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Research Article

HARMONICS ELIMINATION USING PULSE WIDTH MODULATION SWITCHING

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Abstract:

The conventional rectifiers so far use conventional thyristors, natural commutation from the ac supply, and the phase angle firing delay control. The resultant ac currents are both distorted and lag the voltage. The non-sinusoidal nature of the currents and the less power factor make various issues the ac supply power system of the electricity generating and distribution companies. A controlled converter which takes almost sinusoidal current at power factor unity is an ideal, while it is inverts or rectifies. Such a converter is possible using fast switching devices and a control technique known as pulse width modulation (PWM). In this work, 5^{th}, 7^{th}, 17^{th}, 19^{th} order harmonics are eliminated with the help of input Dual Transformer connection and 11^{th} and 13^{th}order harmonics are eliminated by Pulse Width Modulation – Specific Harmonic Elimination (PWM-SHE) pattern in a 12 pulse Voltage Source Rectifier system. The switching angles required to trigger the semiconductor switch was found using Evolutionary Programming (EP) technique and the system is checked in MATLAB/Simulink. The proposed PWM-SHE switching pattern developed for the 12-pulse voltage source topology promised high- quality waveform, while keeping switching frequency to as low as 350 Hz.

Keywords: Harmonics, Pulse Width Modulation, Evolutionary Programming, Switching angle.

1. Introduction

Harmonics are the multiples of an alternating current fundamental frequency. The fundamental frequency is known as the first harmonics. Twice the fundamental frequency is called as second harmonics; the third harmonic is three times the fundamental frequency, and so on. Harmonics are created by nonlinear loads, so-called because the current is not a smooth sine wave. When electronic circuit is witched on to convert ac to dc, it draws pulsated current. These kinds of pulses can bring distorted current wave shapes that are rich in harmonics to the fundamental frequency.Total harmonic distortion is the accumulation of all the harmonic currents to the fundamentalfrequency [1]. The properties of harmonics dependson the number of rectifiers (pulse number) used in a circuit and this can be determined by the following equation.

h = (n x p) ±1

Where, n = integer (1, 2, 3…)

p = number of pulses or rectifiers

For example, using 6 pulse rectifier,

Characteristic harmonics are,

h = (1 x 6) ±1= harmonics (**5th** &**7th**)

h = (2 x 6) ±1=harmonics (**11th** &**13th**)

h = (3 x 6) ±1= harmonics (**17th** &**19th**)

h = (4 x 6) ±1=harmonics (**23rd** &**25th**)

Existence of harmonic currents also direct to exceptional issues in three-phase systems for example, in a four-wire three-phase system, harmonic currents bringmore currents in the neutral conductors, which may easily surpass the conductor rms current rating and Power factor correction capacitors may experience significantly increased rms currents, causing them to fail. The PWM specific harmonic elimination switching (PWM-SHE) eliminates several selected lower-order harmonics [2]. Much research has shown that about 50% reduction in the switching frequency is achieved when compared with the conventional carrier-modulated Sinusoidal PWM (SPWM) scheme. Due to low switching losses, the PWM-SHE scheme is one effective mean of obtaining high efficiency in high-power converters. To maintain unity input power displacement factor (DF), various control strategies namely, phase and amplitude control (PAC), hysteresis current control, and predicted current control with fixed switching frequency control (PCFF), have been proposed in recent works on this type of voltage source rectifiers (VSR). Although these control strategies can achieve the same goals, such as high power factor (PF) and near sinusoidal current waveform, their performance is varied. They all have advantages and disadvantages, which includes switching frequency, steady-state input current THD and dynamic response. One of these strategies is especially suitable for PWM-SHE patterns, because of the fixed modulation index [3]. The highlights of this control scheme are that the converter is operated at a fixed modulation index close to unity, and power transfer is controlled through phase shifting. To maintain near unity PF, the rectifier AC input voltage is made equal to the source voltage. Assuming that the link reactor is less than 0.4 p.u., the resulting power factor is greater than 0.98.

The primary issue in the control of a multilevel converter is to decide the switching angles so that the converter delivers the essential fundamental voltage and it does not produce specific lower order prevailing harmonics. Generally, the amplitude of harmonic components is determined in different according to the available multi-carrier PWM techniques, the modulation index and the switching frequency. Multi-level inverters have turned into a viable and practical solution for rising power and decreasing harmonics of AC waveforms. Compared with a single cell inverter, the main advantages of multi-level inverters are: first, the series connection allows higher output voltage without increasing voltage stress on switches; secondly, multi-level waveforms reduce the dv/dt at the output of an inverter; [4] and thirdly, a multi-level inverter can achieve lower harmonic distortion due to more levels of the output waveform at the same switching frequency.

There are numerous approaches to lessen harmonics, going from variable frequency drive designs to the expansion of supplementary equipment. The primary methods used today to reduce harmonics are12 pulse front end converter, Line Reactors, Delta-Delta,Delta-Wye Transformers, Isolation Transformers etc.

Required PWM-specific harmonic elimination (PWM-SHE) switching patterns were developed by applying Evolutionary Programming (EP) method [5]. Two identical voltage source rectifiers in series were adopted as active-front-end rectifiers.

In this work, 5^{th}, 7^{th}, 11^{th}, $13^{th}17^{th}$, 19^{th} order harmonics were eliminated with the help of input Dual Transformer connection and Pulse Width Modulation – Specific Harmonic Elimination (PWM-SHE) pattern. The system was checked in MATLAB/Simulink and it results in quite a low switching frequency, since only five switching per half cycle is required.

2. Problems and Optimization

2.1 Problems

The fundamental issue in the control of a multilevel converter is to determine the switching angles so that the converter produces the required fundamental voltage and does not generate specific lower order dominant harmonics [6].Generally, the magnitude of harmonic components is determined differently according to the available multi-carrier PWM techniques, the modulation index and the switching frequency. Multi-level inverters have become an effective and practical solution for increasing power and reducing harmonics ofAC waveforms.

The unwanted lower order harmonics of a square wave can be eliminated and the fundamental voltage can be controlled by selected harmonic elimination (SHE) PWM. Notches are created on the square wave in this method at predetermined angles as shown in Fig. 1.

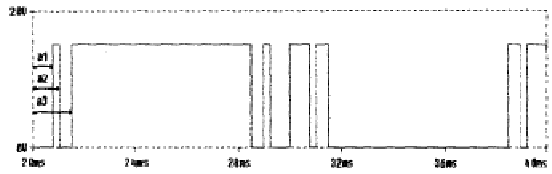

Figure. 1

It can be shown that four notch angles α_1, α_2, α_3 and α_4 can be controlled to eliminate three significant harmonic components and control the fundamental voltage [7]. A large number of harmonic components can be eliminated if the waveform can accommodate additional notch angles.

2.2 Switching angles

The front end of the bridge rectifier circuit utilizes twelve diodes in this design. Elimination of the 5th and 7th harmonics to a higher order are the advantages where the 11th and 13th turn into the prevailing harmonics. It minimizes the amplitude of the harmonics, not elimination. Construction cost is the main disadvantage, which also needs a Delta-Delta and Delta-Wye transformer, autotransformer to achieve the 30° phase shift essential for the suitable operation. This design affects the entire drive system efficiency also, because the voltage drop is connected with the transformer configuration requirement. Fig. 2depicts the typical basic circuit diagram for a 12-pulse converter front end.

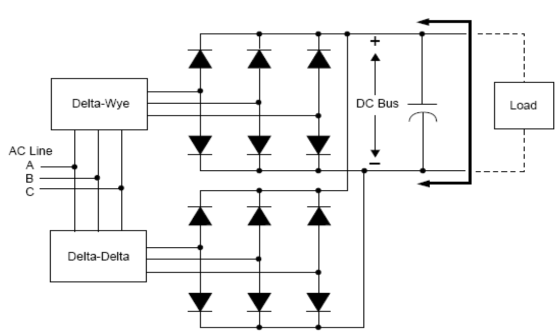

Figure. 2

2.3 Optimization

A novel medium to high voltage AC drive system topology, as shown in Fig. 3 is suggested.

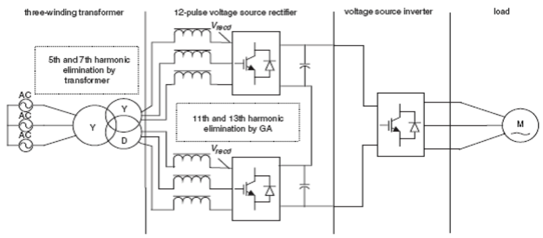

Figure. 3

Required PWM-specific harmonic elimination (PWM-SHE) switching patterns are developed applying a Evolutionary Programming (EP) method. Two identical voltage source rectifiers in series are adopted as active-front-end rectifiers. By use of a 12-pulse rectifier, the lowest order input current harmonics are the 11th and 13th, with a balanced input voltage source. Input current harmonics of 6k±1order, (k= 1, 3, 5… (2n- 1)), i.e. 5th, 7th, 17th and 19th, are eliminated by input dual transformer connection. To eliminate all the harmonics with order lower than 23rd, only 11th and 13th harmonics need to be eliminated by the PWM-SHE pattern. This results in quite a low switching frequency, since only five switching per half cycle is required.

3. Results and Discussion

3.1 Population index

ThePopulation Size is varied from 40 to 140 in terms of 20. The population Size 120 is selected as best (all the fitness values are nearly zero).So, 120 is kept as constant and the competition number is varied.

3.2 Competition number

The competition numbers are varied as 10, 20 and 30. Best results are obtained when the competition number is 20.Hence it is concluded to take the population size as 120 and the competition number as 20.So the parameters 120 and 20 were substituted in the MATLAB Program for Objective Function

3.3 Objective function

PWM-SHE switching pattern's fouriercoefficients for a 3 phase line-to-neutral are as below

$$a_n = \frac{4}{n\Pi}\left[-1-2\sum_{k=1}^{N}(-1)^k \cos(n\alpha_k)\right]$$

$$b_n = 0$$

The equation has N variables ($\alpha_1$to α_N)and a set of solutions are obtainable by equating N-1 harmonics to zero and assigning a specific value of the amplitude of the fundamental α_1 (which is equal to the modulation index M after being normalized), through the following equations

$$f_1(\alpha) = \frac{4}{\Pi}\left[-1-2\sum_{k=1}^{N}(-1)^k \cos(\alpha_k)\right] - M = \varepsilon_1$$

$$f_2(\alpha) = \frac{4}{5\Pi}\left[-1-2\sum_{k=1}^{N}(-1)^k \cos(5\alpha_k)\right] = \varepsilon_2$$

$$f_N(\alpha) = \frac{4}{N\Pi}\left[-1-2\sum_{k=1}^{N}(-1)^k \cos(n\alpha_k)\right] = \varepsilon_N$$

3.4. Modulation index

The calculated switching angles vary with the modulation index.Fig. 4 shows the switching angles for the proposed system.

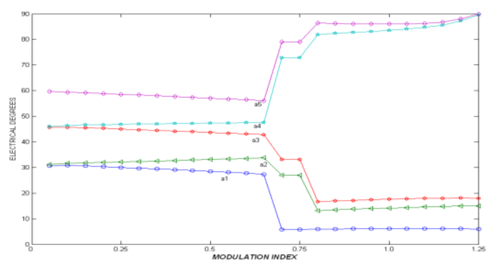

Figure. 4

3.5. Design of the proposed circuit

The proposed 12 pulse Voltage Source Rectifier circuit was designed using MATLAB/Simulink. Thecircuit uses three 230V single phase ac supply sources which are connected to the star connected primary winding of the Dual Transformer. The 12 pulse voltage source rectifier is developed by two six pulse rectifiers connected in series. The design of the circuit using MATLAB/SIMULINK is shown in Fig. 5.

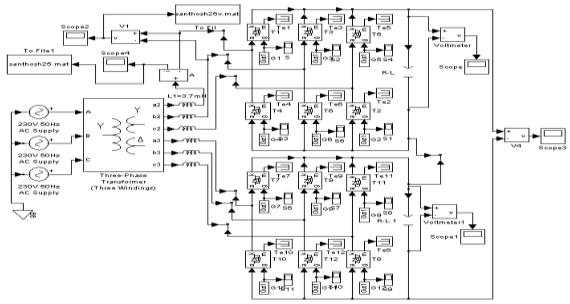

Figure. 5

The ratings of the proposed AC drive system is

1. Power Supply :400V (line to line) 50 Hz
2. AC input inductance:3.7mH
3. DC link capacitance:2x470µF

The harmonics are to be observed in the input line to line voltage and input current. Hence the inverter circuit is not connected in the circuit. The output voltage and output current waveform for the modulation index M=0.5 is shown in Fig. 6 and Fig. 7respectively.

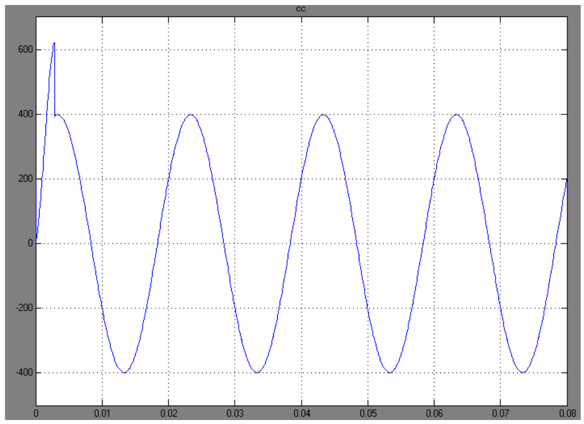

Figure. 6

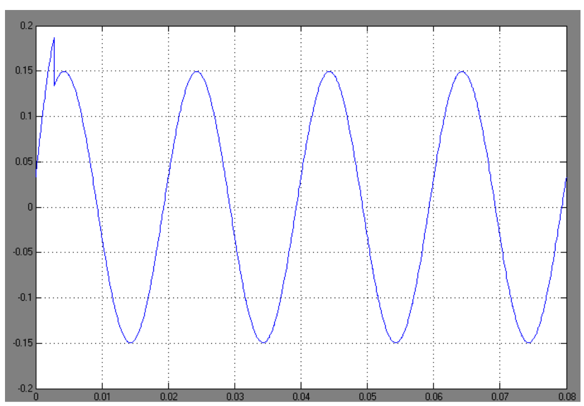

Figure. 7

3.6 Simulation

For analysing the frequency spectrum the waveforms of the output voltage and the output current are stored in separate files in .mat extension. This .mat file is called from the program developed. Hence the output voltage and the output current obtained in the SIMULINK are viewed through the program developed for analysing the frequency spectrum. When the program is executed the Frequency spectrum for the input line to line voltage of Voltage Source

Rectifier and the input current are obtained.The analysis shows that nearly all the harmonic components particularly 11^{th} and 13^{th}harmonics are eliminated except for a few distortions in the beginning.

4. Conclusion

A 12-pulse voltage source front-end rectifier topology utilizing PWM-SHE switching is proposed for a high power three-phase AC drive system. An efficient technique of calculating switching angles through the EP method is illustrated. The employment of low-frequency PWM switching in the front-end rectifiers lets them operate with nearly sinusoidal input currents and unity input power factor (PF). The proposed technique avoids the traditional complex and sometimes unreliable PF correction techniques; instead it uses reliable transformer interconnection and a well-known PWM technique. The novelty of this work lies in the application of EP in finding the optimal PWM-SHE switching angles, and its fast online implementation to the proposed unity PF converter topology. Elimination of low- order harmonics through transformer connection, and the resulting low switching losses in front-end rectifiers, makes it an attractive topology for high-power application.

Analyzing the frequency spectrum states that except for few distortions, almost in all the modulation index ,11^{th} and 13^{th} harmonics are eliminated through the proposed method by using EP except in M=0.7 and 0.75.Hence,to avoid unpredictable converter harmonics and erroneous operation, it is beneficial to keep the modulation index in the range from $0.05<M<0.65$ and $0.8<M<1.25$.The results also shows that the operating range of modulation index in EP is large compared to Genetic algorithm (GA) which operates in the range of $0.4<m<0.9$.The remaining distortions will be minimized by fine tuning of the program as a future work.

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