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Model Predictive Direct Current Control (MPDCC) for Grid Connected Application

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Abstract: This paper deals with the design and simulation of Dual Active Bridge Multilevel Inverter (DABMI) based Model Predictive Direct Current Control (MPDCC) for grid connected application. To achieve multilevel output voltage waveforms, the second inverter will be supply with half of the dc-link voltage. Model predictive direct current control used to control the grid current component in order to achieve minimum grid current error. Modulation is unnecessary in this system because the switching pattern is produce by the possible switching that determined by the proposed MPDCC. The voltage vector which minimizes the cost function will be selected and applied to track the reference current. The performance of the proposed MPDCC is observe and implement by MATLAB/Simulink Software.

Keywords: Multilevel inverter, model predictive direct current control, grid connected inverter

1. Introduction

Nowadays the enthusiasm for introducing more renewable energy sources (RES) to generate electricity power has quickly expanded [1]. Ecological and environmental concern which is to decrease environmental pollution from fossil fuel-based power generation, and quick improvements of small scale power generation advancements and micro grid can be clarified this pattern [2]. Generally, the wind and solar energy are types of RES which are the most winning that as of now rule the development of renewable electricity production [3]. With a specific end goal to use the energy from RES, control transformation framework is fundamental. In order to inject the power into the grid, inverter is the last part involve.

In recent years, multilevel inverters (MLI) topologies are widely utilized as a part of renewable energy system because of lower harmonic distortion in multilevel inverter. By expanding the number of levels in the inverter, the output voltages have more steps producing the waveform which decreased the value of total harmonic distortion (THD) [4, 5]. Dual active bridge multilevel inverter is considered because of its higher adaptation to fault tolerance capacity and the simplicity of power stage. This topology likewise keeps up the dissemination of switching events, accordingly diminishing the losses in the system and prompting to a lower frequency of device commutation.

Because of the persistent increasing in RES installation, new control strategies are important in order to have good operation and management for the new power grid implanted with RES to maintain and enhance the power quality, reliability and efficiency of the system [6]. Model predictive direct current control (MPDCC) is being recognize because of its merit to constraint and nonlinear characteristic [7]. The regular components of this sort of controller are,

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it utilizes a model of the system to anticipate the future behavior of the variables until a period of predefined horizon and optimum the switching state option by minimizing the cost function [8].

In most cases, the traditional control methods require pulse width modulation (PWM) module for its static and dynamic performance. However, modulation in MPDCC technique is unnecessary because of only one switching state is considered in every sampling interval that head to feature of distributed current spectrum [9].

2. Model Predictive Direct Current Control (MPDCC) for DABMI

The MPDCC block diagram is presented in Figure 1, where DABMI consists of two standards three phase two level inverter with isolated dc sources each. The path of common mode current flow in the system allowed to be rid by the use of source isolation. [10]. After coordinate transformation, the three-phase grid voltage v_{sa}, v_{sb} and v_{sc} can be used for current prediction that represent in the dq synchronous reference frame which can be specify by the phase θ. The phase θ is obtained by using phase locked loop (PLL).

The current i_d* and i_q* in dq coordinate that computed by the power equation, then change into abc reference frame before it will transform into αβ reference frame. The reference values of current and the predictive values are compared by the cost function. The minimize cost function will be determine the selected voltage and the appropriate switching state is applied at the next sampling instant. The block diagram of DABMI based MPDCC for grid connected converter is presented in Fig. 1.

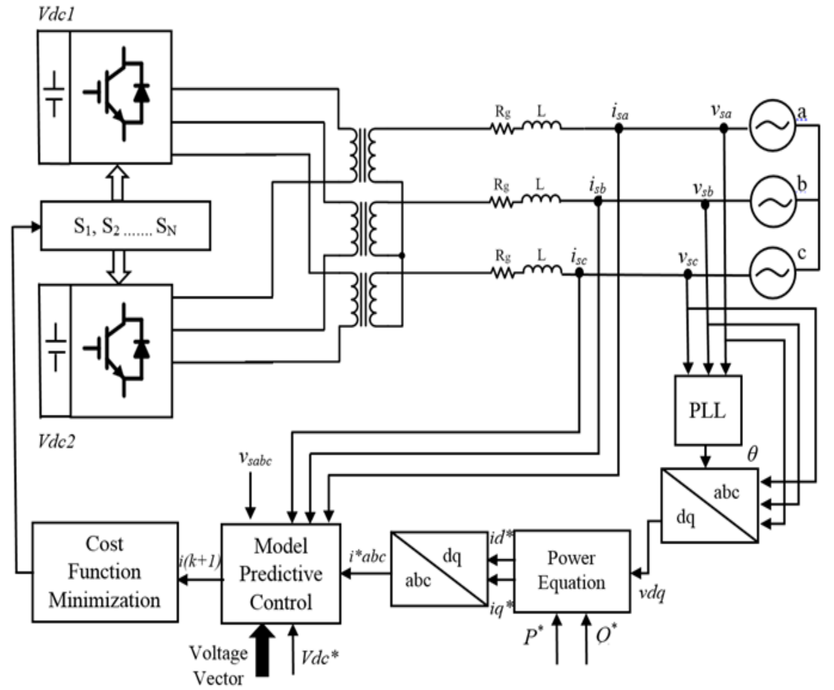

Fig. 1 - Block diagram DABMI based MPDCC.

3. Modeling of DABMI with MPDCC

The proposed MPDCC predicts the behavior of the variable for each switching state. A discrete time model is used in the system to predict the behavior of DABMI. The balanced three phase system can be express as a two-phase system from abc frame to αβ frame by using Clarke's transformation. X can be represents either the voltage or the current in the system that use in Model Predictive Control block in Fig. 1.

$$X_{\partial} = \frac{2}{3}\left[X_a - 0.5X_b - 0.5X_c\right] \qquad (1)$$

$$X_{\beta} = \frac{2}{3}\left[\left(0.5\left(\sqrt{3}\right)X_b\right) - \left(0.5\left(\sqrt{3}\right)X_c\right)\right] \qquad (2)$$

The load current dynamic vector equation can be described as

$$V_s = L\frac{di}{dt} + R_L i + v_c \tag{3}$$

Here R_L and L are the load resistance and inductance respectively, where v_s, v_c, and i are the grid voltage, inverter voltage and phase current. The mathematical model of the DABMI for grid connected application in αβ reference frame is characterized by the following equation.

$$V_{s\alpha\beta} = L\frac{di_{\alpha\beta}}{dt} + R_L i_{\alpha\beta} + v_{c\alpha\beta} \tag{4}$$

According to equation (4) and using backward Euler discretization method, the prediction equations are expressed as

$$i_{k+1} = \left[\left(\frac{L}{L+T_s R}\right)(i_s)\right] + \left[\left(\frac{T_s}{L+T_s R}\right)(v_s - v_c)\right] \tag{5}$$

Where $i_{(k+1)}$ are the predicted grid current components at (k+1)th sampling period, T_s is the sampling period and $i_s=i_{s\alpha}+1j(i_{s\beta})$ is the grid current. 37 switching states combinations including 35 active vectors and 2 zero vectors is taken into account in order to execute the prediction process. For the selection of the appropriate voltage vectors for current control, the sum of absolute error value between reference current and predictive current is selected as the cost function, g by substituting equation (5) into (6).

$$g = \left|i_\alpha^* - \mathrm{Re}(i_{k+1})\right| + \left|i_\beta^* - \mathrm{Im}(i_{k+1})\right| \tag{6}$$

Here, i^*_α and i^*_β are the current component in αβ frame, and $i_{(k+1)}$ are predictive current value.

4. Simulation Results

The simulations were conducted in MATLAB/Simulink to verify the feasibility of the proposed control scheme. The adopted system parameters for all the MPDCC approaches are summarized in Table 1.

Table 1 - System parameter.

Parameter	Symbol	Value
Grid frequency	ω	2π50rad/s
DC side Voltage1	V_{dc1}	300V
Dc side Voltage 2	V_{dc2}	150V
Grid phase voltage	e	122.5Vrms
Sampling Period	Ts	50μs

The reason for using DABMI compared to single sided inverter is redundancy and to modulate high frequency fundamental [11]. The main inverter was supplied by 300V and the second inverter is being supplied with 150V to achieve multilevel voltage output waveform as shown in Fig. 2 while Fig. 3 presented the sinusoidal output current waveform for the proposed DABMI based MPDCC.

The performances of DABMI in grid connected application where it can be seen in Figure 4, shows the grid voltage with regard to injected current for phases a,b and c are properly synchronized and the quality is satisfactory. It explains that only the active power is injected into the grid as shown in Figure 5 and MPDCC has the ability to guarantee that the performance of the system can meet the grid requirements. Hence, there is no need for the grid to provide reactive power and harmonic current for the load.

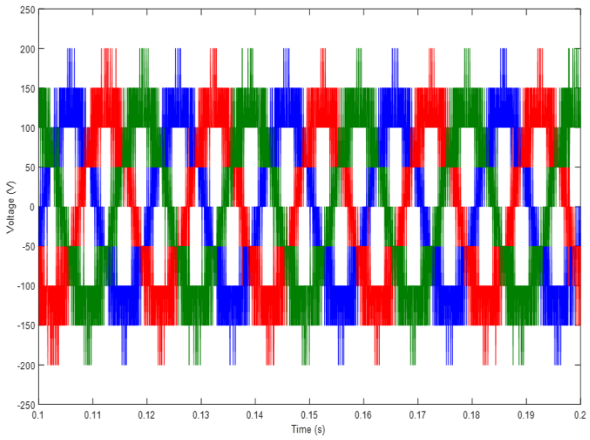

Fig. 2 - Voltage waveform of DABMI.

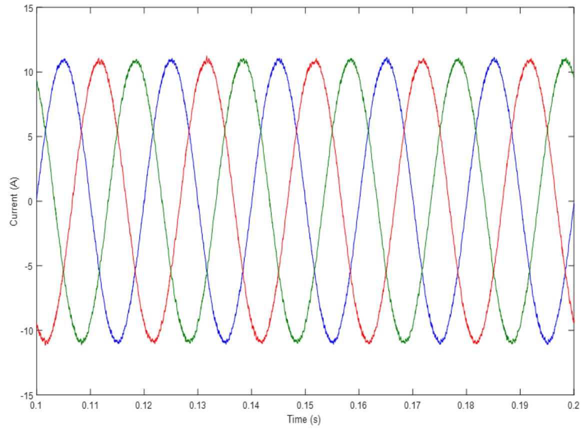

Fig. 3 - Current waveform of DABMI.

The performances of DABMI in grid connected application where it can be seen in Figure 4, shows the grid voltage with regard to injected current for phases a,b and c are properly synchronized and the quality is satisfactory. It explains that only the active power is injected into the grid as shown in Figure 5 and MPDCC has the ability to guarantee that the performance of the system can meet the grid requirements. Hence, there is no need for the grid to provide reactive power and harmonic current for the load.

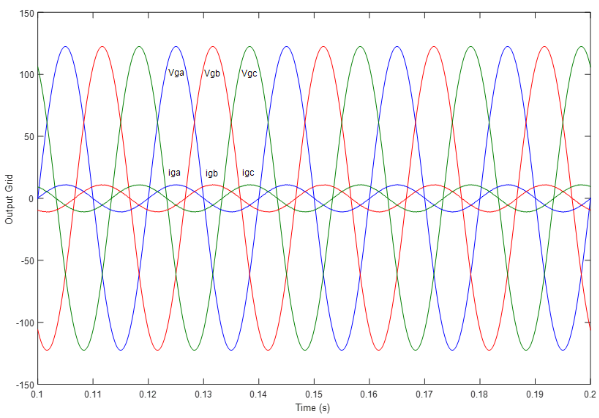

Fig. 4 - Waveform of grid Current and Voltage.

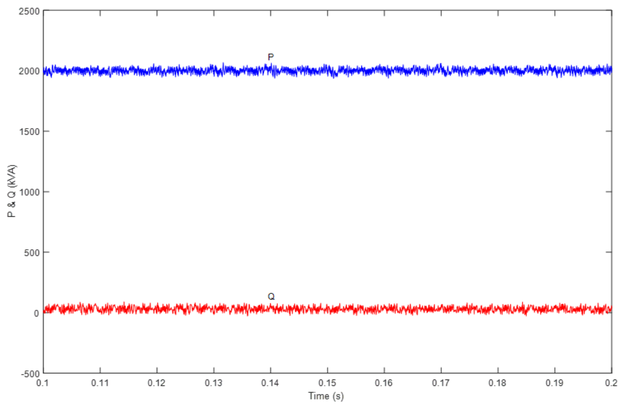

Fig. 5 - Waveform of active and reactive power.

Fast Fourier transform (FFT) analysis was performed on the inverter output current waveform to determine the quality of the output current. In FFT, the total harmonic distortion (THD) is calculated, and the frequency spectrum of the current harmonics for phase a, b and c are shown in Figures 6-8, respectively. It was seen that the DABMI output current THD that referred to phase a, b and c are 2.13%, 2.47% and 2.48% is below the minimum THD within the IEEE standard 519 which is less than 5%.

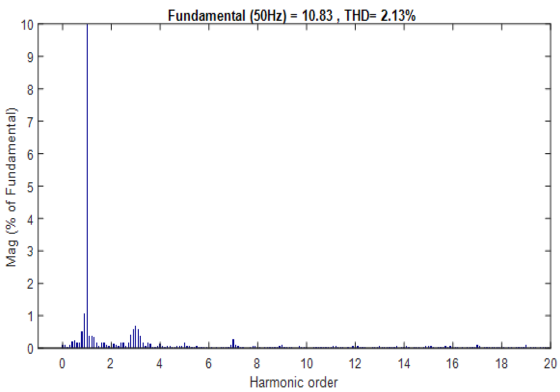

Fig. - 6 FFT for phase a current.

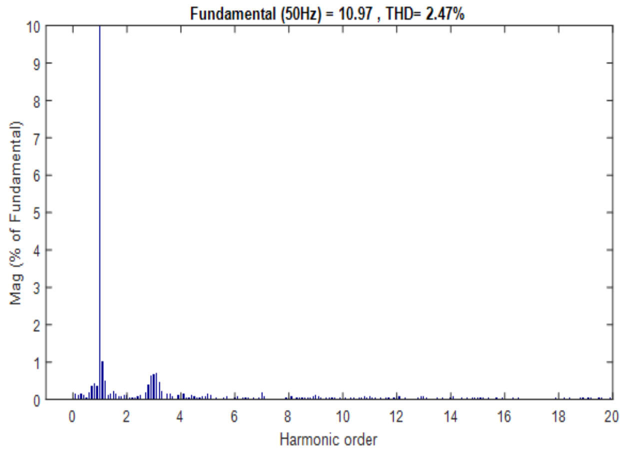

Fig. 7 - FFT for phase b current.

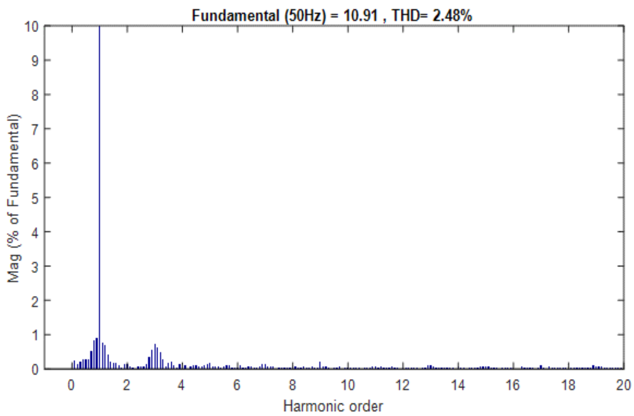

Fig. 8 - FFT for phase c current.

5. Conclusion

A dual active bridge multilevel inverter (DABMI) based model predictive direct current control (MPDCC) has been demonstrated in this paper. This method is used to control the active and reactive power through the controlling α and β grid current component to achieve a minimum grid current error in the next sampling period. The technique has a small amount of calculation to obtain the predictive model. By using DABMI based MPDCC, simulation results show that the proposed system manage to follow the active power reference given into the system and able to produce lower THD that set by IEEE standard.

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