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Digital Current Sensing in Modular Multilevel Converter for HVDC Applications

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Abstract: For long-distance transmission, HVDC (High-Voltage, Direct-Current) is proven to be less expensive and have lower electrical losses as compared to HVAC (High-Voltage, Alternating-Current). Now a days, the advancement of power electronic switches such as IGBT's and MOSFET enables the use of converters for HVDC applications. Among the well-known converters used for HVDC are Voltage Source Converter (VSC) Line Commutated Converter (LCC) and Modular Multilevel Converter (MMC). The MMC is still new and a promising technology for HVDC application. The MMC has many advantages such as controlling high amount of active/reactive power and possess lower losses as compared to other converters. To control the active/reactive power in a MMC, control scheme such as free-running hysteresis uses the reference voltage and the inductor current to produce the required switching pulses. This study proposed a technique in which a voltage sensor is use to measure the inductor current. Conventionally, the inductor current is sensed either with a resistor or Current Transformer (CT). This method is associated with some disadvantages; requires additional circuitry which introduces some power loss and requires higher bandwidth in order to sense accurately. This study instead, measures the current indirectly by using the information of the phase inductor voltage. As the voltage sensor is placed in parallel to the inductor, this measuring technique is immune to I^2R loss. The proposed technique will be investigated using MATLAB simulation to determine its current sensing capability in a MMC for HVDC applications. To design an improved current-less sensing method using a digital RC network. To extract the inductor current values from the phase inductor voltage an RC filter is required and placed in parallel across the inductor. In this way, all the high frequency harmonics will be filtered out and only the low frequency inductor current can be seen across the capacitor. The selection of RC values, however is dependent on the inductor value and inductor DC-Resistance (R_{DCR}). The main concern with this technique is that selection of RC values sometimes can be unavailable for hardware implementation. To further improve the implementation of RC network and eliminate the problems of selecting suitable RC values for hardware implementation. This paper proposed the used of digital filter based on the RC network concept. Instead of using the actual components for filtering the high frequency harmonics, this technique uses only the DSP for filtering to remove the high frequency harmonics. The proposed technique is able to convert the high frequency voltage V_{L1} measured from the phase inductor L_1 into the phase inductor current i_{L1} without any delay or difficulty. By comparing the signals of proposed method to the series sensing method and the conventional RC filter method the waveforms of both signals are almost identical. However, the proposed method eliminates the need for RC components as compared to the conventional RC filter method. This technique improves the efficiency of the system in terms of improve signal noise ratio and eliminates the need for passive component on the system.

Key words: MMC, HVDC, voltage sensor, hysteresis control, Malaysia

INTRODUCTION

The application of HVDC on a transmission network was thought to be expensive and complex since a HVDC cannot utilise a transformer to step up or step down the voltages. Now a days with the advancement of solid-state devices such as the IGBT, thyristor and MOSFET, the use of converters for HVDC in power lines is possible. For very long transmission lines (every 1000 miles) HVDC system becomes less expensive and possess smaller electric loss compared to HVAC system.

HVDC system consists of two conversion stages; rectifier and inverter. The rectifier converts the AC voltages into DC voltages. While the inverter converts the DC voltages into AC voltages. Conventional DC-AC inverter generates three different waveforms such as zero, positive and negative voltages. To obtain a lower Total Harmonic Distortion (THD) this inverter must be switch at

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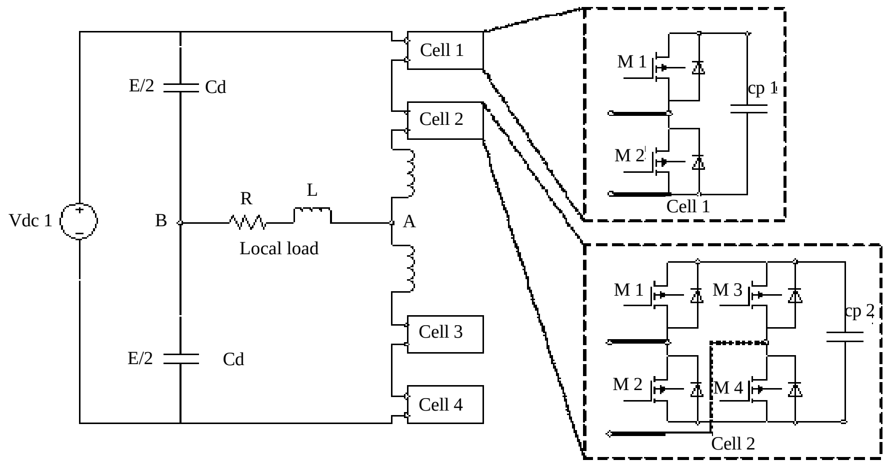

Fig. 1: Modular cascaded multilevel inverter

a high frequency (above 20 kHz). Switching at high frequency however can lead to higher EMI and higher switching loss. A multilevel inverter however can be stacked up to more than three levels. Having more levels in the multilevel produces smoother output waveforms and has a lower THD.

An MMC possess the advantages of a multilevel cascaded inverter, it is different however as it requires only one isolated DC source. The MMC has been widely used in HVDC, grid-connected systems and motor drives. It is capable of handling both active and reactive power and allows power transmission between nodes with unsynchronized AC transmissions signals (Guan and Xu, 2012; Saeedifard and Iravani, 2010).

Control of the power switches for active/reactive power is necessary to obtain a constant output voltage. MMC has more switches compared to conventional inverter and the complexity increases with more level, thus non-linear control scheme such as free-running hysteresis can be use. This type of controller uses the reference voltage and the inductor current to produce the required switching pulses. Normally, the system also incorporates the use of a Phase Lock Loop (PLL) for phase and frequency match.

Conventionally, the series current sensing requires a small resistor (R_S) to be placed in series along with the inductor (Huang, 2001). The voltage drop across the small resistor is then fed into an Integrated Circuit (IC) current sensor chip which will determine the current across the inductor. Although, the series current sensing is easy to implement and does not require any passive components, this method, however, reduces the system efficiency as the small resistor produces an I^2R loss. To solve the issue of I^2R loss, numerous sensing techniques have been proposed. Among the proposed techniques using the ON-resistance of a power transistor (Dallago *et al*., 2000; Zhang *et al*., 2004) and the use of inductor DC-Resistance (R_{DCR}) for measuring (Huang *et al*., 2003; Roh *et al*., 2015).

This study proposed the use of a digital RC network for sensing purposes. This technique converts the inductor voltages into the inductor current by filtering the high frequency harmonics using the proposed method. For hardware implementation, a digital signal processing can be use. The RC transfer function must first be transform into a state-space form to extract the codes which are written into the DSP chip.

MATERIALS AND METHODS

The multilevel modular cascaded inverter

Operating principle of MMC: Figure 1 shows the circuit configuration of an MMC connected to an R_L load. The circuit is made out of bi-directional stacked sub-modules Cell 1-4 which consists of one type or a combination of both H-bridge and Full-bridge converter. It should be noted that each sub-modules require a floating capacitors c_{p1} and c_{p2} as seen in Fig. 1. If a higher level of MMC is required, additional sub-module Cell 5, Cell 6, etc., can be added.

To allow power transfer between the high capacitor voltage and the lower voltage load, an inductor acting as a buffer is placed between capacitor C_d and R_L load where the sub-modules are switched open and close periodically. Two capacitors with the same value C_d are placed in parallel with the voltage source V_{dc1}. In this way, the upper capacitor provides a positive source to the upper-arm while the lower capacitor provides a negative source to the lower-arm.

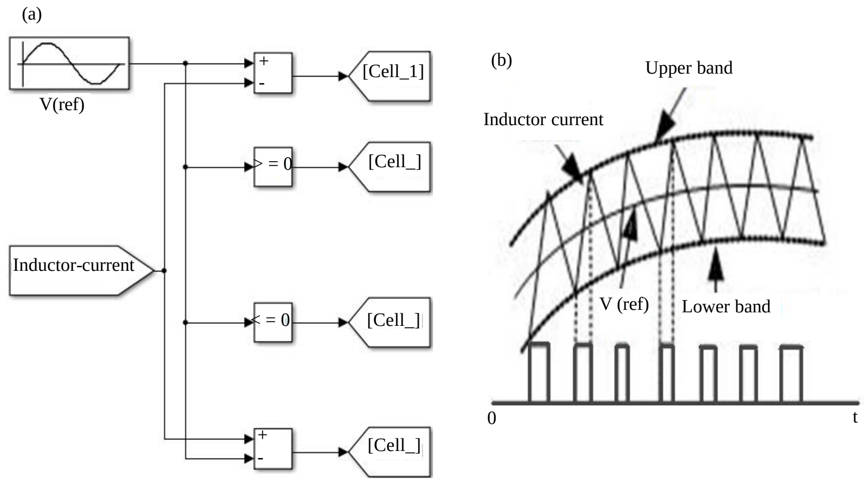

Fig. 2: Hysteresis controller and PWM setup using Matlab/Simulink

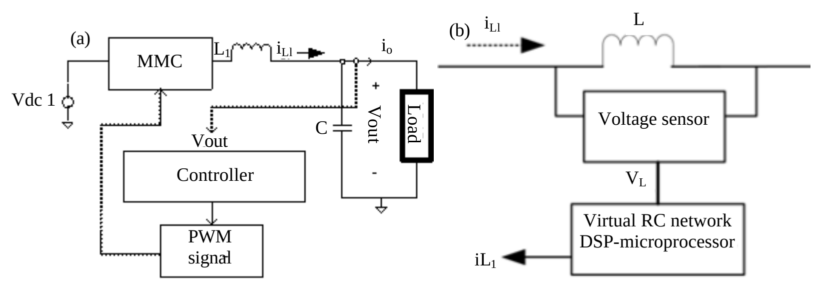

Fig. 3: Circuit configuration: a) LC filter used in MMC and b) Proposed method

Control schemes for MMC: Figure 2 shows the constructed hysteresis controller in Matlab/Simulink. The hysteresis controller is considered as non-linear control, it operates by using the inductor current, the reference $V_{(ref)}$ and a hysteresis band to generate the switching pulses which is shown in Fig. 2.

Figure 3 shows the LC filter used in the MMC configuration. To measure the inductor current i_{L1} as seen in Fig. 3a the conventional method requires the sensor to be placed in series with inductor L_1. If a high current is seen across node, the sensor will also be exposed to the high current. Figure 3b shows the circuit configuration for proposed method. Since, the voltage sensor is placed in parallel to the component it will not be exposed to the high current passing through the node. From Fig. 3b, the measured voltage signal is then fed into a DSP to produce the inductor current. Equation 1 shows the transfer function of a digital RC network. It should be noted that R_{DCR} represent the inductor DC-Resistance:

$$i_{L1} = V_L \times \frac{1/R_{DCR}}{1+S(L/R_{DCR})} \quad (1)$$

Table 1: MMC specification

Input voltage (Vdc1)/nominal output	50 kV/11 kV
Modular multilevel converter	
Hysteresis band	0.25
Output Capacitor (C)	1 mF
Inductor (L)/R_{DCR}	10 mH/0.1 Ω
Buffer inductor/Cd/Cp	1.5 mH/7 mF/1 mF
RL load	33.33 Ω/76 mH
Line impedance	1 mH, 0.1 Ω
Grid voltage	11 kV

RESULTS AND DISCUSSION

Using the parameters shown in Table 1 the performance of the MMC is demonstrated under Matlab/Simulink Software. The system is tested for an 11 kV output for active power injection. Here, the hysteresis controller uses the proposed technique to obtain the inductor current for controlling the active/reactive power.

Figure 4 shows the response of a 50 kV system that is connected to an 11 kV grid system. From Fig. 4 initially, the MMC produces an 11 kV output that is synchronize with the grid. During that time as seen in Fig. 4 the grid

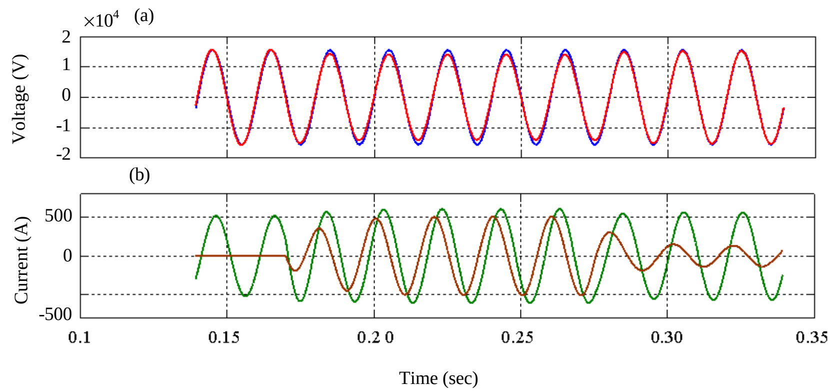

Fig. 4: Output responses for MMC under step load changes (linear control)

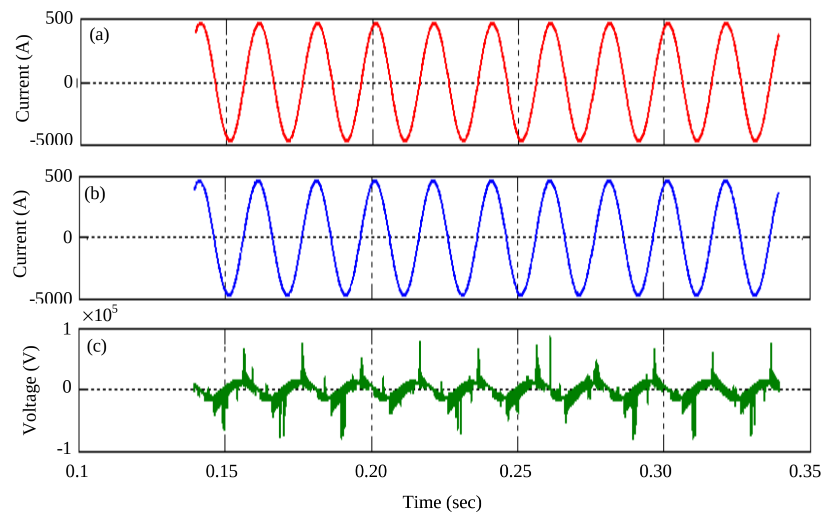

Fig. 5: Simulation results for VL1: a) Series measurement; b) Proposed technique and c) Inductor voltage

line is 0A since it is not connected to the system. Since, a local RL load is connected to the MMC, the MMC is producing a 353A for the local load. At 0.17 sec, the MMC is connected to the grid. The grid line takes around 2 cycles to increase until 353A while the MMC takes around 1 cycle to reach 367A. The increased of grid line current, indicates that power is being supplied from the grid to the MMC and the RL load. It is also observed that the grid voltage is slightly higher than the MMC's.

During a step change at 0.27 sec the output voltage and output current of the MMC is in phase. This indicates that the MMC is supplying active power to the grid. The grid line takes around 1 cycle to drop to 70A. From this simulation, it is proven that the proposed technique is successfully implemented for a HVDC application.

Figure 5a, b shows the comparisons using different sensing technique. From Fig. 5, it can be seen that the proposed method is able to measure the inductor current i_{L1} and is identical compared to the direct series measurement Fig. 5. Despite measuring the signal indirectly and requires a digital filter to obtain the required signals, there is no significant delay in using this technique for current sensing. Figure 5 shows the measured inductor voltage of V_{L1}. Here in the simulation results, it shows that the inductor voltage signals consist of high frequency pulses with respect to the input voltage V_{dc1}.

CONCLUSION

This study has presented a sensing method in measuring the inductor by using a digital RC network. This method eliminates the needs of having additional components and can be applied to any levels of MMC for HVDC applications.

The comparisons of digital RC network as compared to the conventional series measurement have been investigated. The proposed method is able to convert the high frequency voltage V_{L1} measured from the inductor L_1 into the phase current i_{L1} without any delay or difficulty. By comparing the signals of proposed method to the series sensing method the waveforms of both signals are almost identical. Future studies can be made to improve the algorithm to eliminate certain harmonics and use for other applications.

ACKNOWLEDGEMENT

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