IMPROVING HARMONIC IMMUNITY DURING AC-DC INTERACTION IN VSC HVDC TRANSMISSION

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ABSTRACT

Voltage Source Converter (VSC) based HVDC transmission technology has been selected as the basis for several recent papers due to its controllability, compact modular design, ease of system interface, and low environmental impact. This feature also results in the lowest possible level of converter switching losses. For this reason, they are very attractive techniques for the voltage-source-converter-(VSC) based high-voltage dc (HVDC) power transmission systems. The application focuses on the conventional two-level converter when its dc-link voltage contains a mix of low-frequency harmonic components. Control methods based on selective harmonic elimination pulse-width modulation (SHE-PWM) techniques offer the lowest possible number of switching transitions. Amplitude modulation (AM) is a method of impressing data onto an alternating-current (AC) carrier waveform. The highest frequency of the modulating data is normally less than 10 percent of the carrier frequency. The instantaneous amplitude (overall signal power) varies depending on the instantaneous amplitude of the modulating data. The conventional Regular Sampled PWM technique can be simply extended to allow Harmonic Minimization and also Harmonic Elimination PWM to be closely reproduced using simple algebraic equations. FIS (Fuzzy Interference System) technique, a new controlling technique for control of harmonic immunity produce by external frequency is incorporated in this paper along with the filter.

Key Words: FIS, SHE-PWM, VSC

I.INTRODUCTION

Electric power transmission was originally developed with direct current. D.C. transmission now became practical when long distances were to be covered or where cables were required. In 1950, a 116 km experimental transmission line was commissioned from Moscow to Kasira at 200 kV. The first commercial HVDC line built in 1954 was a 98 km submarine cable with ground return between the island of Gotland and the Swedish mainland.

Thyristors were applied to D.C. transmission in the late 1960's and solid state valves became a reality. In 1969, a contract for the Eel River D.C. link in Canada was awarded as the first application of sold state valves for HVDC transmission. Today, the highest functional D.C. voltage for D.C. transmission is +/- 600 kV for the 785 km transmission line of the Itaipu scheme in Brazil. D.C. transmission is now an integral part of the delivery of electricity in many countries throughout the world. Advanced technologies, such as voltage-source converter (VSC)-based high-voltage dc (HVDC) power transmission systems [8] and [9], are essential for the restructuring of the power systems into more automated, electronically controlled smart grids. Efficient control of unbalanced compensator currents can be achieved by a control algorithm based on the D-STATCOM model [22]. D-

STATCOM [25] allows separate control of positive & negative sequences currents and decoupled current control of the - frame. With the invention of fully controlled power semiconductors, such as insulated-gate bipolar transistors (IGBTs) and integrated gate-commutated thyristors (IGCTs), the VSC topologies are more attractive due to their four-quadrant power-flow characteristics.

The objective of this paper is to discuss the effectiveness of optimized modulation based on pre calculated SHE-PWM in a two-level three-phase VSC [16] to make the ac side immune from the fluctuations of the dc link without the use of passive components. A method is proposed to prevent the dc-link ripple voltage [29] from creating low-order harmonics on the ac side of fixed and variable frequency inverters. However, only one of the multiple SHE-PWM set of solutions is reported. An investigation of the harmonic interaction between the ac and dc side for STATCOM is presented including the so-called dynamic SHE-PWM [23] scheme based on pre calculated angles for better THD. However, the dynamic SHE-PWM scheme is applied only for a three-level converter and can be applied only for known magnitude and frequency of the ripple.

Fuzzy Inference System (FIS) can be viewed as a method where a multiple-input model can be constructed in an easy manner (Jang et al., 1997; Lin & Lee, 1995). FIS has demonstrated its ability in a variety of problem domains, e.g. control, modeling, and classification problems. One of the key factors of its success is the ability to incorporate human/expert knowledge where information is described by vague and imprecise statements. Besides, the behavior of an FIS is also expressed in a language that is easily interpreted by humans. Biswas (1995) presented a fuzzy set related method to evaluate students' answer scripts. This work was then further enhanced by Chen and Lee (1999). Next, Ma and Zhou (2000) presented fuzzy set related methods.

II.OVERVIEW OF VSC-BASED HVDC TRANSMISSION SYSTEM

The typical configuration of VSC-based HVDC transmission system is presented in Figure1. Such a transmission system consists of: two voltage source converters, transformers, phase reactors, AC filters, DC-link capacitors and DC cables.

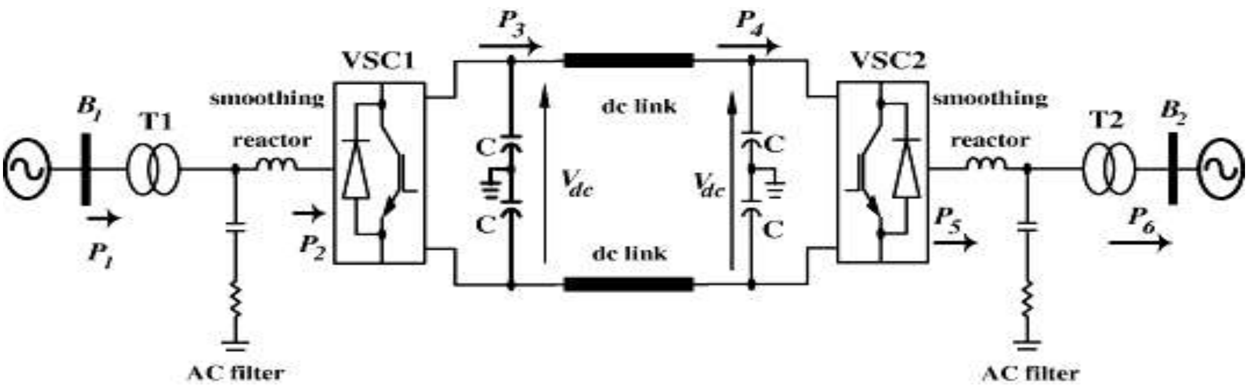


Figure 1 Typical VSC-HVDC system

2.1 Voltage Source Converter

The two VSCs may be seen as the core of this transmission system topology. One of the VSCs works as rectifier, while the other one works as an inverter, and both of them are based on IGBT power semiconductors. The two VSC stations are connected through a DC transmission line or an overhead line. Mainly, two basic configurations of VSCs are used on HVDC [3] transmission system. These are the two-level VSC converter, presented in Figure 2(a), and the three-level VSC converter, which is presented in Figure 2(b).

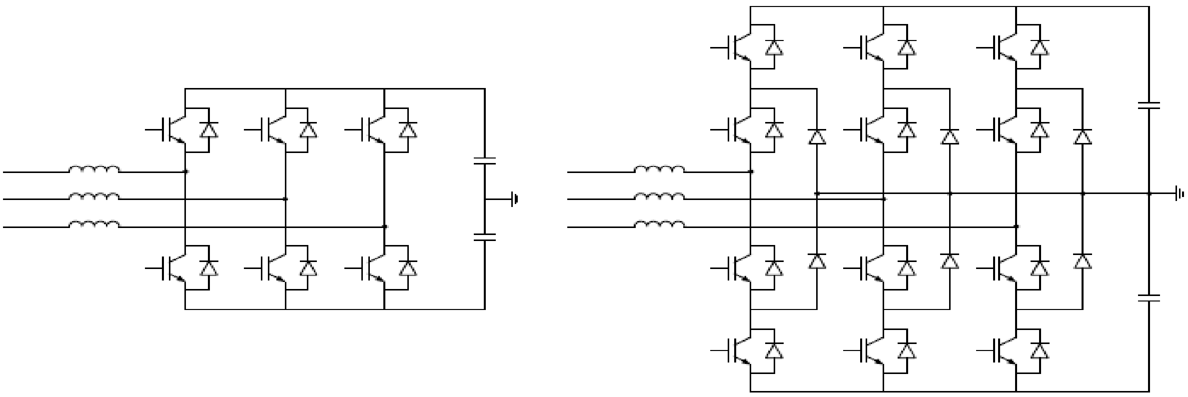


Figure 2 (a) Two-level VSC **(b) Three-level VSC**

The two-level VSC, also known as the three phases, two level, six-pulse Bridge, is the simplest configuration suitable for HVDC transmission.

The basic design for practically all HVDC converters is the 12-pulse double bridge converter which is shown in Figure 2 the converter consists of two 6-pulse bridge converters connected in series on the DC side. One of them is connected to the AC side by a YY-transformer, the other by a YD transformer. The AC currents from each 6-pulse converter will then be phase shifted 30°. This will reduce the harmonic content in the total current drawn from the grid, and leave only the characteristic harmonics of order 12 m±1, m=1,2,3..., or the 11th, 13th, 23th, 25th etc. harmonic. The non-characteristic harmonics will still be present, but considerably reduced. Thus the need for filtering is substantially reduced, compared to 6pulse converters. The 12-pulse converter is usually built up of 12 thyristor valves.

2.2 Two-Level Vsc for The Hvdc Power Transmission System

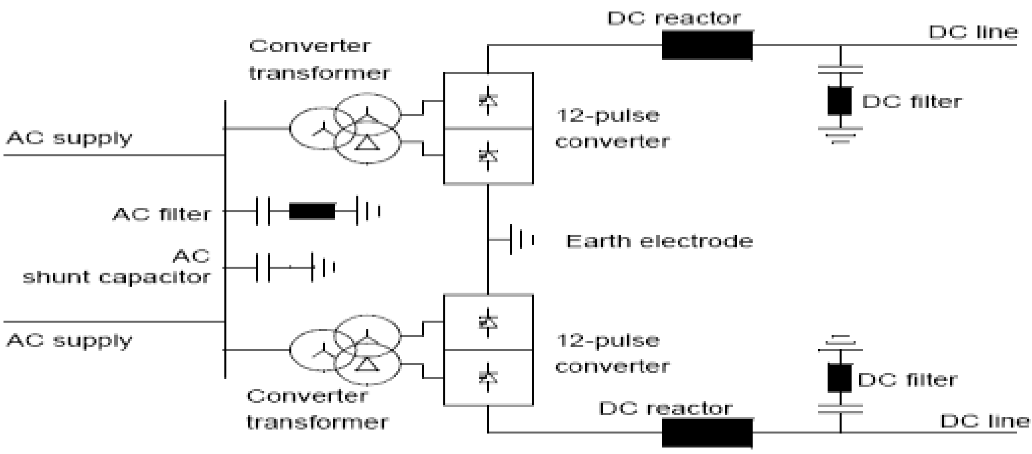


Figure 3 Two 12-pulse converter

The first generation of utility power converters is based on current-source converter (CSC) topologies. Today, many projects still use CSCs due to their ultra-high power capabilities. With the invention of fully controlled power semiconductors, such as insulated-gate bipolar transistors (IGBTs) and integrated gate-commutated thyristors (IGCTs), the VSC topologies are more attractive due to their four-quadrant power-flow characteristics. A typical configuration of the VSC-based HVDC power transmission system is shown in Figure 3 as it is shown.

III.SELECTIVE HARMONIC ELIMINATION

3.1 Modeling of Case Study Analysis of The PWM Converter And She-Pwm

The optimized SHE-PWM technique [23] is investigated on a two level three-phase VSC topology with IGBT technology [6] typical periodic two-level SHE-PWM waveform is shown in Figure 4.

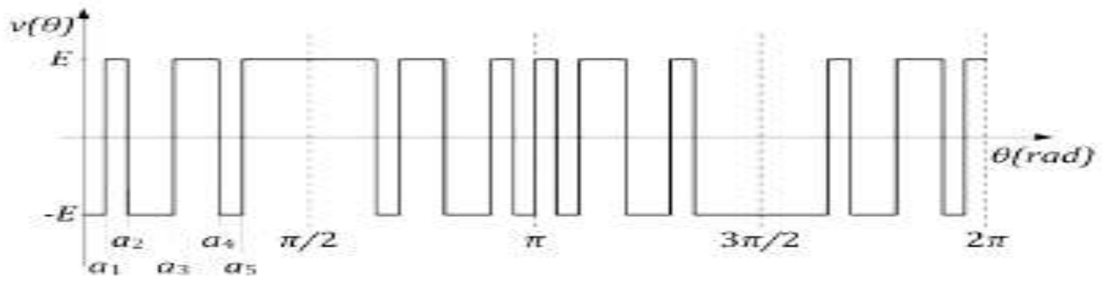


Figure 4 Typical two -level PWM switching waveform with five angles per quarter cycle

The waveforms of the line-to-neutral voltages can be expressed as follows

$$V_{LN} = \begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix} = V_{dc} \begin{bmatrix} \sum_{n=1}^{\infty} A_n \sin n\omega_o t \\ \sum_{n=1}^{\infty} A_n \sin n\left(\omega_o t - \frac{2\pi}{3}\right) \\ \sum_{n=1}^{\infty} A_n \sin n\left(\omega_o t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (1)$$

When *wo* is the operating frequency of the ac, and Vdc is the dc-link voltage. Thus, the line-to-line voltages are given by

$$V_{LL} = \begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix} = \sqrt{3} \cdot V_{dc} \begin{bmatrix} \sum_{n=1}^{\infty} A_n \sin n\left(\omega_o t + \frac{\pi}{6}\right) \\ \sum_{n=1}^{\infty} A_n \sin n\left(\omega_o t - \frac{\pi}{2}\right) \\ \sum_{n=1}^{\infty} A_n \sin n\left(\omega_o t + \frac{5\pi}{6}\right) \end{bmatrix} \quad (2)$$

The SHE-PWM method offers numerical solutions which are calculated through the Fourier series expansion of the waveform

$$M = 1 + 2 \sum_{i=1,2,3\ldots}^{N+1} (-1)^i \cos(\alpha_i)$$

$$0 = 1 + 2 \sum_{i=1,2,3\ldots}^{N+1} (-1)^i \cos(k\alpha_i) \quad (3)$$

Where N+1 are the angles that need to be found. Using five switching angles per quarter-wave (N= 4) in SHE-PWM, k= 5, 7, 11, 13 to eliminate the 5th, 7th, 11th, and 13th harmonics. During the case of a balanced load, the third and all other harmonics that are multiples of three are cancelled, due to the 120°symmetry of the switching function of the three-phase converter. The even harmonics are cancelled due to the half-wave quarter-wave symmetry of the angles, being constrained by

$$0 < \alpha_1 < \alpha_2 < \cdots < \alpha_{N+1} < \pi/2.$$

3.2 Selective Harmonic Elimination

Notice that in the SPWM strategy developed above, a large number of switching are required, with the consequent associated switching losses. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching's. This method however can be difficult to implement on-line due to computation and memory requirements. For a two level PWM waveform with odd and half wave symmetries and n chops per quarter cycle as shown in Figure 5, the peak magnitude of the harmonic components including the fundamental, are given by Equation 4.

$$\begin{aligned}
h_1 &= \left(4 \cdot \frac{E}{\pi}\right) \cdot [1 - 2\cos\alpha_1 + 2\cos\alpha_2 \\
&\qquad - 2\cos\alpha_3 \ldots 2\cos\alpha_n] \\
h_3 &= \left(4 \cdot \frac{E}{3\pi}\right) \cdot [1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 \\
&\qquad - 2\cos 3\alpha_3 \ldots 2\cos 3\alpha_n] \\
&\vdots \\
h_k &= \left(4 \cdot \frac{E}{k\pi}\right) \cdot [1 - 2\cos k\alpha_1 + 2\cos k\alpha_2 \\
&\qquad - 2\cos k\alpha_3 \ldots 2\cos k\alpha_n]
\end{aligned} \tag{4}$$

It is the magnitude of the i^{th} harmonic and α_j is the j^{th} primary switching angle. Even harmonics do not show up because of the half-wave symmetry. The n chops in the waveform afford n degrees of freedom. Several control options are thus possible. For example n selected harmonics can be eliminated. Another option which is used here is to eliminate n-1 selected harmonics and use the remaining degree of freedom to control the fundamental frequency ac voltage. To find the α's required to achieve this objective, it is sufficient to set the corresponding the above equations to the desired values (0 for the n-1 harmonics to be eliminated and the desired per-unit ac magnitude for the fundamental) and solve for them α's.

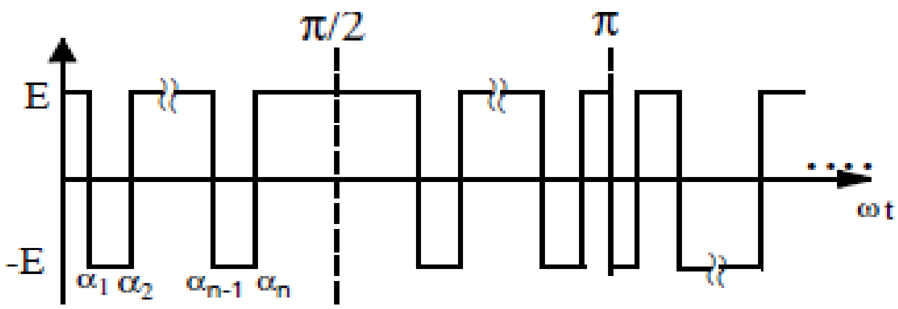


Figure 5 A two-level PWM waveform with odd and half wave

Equation 4 can be readily proved by finding the Fourier coefficients of the waveform shown in Figure 5. In general, for a periodic waveform with period 2Π, the Fourier Cosine and Sine Coefficients are given by

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(\Theta)\,d\Theta$$
$$a_k = \frac{1}{\pi}\int_0^{2\pi} f(k\Theta)\cos(k\Theta)\,d\Theta$$
$$b_k = \frac{1}{\pi}\int_0^{2\pi} f(k\Theta)\sin(k\Theta)\,d\Theta) \qquad (5)$$

Because of the half-cycle symmetry of the waveform of Figure 5, only odd order harmonics exist. Also, it is easy to see that the Fourier Cosine coefficients disappear with the choice of coordinate axes used. Utilizing the quarter cycle symmetry, the Fourier Sine coefficients become

$$b_k = \frac{4}{\pi}\int_0^{2\pi} f(k\Theta)\sin(k\Theta)\,d\Theta) \qquad (6)$$

Substituting the two-value pwm waveform for F , one obtains (see Figure 4).

$$b_n = \frac{4E}{\pi}\left(\int_0^{\alpha_1}\sin(k\theta)d\theta - \int_{\alpha_1}^{\alpha_2}\sin(k\theta)d\theta + \int_{\alpha_2}^{\alpha_3}\sin(nk)d\theta \ldots \int_{\alpha_n}^{\frac{\pi}{2}}\sin(k\theta)d\theta\right)$$
$$= \frac{4E}{\pi k}\left(-\cos(k\theta)\Big|_0^{\alpha_1} + \cos(k\theta)\Big|_{\alpha_1}^{\alpha_2} - \cos(k\theta)\Big|_{\alpha_2}^{\alpha_3}\ldots\right)$$
$$= \frac{4E}{\pi n}[1 - 2\cos n\alpha_1 + 2\cos k\alpha_2 \quad -2\cos k\alpha_3 \ldots 2\cos k\alpha_n] \qquad (7)$$

The following example illustrates the use of three chops per quarter cycle which allow for three degrees of freedom. We may use these to eliminate two harmonics and control the magnitude of the fundamental to any desired value

IV.FUZZY INTERFERENCE SYSTEM & FILTER

4.1 Analysis of Fuzzy Logic Technique

(a) Fuzzy Logic

Unlike Crisp logic based on binary sets which is essentially a two-valued logic, "fuzzy logic" is a form of multi-valued logic and is based on fuzzy set theory. To deal with fluid or approximate reasoning, fuzzy logic variables can take a truth value that ranges in degree between 0 and 1. Fuzzy logic is a super set of conventional logic that has been extended to handle the concept of partial truth: the truth values between completely true and completely false.

(b) Fuzzy Set & Membership Function

A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership.

A membership function (MF) is a mapping from an input space (often referred to as the universe of discourse) to a membership value between 0 and 1... In fuzzy logic, it represents the degree of truth as an extension of valuation.

A classical set can be expressed as

A = {x | x < 13}

If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs.

A = {x, μA(x) | x ∈ X}

μA(x) is the membership function of x in A.

(c) Fuzzy Inference System

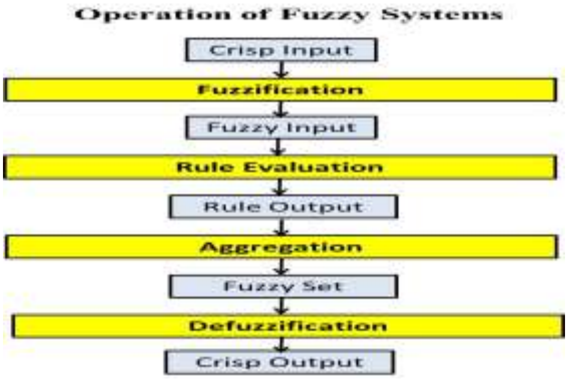


Figure 6 Fuzzy Interference System

4.2 Simulation Parameters of The Conventional and The Proposed System:

Input DC voltage Source = 100V
Voltage tolerance = ± 10%
Frequency = 48 … 63 Hz
Power factor = 0.98 (fundamental) 0.93 0.95 (total)
Modulation Index = 0.75 or (less than 1)
Reference frequency = 50Hz (output requirement)
Career frequency = 20KHz

Table 1

Three-phase series RL branch Load
Resistance R (Ohms): 1 Ω
Inductance L (H): 1e-3 (0.001) H

Table 2 Ideal three-phase voltage and current

4.3 Measurements

Internal resistance Ron (Ohms) : 1e-3(0.001)
Snubber resistance Rs (Ohms) : 1e5(100KΩ)
Snubber capacitance Cs (F) : inf

Table 3 IGBT Rating

Simulation parameters of the conventional and proposed system The simulation model of the conventional VSC based HVDC parameters is shown in the Table MATLAB simulation package has been used to simulate this paper. Simulation results are analyzed swith R-L load for the modulation index M=0.75 for the elimination of 5th, 7^{th}, 11^{th} and 13^{th} harmonics with dc reference voltage. Using five switching angles per quarter-wave (N=4) in SHE-PWM, *K*= 5, ,7, 11, 13 to eliminate the 5th, 7th, 11th, and 13th harmonics. During the case of a balanced load, the third and all other harmonics that are multiples of three are cancelled, due to the 120 symmetry of the switching function of the three-phase converter. The even harmonics are cancelled due to the half-wave quarter-wave symmetry of the angles, Equations 6.4 can solved by using Newton – Raphson method by using below MATLAB code 8.2.

V.SIMULATION MODEL AND RESULTS

5.1 Simulation Model Of Vsc Based Hvdc With Shepwm Technique

By using SHE-PWM technique eliminating 5^{th}, 7^{th}, 11^{th}, and 13^{th} harmonics. Make the system immune to external disturbance during ac-dc interaction VSC based hvdc transmission. The SHE PWM method offers numerical solutions which are calculated through the Fourier series expansion of the waveform

- The switching frequency of the converter is 3240Hz
- The modulation indexes for the rectifier (m_r) both is at 75

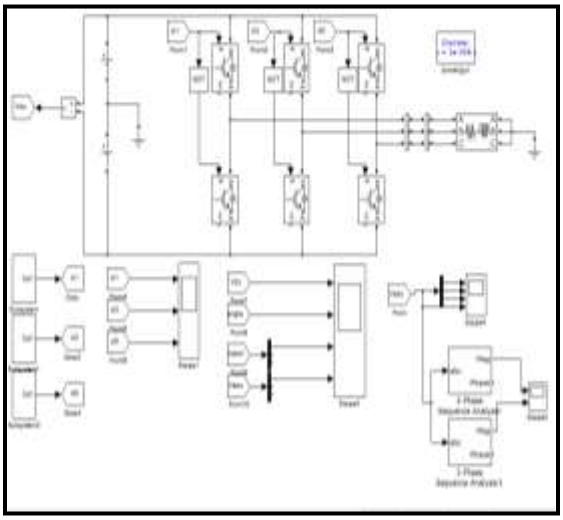


Figure 7 Simulation Model for elimination 5th, 7th, 11th, and 13th Harmonics of a VSC –HVDC by SHE-PWM.

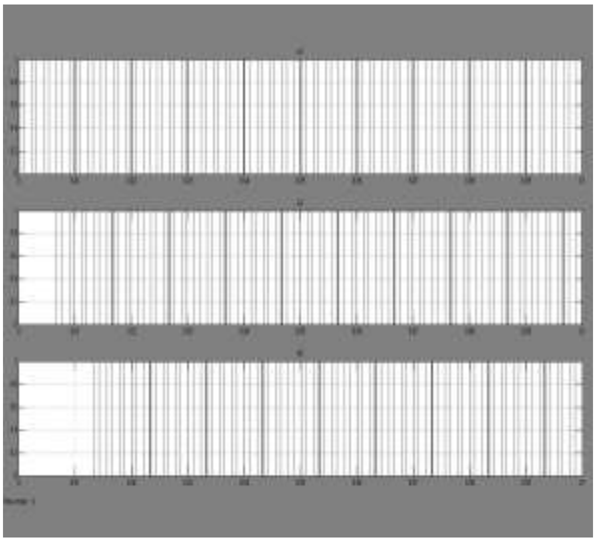


Figure 8 Input Pulses for conduction of IGBT's at regular interval

5.2 Simulation Result for SHE-PWM Technique

5.2.1 Input Pulses to the VSC

This input pulses are play vital role for elimination dominate low order and to produce less switching loss. Proposed M-type modulation technique allows reduction in the switching transitions without lowering the order of the predominant harmonic. Here it can observe for the above figure 8 delay is produce for conduction of IGBT's at regular interval.

5.2. 2 Simulation Results For She-PWM Elimination

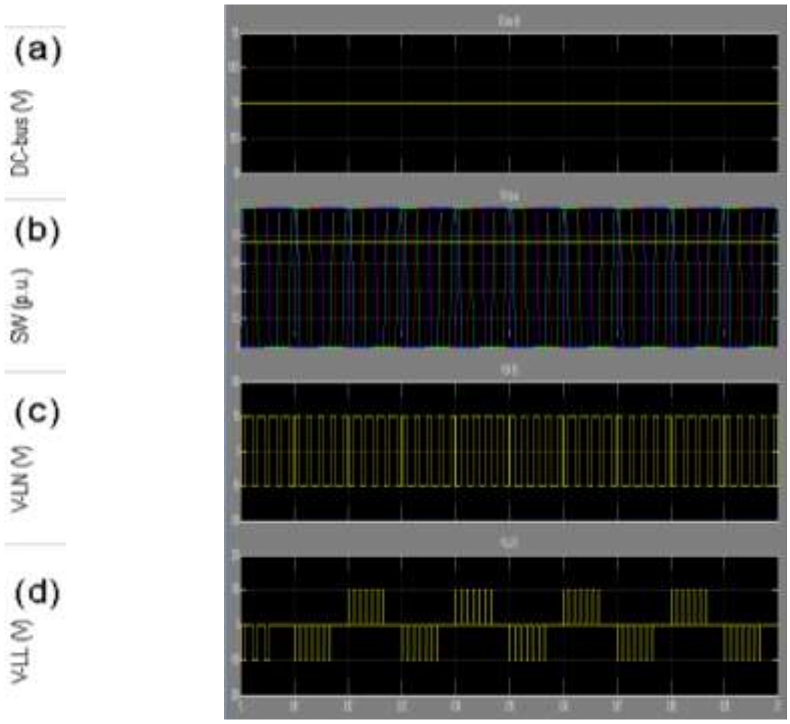
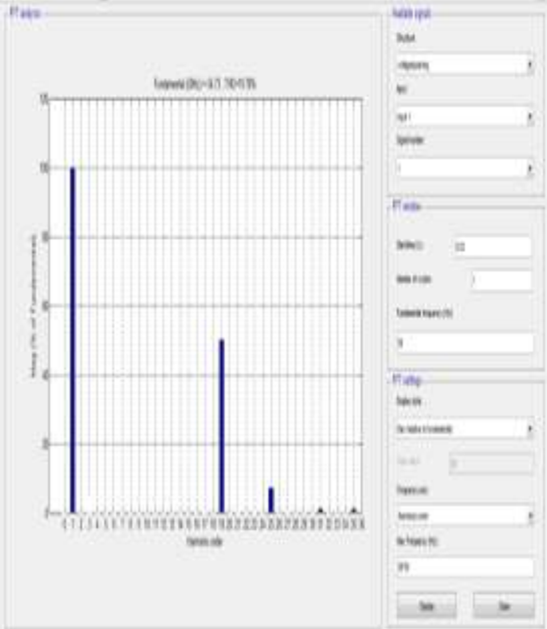


Figure 9 Simulation results for SHE-PWM eliminating 5th, 7th, 11th, and 13th harmonics. (a) DC-link voltage. (b) olution trajectories to eliminate harmonics and intersection points with the modulating signal (M=0.75). (c) Line-to-neutral voltage. (d) Line-to-line voltage.



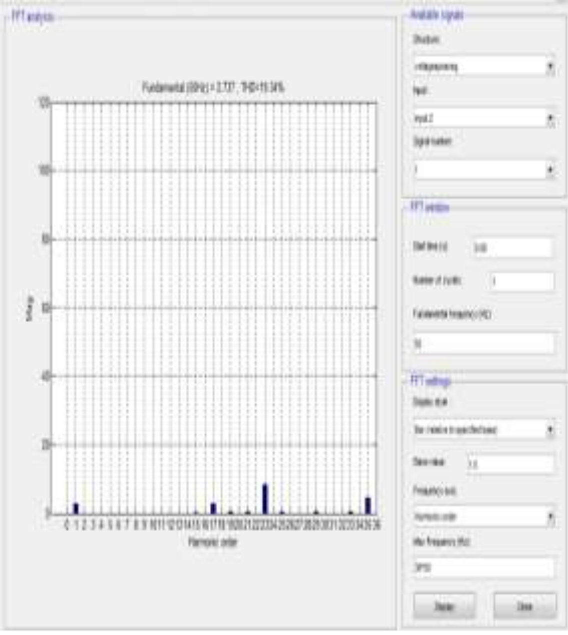


Fig 10 Positive sequence line-to-line voltage spectra Fig11 Negative-sequence line-to-line voltage spectra.

Simulation results for SHE-PWM eliminating 5th, 7th, 11th, and 13^{th} harmonics figure 10 and figure 11 Positive- and negative-sequence line-to-line voltage spectra, respectively.

5.3 Comparison

Parameters	Conventional Values	Proposed Values
Input Supply Voltage(Vdc)	100V	100V
Operating Frequency(f)	50Hz	50Hz
Modulation Index (M)	0.75	0.75
Voltage Tolerance	± 10%	± 10%
Output Line to Line Voltage(VLL)	100V	100v
Output Line to Neutral Voltage (VLN)	50V	50V
Eliminated Harmonics	5^{th},7^{th},11^{th} & 13^{th}	5^{th},7^{th},11^{th} & 13^{th}
Harmonics Effect	Dominate Harmonic is 19^{th}	Dominate Harmonic is 19^{th}

Table 4 Comparison of values between conventional and proposed

5.4 Improvements In Conventional

Implement FIS (Fuzzy Interference System) technique, as it has following advantages like:

- Parallel execution of rules
- output calculated once at end of cycle
- rules are evaluated in parallel

- order does not matter

In addition to this high order harmonic are eliminating by using a Filter.

5.5 Simulation Circuit By Fis (Fuzzy Interference System)-Filter

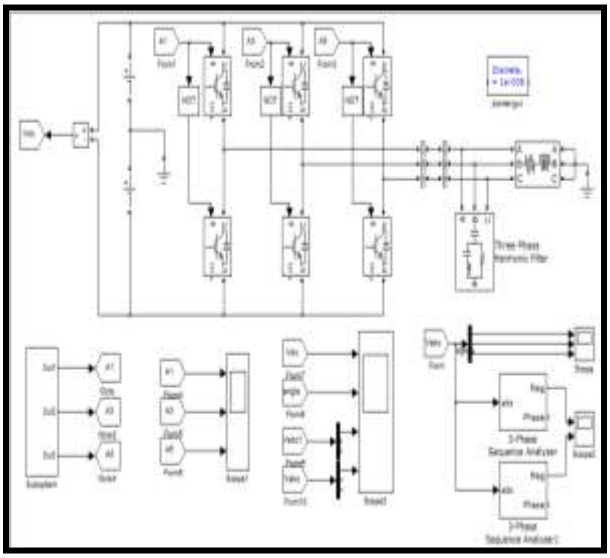


Figure 12 Simulation Model for elimination Harmonics in VSC –HVDC by FIS (fuzzy Interference System)-Filter. ere in the simulation model in the VSC –HVDC

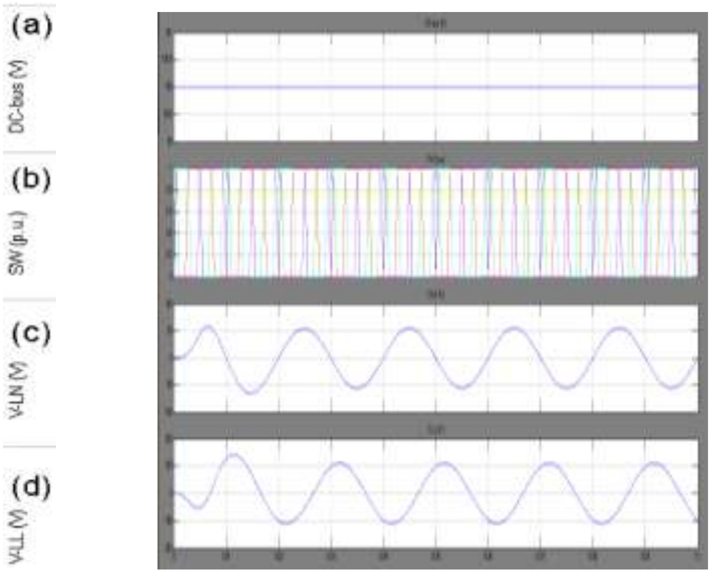


Figure 13 (a) DC-link voltage. (b) Solution trajectories to eliminate harmonics and intersection points with the modulating signal (M=0.75). (c) Line-to-neutral voltage. (d) Line-to-line voltage.

✓ By FIS (fuzzy Interference System) lower orders dominate Harmonics (5th, 7th, 11th, and 13th harmonics) can be eliminated for a Three-phase two-level VSC.

✓ For elimination dominate high order (i.e. 19th and above) can be eliminated by using three phase harmonic filter. Make the system within the permissible THD values

Here in this delay blocks are changed…so that the math function what you are writing is also changes…whenever the pulse is changing the output angle also changes so that triggerening changes.

5.6 Simulation Result for FIS & Filter

Simulation results FIS (Fuzzy Interference System) for eliminating 5th, 7th, 11th, and13th harmonics and elimination of high order harmonic by using Filter. Figure (14) and (15) are Positive and negative-sequence line-to-line voltage spectra, respectively.

Fig 14 Positive sequence line-to-line voltage spectra Fig15 Negative sequence line-to-line voltage spectra

FIS Technique to reduce the lower order harmonics according to the required modulation index. Eliminating the high order harmonic effects by using filter and make the THD (Total Harmonic Distortion) with in permissible value.

VI. CONCLUSION

An optimized SHE-PWM & FIS technique, offers immunity between the ac and dc side in a two-level three-phase VSC which are used in this paper. These techniques are highly significant in VSC based HVDC as every low-order harmonics is eliminated. In order to eliminate higher order harmonics filters have been used. There are some limitations related to the maximum modulation index available for SHE-PWM angles calculations. FIS to reduce the lower order harmonics according to the modulation index. Eliminating high order harmonic effects by using filter and make the THD (Total Harmonic Distortion) with in permissible value.

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