Simple FCS-MPC Method for Reducing Common-Mode Voltage in a Three-Phase Two-Level Voltage Source Inverter

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Abstract. Common mode voltage (CMV) causes various issues, including a negative impact on the performance of a hybrid electric vehicle's power system (HEV). Many papers have published methods that mitigate CMV, almost all of which attempt to avoid zero vectors, but this increases total harmonic distortion (THD). This work describes a simple and efficient method for reducing CMV in a two-level three-phase voltage source inverter (VSI) with an RL load. This method uses only active vectors .It replace the zero vector with the two opposite vectors V_2 and V_5, for T_1 and T_2 respectively in a one sampling period T_s. A numerical simulation, using Matlab-Simulink, is achieved to assess the effectiveness of the proposed control technique. The obtained results show a reduction in THD value (17% improvement) and a decrease in the peak value of CMV from ($\frac{+V_{dc}}{2}$ and $\frac{-V_{dc}}{6}$) to $\pm\frac{V_{dc}}{6}$. These results are compared to those obtained by using the traditional predictive control model MPC.

1 Introduction

The combustion of fossil fuels generates harmful toxic substances such as CO_2, which are the primary cause of rapid climate change, global warming, and polar ice melt. Furthermore, due to worldwide development, automobiles on the road have increased dramatically. Indeed, the internal combustion engine (ICE) in the vehicle is to blame for such a large amount of transportation emissions (ICE) [1]. Therefore, by combining the benefits of an electric vehicle (EV) and a conventional car, the HEV can reduce toxic gas emissions in the air and improve the environmental conditions.

In recent decades, significant advances in power electronics, electrical machines, and lithium-ion battery technology have given electric vehicles a considerable advantage in competing with their ICE counterparts. Therefore, HEVs require an efficient control system and inverters to power the electric motor, which should be built with a quick response time[2].The common-mode voltage appears in the system due the fast switching operations in the VSI , which have been reported to generate overvoltage stress on drive winding insulation and emit electromagnetic interference (EMI) [3],[4].

The CMV can be reduced by hardware or software solutions. Hardware solutions include installing additional filter or modifying the inverter topology[5]. However, both

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hardware improvements have a size and cost penalty[6]. Therefore, many software improvements without additional costs have been proposed to minimize the CMV. Thus, software solutions can be divided into two types to know: the Common Mode Voltage minimization methods based on: i) Pulse Width Modulation (CMVR-PWM) strategies[7],[8]. ii) Model Predictive Control (RCMV-MPC) [9], [10].

Predictive control model has a lot of benefits that make it a good choice for power converter control. Indeed, constraints and nonlinearities can be easily included, and multivariable cases can be considered. Therefore, the resulting controller is simple to implement [11]. The Finite control set (FCS-MPC) is a type of MPC that includes reference tracking and it is the most commonly method used in research due to its notable features, such as its simple design procedure and implementation [12].

This paper describes a simple and effective method based on the use of MPC model for reducing the CMV in a two-level VSI inverter with an RL load. This approach uses only active vectors and replaces the zero vector with two opposite vectors V_2 and V_5, for T_1 and T_2 in one sampling period.

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2 Model Predictive Control Method

2.1 The conventional MPC model

The MPC approach for the VSI assumes that the VSI can only apply a finite number of voltage vectors [13]. The output voltage vectors applied to the loads by the three-phase VSI depicted in Fig.1, can be expressed in the αβ frame as follows:

$$V = \frac{2}{3}(V_{an} + aV_{bn} + a^2V_{cn}) \qquad (1)$$

Where: $a = e^{J(\frac{2\pi}{3})}$,

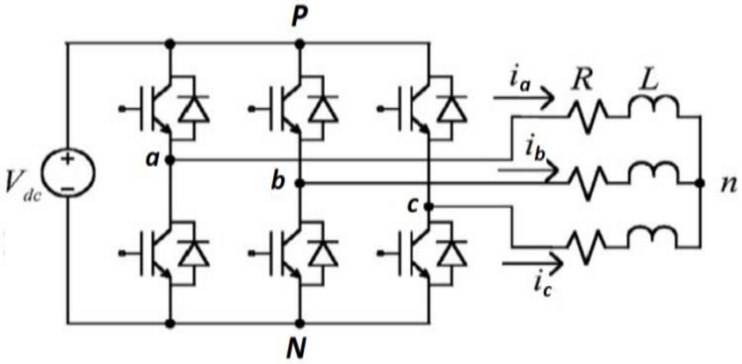


Fig. 1. Three-phase two-level voltage source inverter

Only seven voltage vectors are available in the finite control set of the three-phase VSI due to duplicating the two zero-voltage vectors that produce an equal output voltage vector.Therefore, the load current is expressed as follows:

$$i = \frac{2}{3}(i_a + ai_b + a^2i_c) \qquad (2)$$

Then the load voltage dynamics can be described by the following differential equation:

$$\mathrm{V} = Ri + L\frac{di}{dt} \qquad (3)$$

When MPC is used, the controller must take into account the following tasks:

- Predict the behavior of the controlled variables for all possible switching states.
- For each prediction, compute the cost function.
- Choose the switching state with the lowest cost function.

The following equation expresses the cost function:

$$g = |i_\alpha^*(k+1) - i_\alpha^P(k+1)| + |i_\beta^*(k+1) - i_\beta^P(k+1)| \quad (4)$$

Where $i_\alpha^P(k+1)$ and $i_\beta^P(k+1)$are the real and imaginary parts of the predicted load current vector $i^P(k+1)$.The reference currents $i_\alpha^*(k+1)$ and $i_\beta^*(k+1)$are the real and imaginary parts of the reference current $i^*(k+1)$ [14].

2.2. Proposed Model Predictive Control for the CMV reduction

The proposed method for reducing the CMV is based on the conventional MPC method. The CMV voltage is defined as:

$$V_{n0} = V_{cm} = \frac{V_{dc}}{6}(S_a + S_b + S_c) \quad (5)$$

CMV reaches its maximum value when using zero vectors. Therefore, avoiding zero vectors is a good solution. However, when the zero vectors are removed, the THD increases.

The paper proposes a method that replaces the zero vector selected by the cost function with two opposite active vectors, V_2 and V_5, respectively, for time T_1 and T_2 as shown in figure 2. By the way, T_1 and T_2 are chosen using the principle of trial and error.

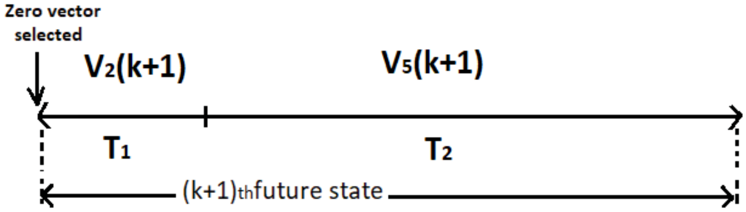


Fig. 2.the substitution of two active vectors for the zero vectors (V_2, V_5)

4 Results and discussion

The simulation of three approaches is shown in this part, along with a comparison of their CMV mitigation and harmonic performance (THD). The conventional MPC is depicted in Fig.3, the MPC employing only the active zero is shown in Fig.4, and the proposed MPC is illustrated in Fig.5.

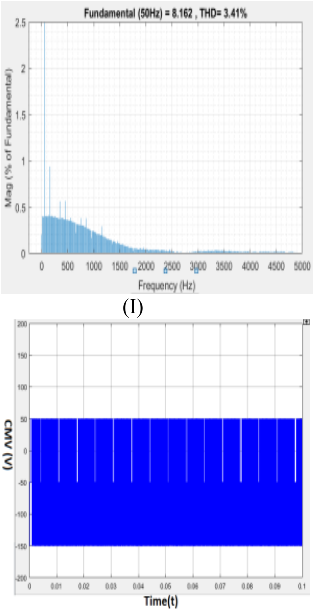
The following parameters are used in simulation using Matlab-Simulink: Ts=50µs, Iref (peak) =8A, L=12mH, R=10Ω, f=50Hz, Vdc=300V, T1=3 µs, T2=47 µs.

The CMV mitigation results (table 1) indicated that the conventional MPC's zero vector selection is the origin of the high CMV value. Therefore, the zero vectors are avoided using the standard method as a solution. However, avoiding zero vectors resulted in a higher THD value

So, THD must be reduced while CMV is decreased. The research found that when the zero vector was replaced with the two opposite vectors, V_2 and V_5, for time T_1 and T_2, respectively, the CMV and THD were lowered at he same time using the suggested MPC. The proposed simple method could reduce the peak value of CMV from ($\frac{+V_{dc}}{2}$ and $\frac{-V_{dc}}{6}$) to $\frac{\pm V_{dc}}{6}$ and decrease the THD value from 3.47 % to 3.30% (17 % improvement).

Table. 1. Comparison between Methods used in terms of THD and CMV

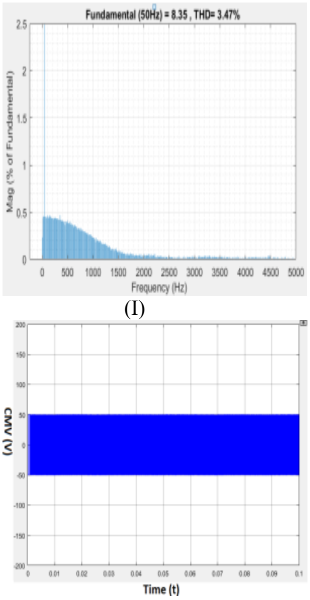
Method Used	THD	CMV
Standard MPC without CMV mitigation	3.41%	$\begin{cases} \frac{+V_{dc}}{6} = +50V \\ \frac{-V_{dc}}{2} = -150V \end{cases}$
Standard MPC with CMV mitigation	3.47%	$\frac{\pm V_{dc}}{6} = \pm 50V$
Proposed MPC Method	3.30%	$\frac{\pm V_{dc}}{6} = \pm 50V$



(I)

(II)

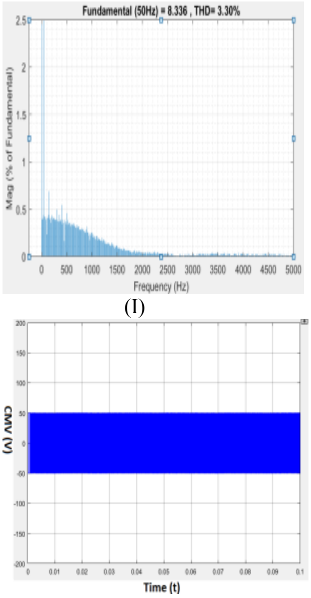
Fig. 3 Standard MPC: (I) FFT analysis of the output current; $i_a(t)$. (II) V_{cm} (t), [V]



(I)

(II)

Fig. 4 Standard MPC with only active vectors: (I) FFT analysis of the output current; $i_a(t)$. (II) V_{cm} (t), [V]



(I)

(II)

Fig. 5 Proposed MPC: (I) FFT analysis of the output current; $i_a(t)$. (II) V_{cm} (t), [V]

4 Conclusion

This paper proposed a simple FCS-MPC method to mitigate the common-mode voltage CMV in a three-phase VSI with RL load and compared it to conventional MPC methods. The selection of zero vectors V_0 and V_7 yields the highest possible value of CMV ($\frac{\pm V_{dc}}{2}$) but eliminating those vectors causes another problem: an increase in the total harmonic distortion THD value.

The proposed method replaces the zero vector chosen by the opposite active vectorsV_2 and V_5 for T_1 and T_2, respectively. This strategy achieved two goals: first, it mitigated the peak value of CMV from ($\frac{+V_{dc}}{2}$ and $\frac{-V_{dc}}{6}$) to $\frac{\pm V_{dc}}{6}$, second, it reduced the THD value from 3.47% to 3.30% (17% of improvement), which improved the harmonic performance of the system.

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