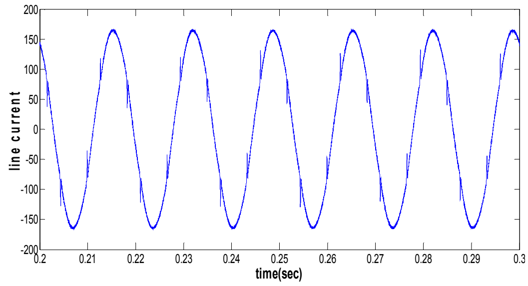
Figure٥. Modulation with variable index
(a) Sine wave and triangular wave
(b) Logic signal for driving transistor T١

٤-Simulation Results

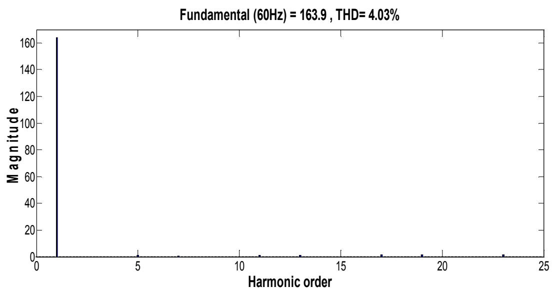
To show the ability of the SAF under the proposed control strategy, two cases have been simulated. In the fist case, the load is nonlinear but the source voltage is pure sinusoidal , while in second case the source is non-sinusoidal as well

Case١

The performance of the VIPWM technique is evaluated via digital simulation by its application on a three phase SAF using MATLAB Simulink and PSIM software. To demonstrate its ability in reducing the harmonic components from line current, a bridge rectifier with an RL circuit is considered as a non-linear load. The line current without SAF is shown in Fig.٦a. The line current frequency spectra can be calculated using following equations in



(a)



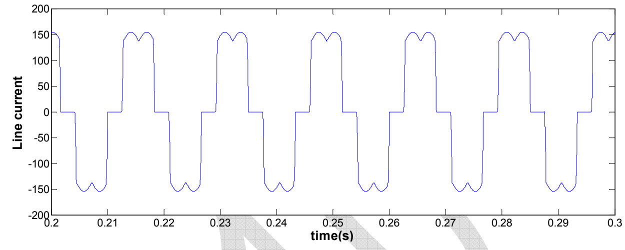
(b)

Figure٨. Line current with SAF operated by VIPWM method
(a) Original current waveform
(b) Current frequency spectra

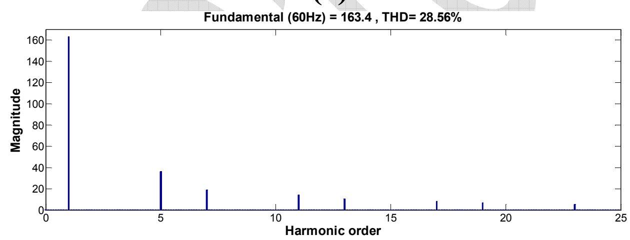
Case٢

In most of research works found in the literature which are dealing with the problem of active filtering, the source is considered to be pure sinusoidal, whereas due to the wide speared nonlinear loads in modern electric systems, this assumption is no longer valid. It is shown that the proposed method of PWM has the ability to tackle the problem of non-sinusoidal voltage. For this purpose a triangular voltage is applied on the test system. This input voltage and its frequency spectra are shown in Fig.٩ (a) and Fig.٩ (b) respectively. According to the frequency

Furthermore, its implementation is easy and requires lower costs and circuitry.

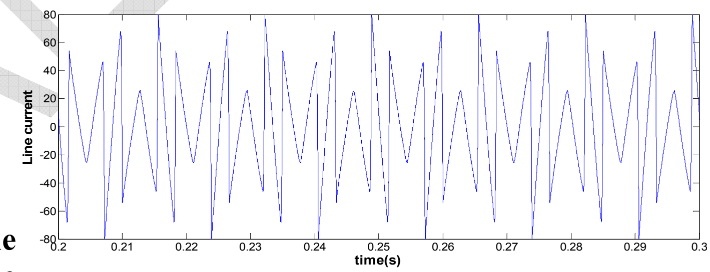


(a)

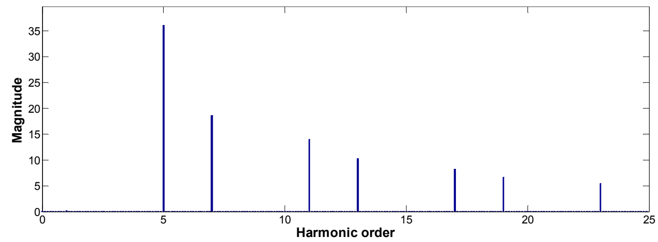


(b)

Figure٦. Line current without SAF for non-linear load
(a) Original current waveform
(b) Current frequency spectra

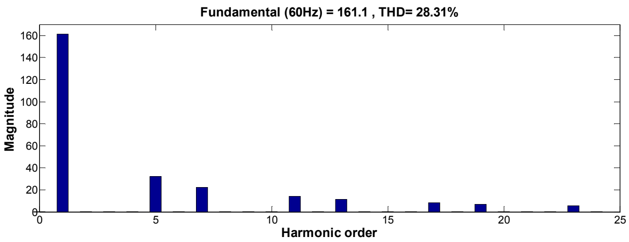


(a)



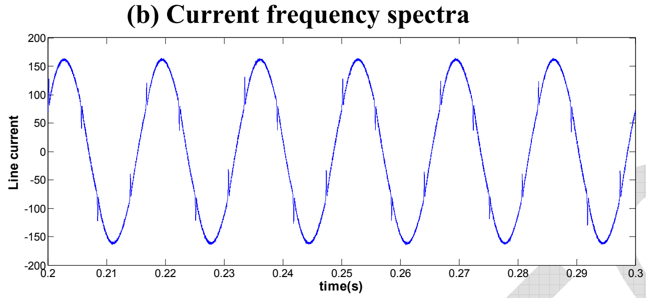
(b)

Figure٧. Desired current to be provided by SAF
(a) Original current waveform
(b) Current frequency spectra

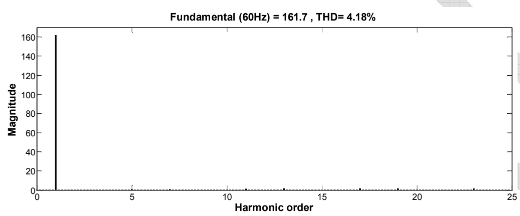


(b)

Figure۱۰ . Line current without SAF for non-linear load
(a) Original current waveform
(b) Current frequency spectra



(a)



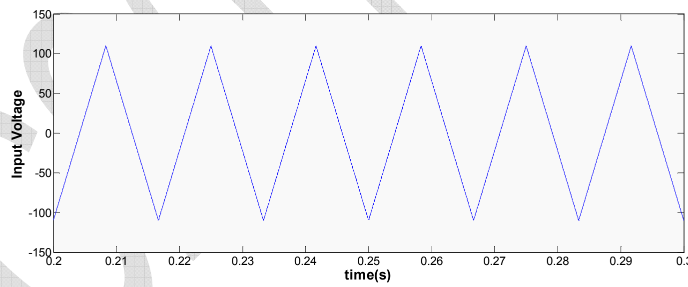
(b)

Figure۱۱. Line current with SAF operated by VIPWM method
(a) Original current waveform
(b) Current frequency spectra

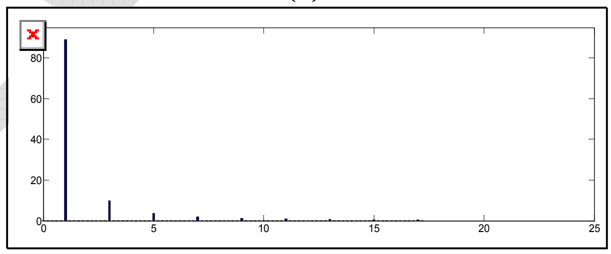
۵- Conclusion

In this paper, the ability and the performance of shunt active filters (SAF) are improved by proposing a new type of PWM technique. In our proposed PWM method, the modulation index is varied according to the variations of the reference signal, so it is termed as Variable Index Pulse Width Modulation (VIPWM)

spectra the THD of this signal is equal to ۱۲,۱۲٪. The line current and its frequency spectra are also shown in Fig.۱۰ (a)-(b). The THD of line current before compensation is ۲۸,۳۱٪. The line current and its frequency spectra after compensation are shown in Fig. ۱۱ (a)-(b). The THD of compensated line current is equal to ٤,۱۸٪. It is clear from this figure that the amount of THD is greatly reduced. Hence the SAF can properly works for both cases.

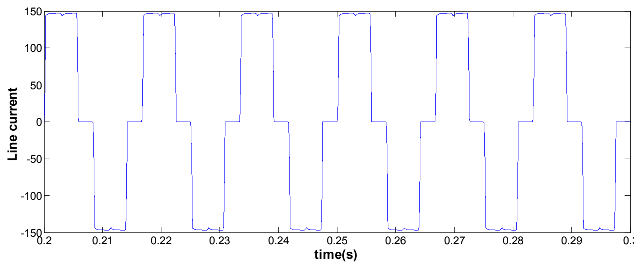


(a)



(b)

Figure۹. Input voltage without SAF
(a) Voltage waveform
(b) Frequency spectra



(a)

technique. The simulation results show that the SAF under this PWM technique can greatly reduce the harmonic components from line current to satisfy the requirement of IEEE standard. The obtained results also show that this technique can do the filtering action in the case of non sinusoidal voltage source. This method is easy to implement with lower cost and circuitry.

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of both current and voltage harmonics production in the distribution system leading to the power quality problem. In response to the power quality problem, IEEE ٥۱۹ and IEC EN ٦۱۰۰۰-۳ standards specify regulations governing harmonic compliance. Numerous active filters are introduced as effective means to meet the harmonic standards beside the passive filters have been proposed [۱]-[۱۲]. The shunt active filter (SAF) has become a mature technology in recent years. The operation principle of an active filter is based on PWM or SVM three-phase inverter to generate non- sinusoidal currents to meet harmonic current requirement of the nonlinear load. Many various configurations, control strategies, and applications of active filters are offered in the literature [۱۳-۱۹]. The SAF performs the filtering action by injecting harmonic components, which cancel those from the load, thereby the line current becomes free of harmonics [۲۰]. In filter design and its application, the methods for extraction of the harmonics from line current and determination of the filter reference current play an important and crucial role. Indeed, accuracy and speed of the SAF response are related to this point [۲۱]-[۲۳]. Time domain and frequency domain are two well-known methods for generation of reference current [۲٤]-[۲۷]. Time domain methods are based on measurements and transformation of

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three-phase quantities such as d-q or p-q transformation, whereas the frequency methods are based on the Fast Fourier Transformation (FFT). The main advantage of time domain methods is their fast response. On the other side, frequency domain methods can provide accurate individual and multiple harmonic detection of load current. With regard to the compensation objectives, the control strategy and the method for extracting the non-active load currents references are determined [۲۰]-[۲۷]. The purpose of this paper is to compensate