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HARMONIC ANALYSIS OF SERIES HYBRID MODULAR MULTILEVEL CONVERTER

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Abstract*— Recent research on modular multilevel converter (MMC) have brought numerous advantages of it in high power applications. However, main drawback of MMC is lack of DC fault blocking. Hence, hybrid configurations consist of MMC and two-level converters are investigated to overcome the drawbacks of MMC. These converters offer the advantages of both these configurations and also help in blocking DC fault. In this paper harmonic analysis of series hybrid MMC is presented. Series hybrid MMC consists of two-level converter and series connections of full-bridge modules on ac side. The two-level converters gives square wave output which operates at fundamental frequency and series connections of full bridge modules act as filters and absorbs the difference of square wave and required multilevel waveform. The series modules are operated with pulse width modulation and hence the harmonic spectrum of output voltage waveform is improved.

***Keywords*— High voltage DC transmission, Modular Multilevel Converter, Series-Hybrid Modular Multilevel Converter, Wave-Shaping circuit, Sub-Module**

I. INTRODUCTION

Modular multilevel converters (MMC) for high voltage DC transmission are becoming more comprehensive as newer converter topologies. MMCs are being conceived for high voltage DC transmission system because they give reliable and stable transmission operation [1]. High voltage DC transmission system using modular multilevel converters is set to occupy a significant proportion of future DC transmission system. The function of MMC module is to impart a wave-shaping function to obtain the multilevel output voltage waveforms [2].

However, main problem associated with MMC is that it cannot block fault on DC link. Therefore many researchers have proposed hybrid convertor topologies which consist of series connection of full bridge modules on AC or DC side along with two-level converters [3]-[6]. These converters offer the advantages of both these configurations and also help in blocking DC fault [7]-[10]. In this paper harmonic analysis of series hybrid MMC is presented. Series hybrid MMC consists of two-level converter and series connections of full-bridge modules on AC side. The two-level converters gives square wave output which operates at fundamental frequency and series connections of full bridge modules act as filters and absorbs the difference of square wave and required multilevel waveform. The series modules are operated with pulse width modulation and hence the harmonic spectrum of output voltage waveform is improved.

II. SERIES HYBRID MMC

Figure 1 shows series hybrid multilevel converter which is a combination of two-level and series connections of full bridge modules on AC side. Figure 2 shows the configuration of the full bridge module and series connections of these modules will act as wave-shaping circuit. The two-level converters gives square wave output which operates at fundamental frequency and series connections of full bridge modules act as filters and absorbs the difference of square wave and required multilevel waveform as shown in Figure 1. If the number of series modules are sufficiently large then they can be operated with nearest level modulation otherwise they are operated with pulse width modulation and hence the harmonic spectrum of output voltage waveform is improved.

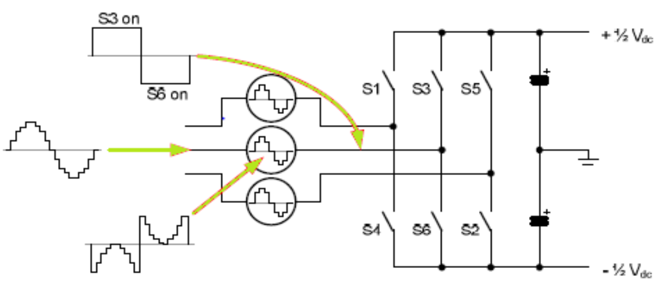

Figure 1: Configuration of series hybrid MMC

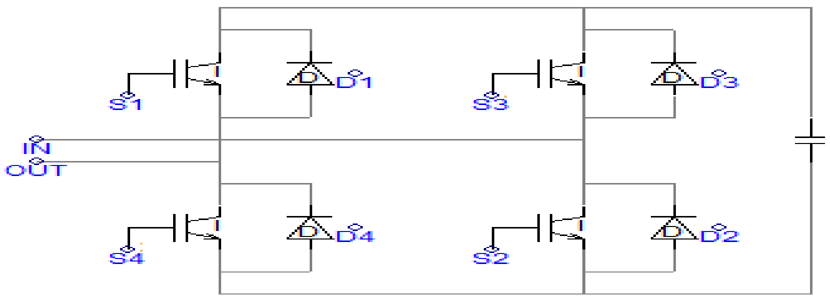

Figure 2: Full-bridge module of wave-shaping circuit

To understand the operation of the full bridge module in a wave-shaping circuit, four modes of operation are illustrated in Figure 3. These possible modes are explained as follows.

1) In the first mode, switches S1 and S2 are turned-on. Node IN gets connected to positive point and node OUT gets connected to negative point as shown in Figure 3(a). Hence, the output voltage is positive and current is also positive.
2) In the second mode, forward conduction will continue through diodes D3and D4. However, node IN gets connected to negative point and node OUT gets connected to positive point as shown in Figure 3(b). Hence, the output voltage is negative.
3) In the third mode, switches S3 and S4 are conducting. Hence, node IN gets connected to negative point and node OUT gets connected to positive point as shown in Figure 3(c). Hence, the output voltage is negative and current is also negative.
4) In the fourth mode, reverse conduction will continue through diodes D1 and D2. However, node IN gets connected to positive point and node OUT gets connected to negative point as shown in Figure 3(d). Hence, the output voltage is positive.

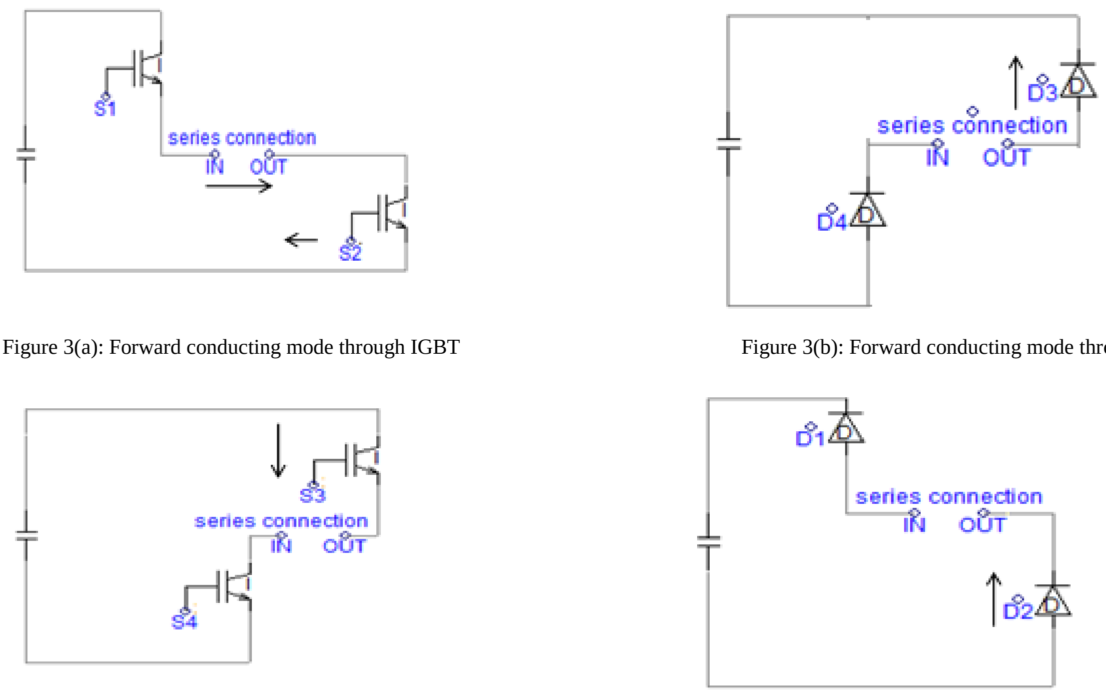

Figure 3(a): Forward conducting mode through IGBT

Figure 3(b): Forward conducting mode through diode

Figure 3(c): Reverse conducting mode through IGBT

Figure 3(d): Reverse conducting mode through diode

Figure 3: Operating modes of Full-bridge module of wave-shaping circuit

III. CONTROL OF SERIES HYBRID MMC

The control of series hybrid multilevel converter is divided into three parts: 1) modulation of two-level inverter to generate square wave output; 2) modulation of series connected full bridge modules to decide number of modules to be inserted and; 3) capacitor voltage balancing of full bridge modules. In first part of the control, reference signal is compared with triangular signal of fundamental frequency to generate square wave output. To obtain the desired multilevel output the wave shaping circuit consisting of series connections of full bridge modules will act as filters and absorbs the difference of square wave and required multilevel waveform. This is achieved by the modulation control of wave shaping circuit. Since, to generate the multilevel output, the modules of wave shaping circuits are inserted and bypassed continuously; it is to be done by monitoring the capacitor voltages of the modules such that they remain balanced to get stable operation of converter.

To keep the capacitor voltage balanced as possible, the modules inserted or bypassed have to be selected based on their voltage level and direction of current [11], [12]. The capacitor voltage of modules will change only if modules are inserted. The capacitor voltage remains unchanged if modules are bypassed. If the direction of the current is positive, the capacitor will charge and its voltage level will increase, hence the module with the lowest capacitor voltage is inserted. Similarly, if the direction of the current is negative, the capacitor will discharge and its voltage level will decrease, hence the module with the highest capacitor voltage is inserted. Hence, based on the direction of current, this will lead to four cases:

1) If the direction of current through the waves shaping circuit is positive and a module is to be bypassed then the module with the highest voltage level should be bypassed.
2) If the direction of current through the waves shaping circuit is positive and a module is to be inserted then the module with the lowest voltage level should be inserted.
3) If the direction of current through the waves shaping circuit is negative and a module is to be bypassed then the module with the lowest voltage level should be bypassed.
4) If the direction of current through the waves shaping circuit in the limb is negative and a module must be inserted then the module with the highest voltage level should be inserted.

IV. PSCAD IMPLEMENTATION

The model of series hybrid multilevel converter with four full bridge modules in wave shaping circuits is implemented in PSCAD/EMTDC simulation software as shown in Figure 4. Figure 5 shows the logic diagram for modulation of square wave inverter. Figure 6 shows the series connections of four full bridge modules in wave shaping circuit of each phase. Figure 7 shows the control diagram for wave shaping circuit which consists modulation block to select number of modules to be inserted and balancing block to maintain the capacitor voltages at same level. Figure 8 shows the pulse width modulation of wave shaping circuit in which triangular signals of 1 kHz is compared with the reference voltage of wave shaping circuit. This will give the number of modules to be inserted.

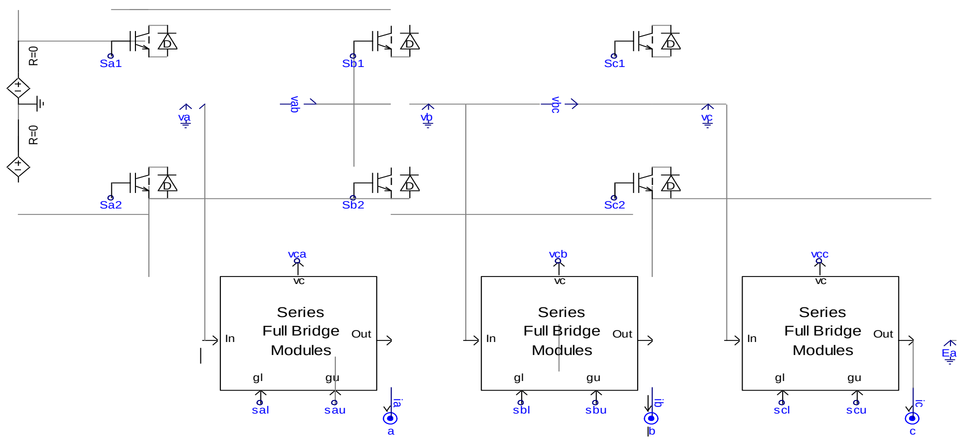

Figure 4: Series hybrid MMC implementation in PSCAD

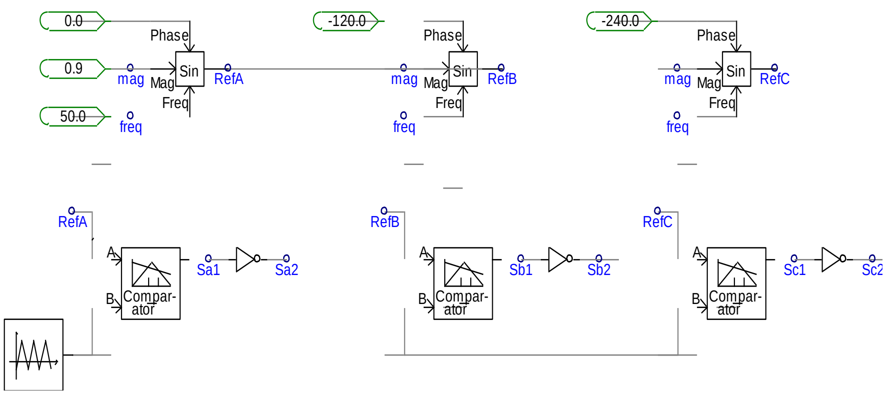

Figure 5: Modulation of square wave inverter

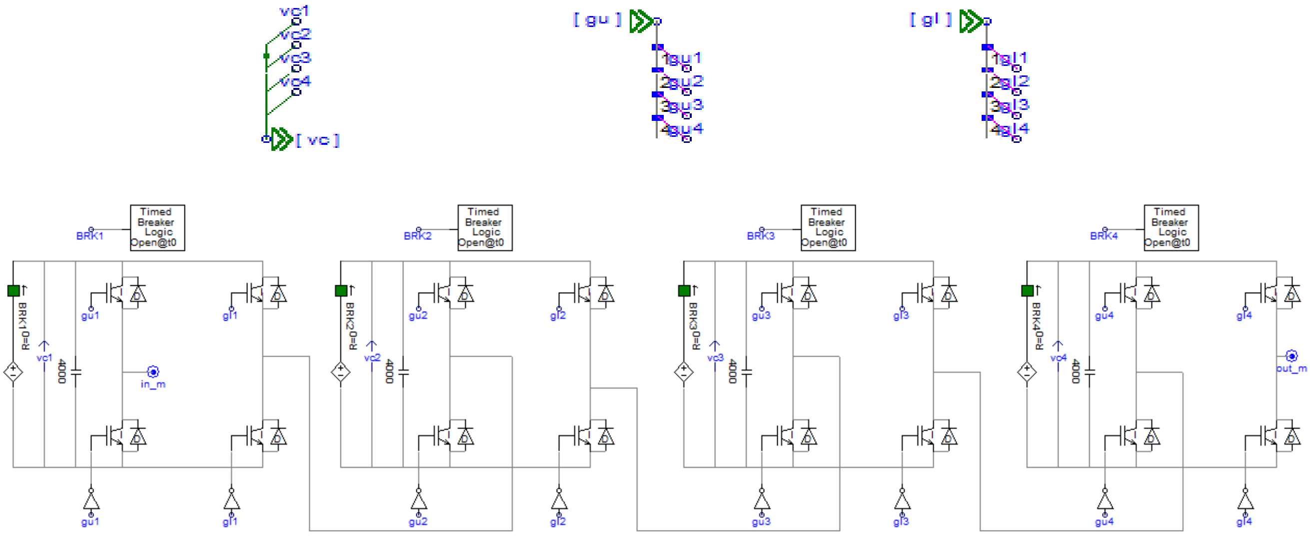

Figure 6: Series connections of full-bridge modules in wave shaping circuit

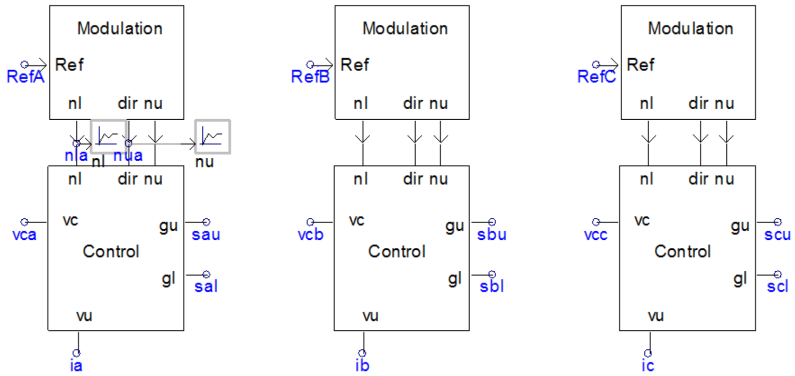

Figure 7: Control of series hybrid MMC

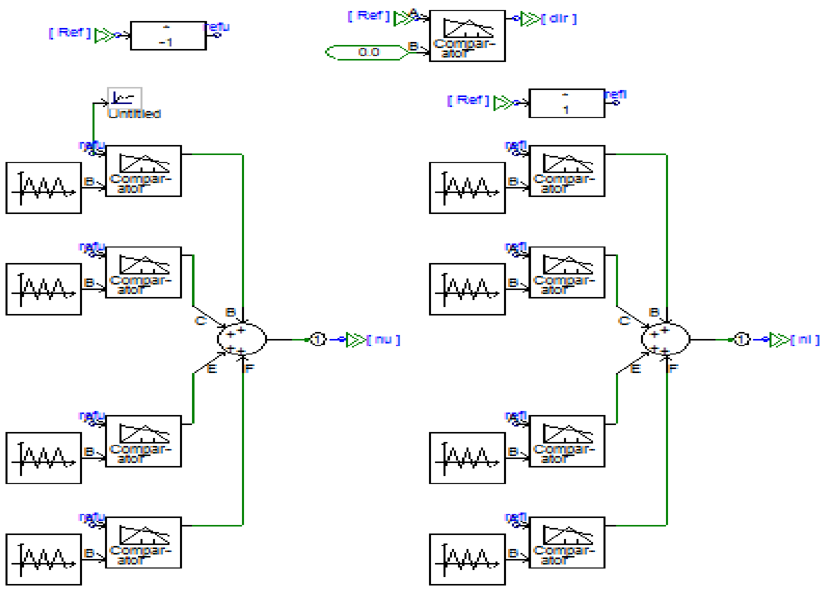

Figure 8: Pulse width modulation of wave shaping circuit

V. SIMULATION RESULTS

The reference signal for wave shaping circuit is generated by subtracting desired multilevel output waveforms and the square output of two-level inverter. This reference signals for positive and negative half cycle are shown in Figure 9. The voltage output waveforms are shown in Figure 10. The number of level in output voltage is 9 with 4 modules in wave shaping circuit. The MMC requires 8 modules to achieve the 9 level output voltage. The harmonic spectrum of output voltage waveform is shown Figure 11. The THD of series hybrid inverter and square wave inverters are shown in Figure 12 and Figure 13 respectively. The value of THD is 48.24% in two-level inverter and 15.03% in 9-level series hybrid inverter. It can be clearly seen from the results that the harmonic spectrum of output voltage waveform is improved in series hybrid inverter.

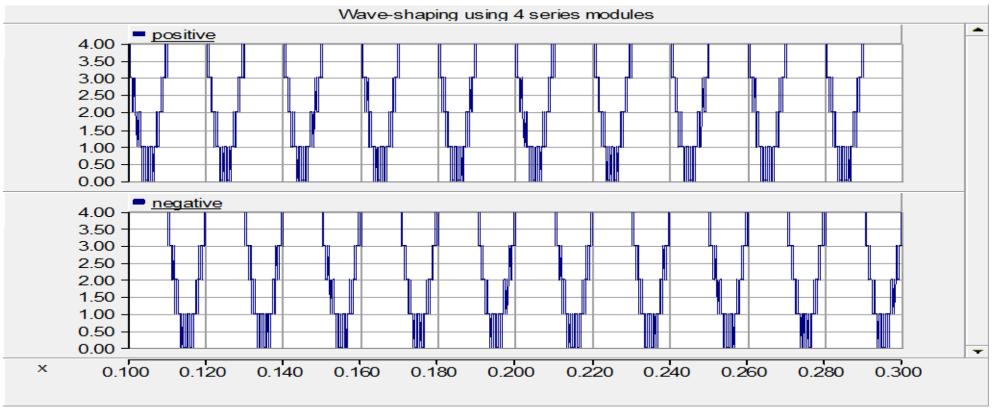

Figure 9: Waveforms of wave shaping circuit

From the figure, we get the output waveform of inverter of the positive and negative of each arm.

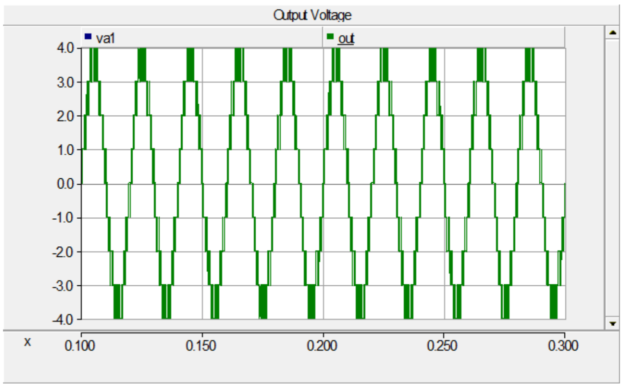

Figure 10: Output waveform of series hybrid MMC

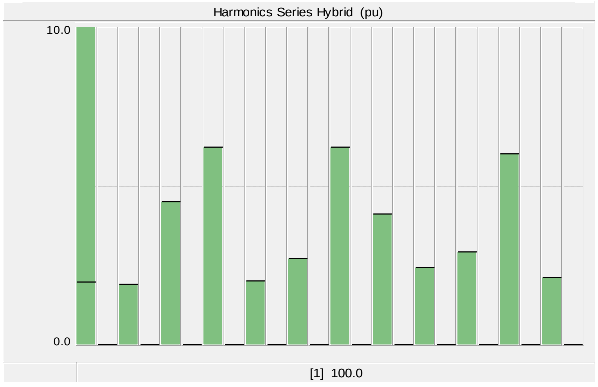

Figure 11: Harmonic Spectrum of Series Hybrid Inverter

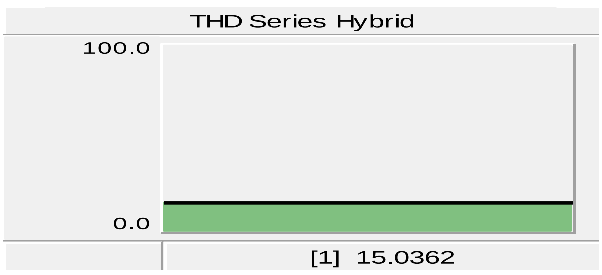

Figure 12: THD of Series Hybrid Inverter

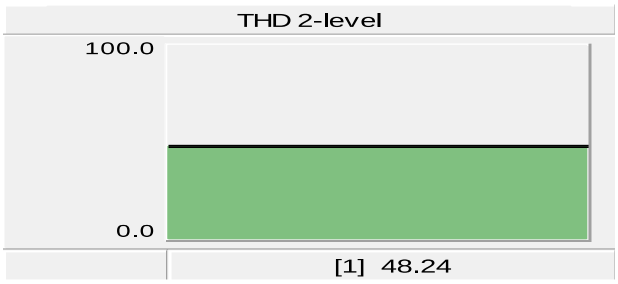

Figure 13: THD of Square Wave Inverter

VI. CONCLUSION

In this paper, the harmonic analysis of series hybrid MMC topology is presented which has the advantages of using fewer modules than other topologies with similar performance. The implemented model was tested in PSCAD/EMTDC simulation software. The total harmonic distortion is quite less in series hybrid MMC compared to two-level converter. It can also be observed from the output waveform that the series hybrid multilevel converter gives more number of levels with a lesser number of modules compared to normal MMC.

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