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ANGULAR MODULATION OF DUAL-VSI FED OPEN-END MOTOR FOR ELECTRICAL VEHICLE APPLICATIONS

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Abstract:

In this system, Angular Modulation Index (AMI) implemented through modified SVM for dual-VSI is proposed with the primarily aiming to reduce switching losses. The desired voltage across the load is synthesized by applying appropriate phase angle displacement between space vector references. The proposed approach avoids the use of a dc/dc boost converter [which imposes loss and weight/price penalty to duplicate the dc-link voltage] and results to be particularly suitable for electrical/hybrid vehicle applications. Namely, the application of saving energy to keep driving has been identified as major concern. Hence, this work focuses on the strategy to enhance efficiency. The principles of the proposed controlling method and switching loss, which is reduced at least by 50%, are theoretically evaluated. The paper proposes a pioneering mathematical approach to correctly determine THD value of the voltage/current for dual-VSI structure. Furthermore, simulation and experimental results prove that the proposed method insures benefits in terms of common mode voltage (CMV), THD of voltage, and switching loss reduction. the simulation results carried out through MATLAB/Simulink environment are given to confirm performance of this easy-to-implement and high-efficient method.

Keywords – AMI, VSI, THD, MATLAB.

1. INTRODUCTION

Recently Voltage Source Inverters (VSIs) have been widely used; as distributed generators (DGs), in order to improve power system characteristics, or as motor drives. Conventionally, in medium/high power motor-drive applications (especially in electrical/hybrid vehicles, tram, etc.), medium voltage dc-source has been employed in order to respect battery safety concerns. The DC/DC converter, containing passive component, involves size/price penalty as well as degradation of the total efficiency of the system. In conventional power stages, switching losses are further deteriorated by the presence of a DC/DC stage followed by the VSI stage, since the total efficiency is obtained by multiplying the efficiencies of the two power converters. The patent strives by allocating null-time to that of nearby active space-vectors enhances VSI efficiency by around 4%. Through multi-level converters, the dual two-level VSI configuration has been of interest not only thanks to its independent easy controlling feature but also due to its simple power stage. Furthermore, the dual-inverter topology benefits from no neutral-point fluctuations as well as reliability and fault tolerance. This system concentrates on efficiency issue as the main objective. Switching loss, which is theoretically mitigated by 50%-87%, is formulated respecting AMI and load power factor cos(Ø). Authors tried to analyze the output-voltage error and current ripple. However, due to system complexity as well as the high number of possibilities, they eventually fail in achieving straightforward value or formula for THD. However, this system introduces pioneering solution to accurately calculate THD value of the output voltage/current for dual-VSI structure.

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2. THEORTICAL ANAYSIS

In this area, principles of the proposed method are outlined from the standpoint of modulation, switching loss, and voltage/current THD. Percentage of switching losses not only is proportional to effective switching frequency, which is reduced by 66% in this paper, but also related to absolute magnitude of output current while switching action. In the first sub-section, conventional space vector modulation (CSVM) is modified by avoiding null-vector utilization to achieve switching loss and CMV mitigation. Hence, for each sector two phases are clamped to positive/negative dc rail. In the second sub-section, concepts for synthesizing output voltage via adjusting phase-angle displacement between two reference vectors is formulated.

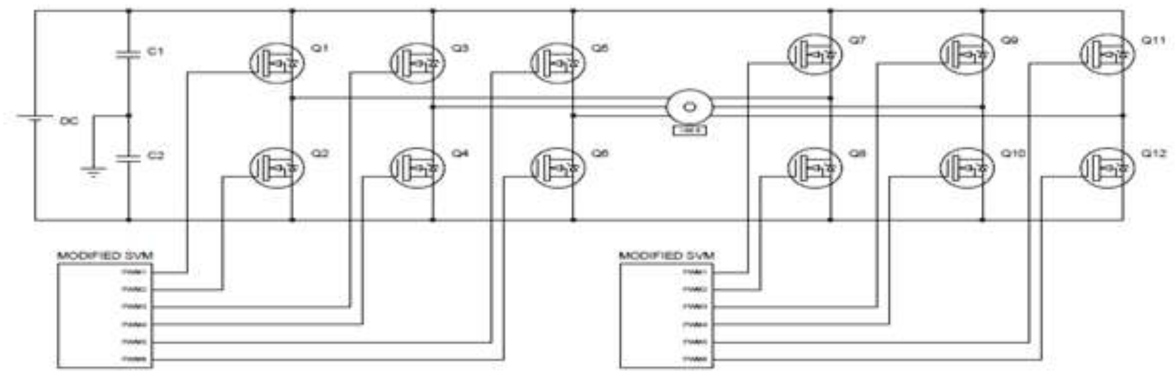

Fig.1. Dual-VSI fed open-end motor proposed for. electrical vehicle

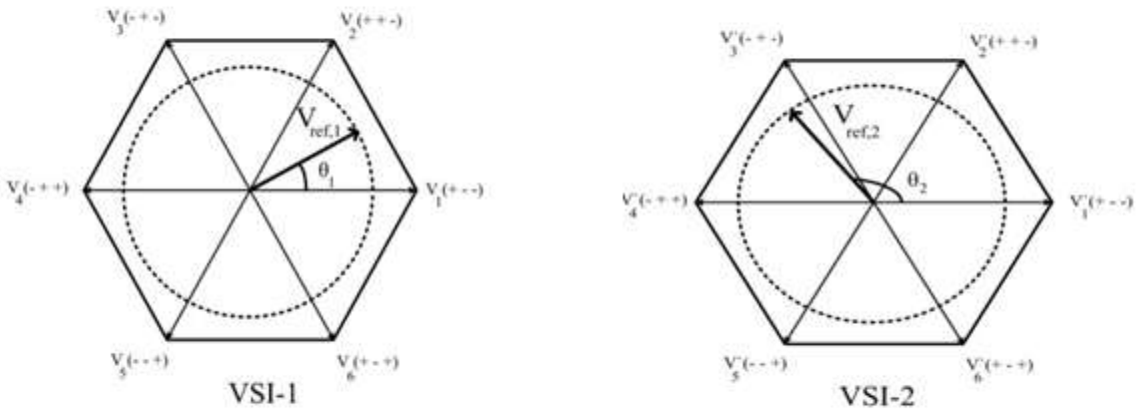

Fig.2. Space vector diagram and references

3. MODIFID CSVM

Modulation methods of dual-VSI fed open-end winding motor have been extensively researched with both carrier-based and space-vector-based PWMs. Application of CSVM results in 15% higher output voltage for a given dc bus voltage. Additionally, this leads to less harmonic content compared to the SPWM technique.The duty cycles of active vectors, where modulation index Mi is defined as peak value of fundamental phase-voltage, $Vpeak$, over that of square-wave, $2Vdc\pi$.

$$\alpha_i=(2\sqrt{3}/\pi)M_i\sin(i(\pi/3)-\theta) \quad (1)$$

$$\alpha_{i+1}=(2\sqrt{3}/\pi)M_i\sin(\theta-(i-1)\pi/3) \quad (2)$$

By applying the above-discussed modifications, the modified duty cycles are expressed as

$$\alpha_{i(new)}=1/2-3/\pi M_i\sin(\theta-(i-1/2)\pi/3) \quad (3.a)$$

$$\alpha_{i+1(new)}=1/2+3/\pi M_i\sin(\theta-(i-1/2)\pi/3) \quad (3.b)$$

After some algebra not reported here for the sake of brevity, the new reference voltage vector $\vec{V}ref$, is mathematically extracted as

$$\vec{V}_{ref,new}=(\vec{V}_{i+1}+\vec{V}_i)/2+(\alpha_{i+1}-\alpha_i)(\vec{V}_{i+1}-\vec{V}_i)/2 \quad (4)$$

For instance, in the modified CSVM the number of commutations within a switching interval is limited to two instead of six by applying symmetric sequence.

4. PROPOSED ANGULAR MODULATION

AMI based on variable phase angle displacement between two references is proposed, in order to minimize the commutation numbers while having full range modulation index. The open-end load requires the voltage across the two sides to be subtraction of the voltages produced by the first and second VSI, respecting virtual neutral point. However, note that each reference space vector can be separately built regardless of being in opposite direction, having $\Delta\theta(=\theta_1-\theta_2)$. in Fig.2, where θ_x, and $\|\theta_{refx}\|$ are initial angle and magnitude of reference space vectors, respectively, and x(=1, 2).

$$\vec{V}_{ref1}=\|\vec{V}_{ref1}\|(e^{j(wt+\theta_1)} \quad (5.a)$$

$$\vec{V}_{ref2}=\|\vec{V}_{ref2}\|e^{j(wt+\theta_2)} \quad (5.b)$$

Assuming $\|\vec{V}_{ref1}\|=\|\vec{V}_{ref2}\|$ and making use of (5.a) and (5.b), the obtained voltage across the load can be cast as

$$\vec{V}_{ref}=\vec{V}_{ref1}-\vec{V}_{ref2}=2\|\vec{V}_{ref1}\|\sin((\theta_1-\theta_2)/2)e^{j(wt+\theta_t)} \quad (6)$$

From (6) and due to $\|\vec{V}_{ref1}\|=\sqrt{6}/\pi V_{dc} M_i^{new}$, angular modulation index, AMI (5.a), which demonstrates non-linear (sin-shaped) dependence on the phase shift, $\Delta\theta$, and initial phase angle, θ_t (5.b), can be extracted as

$$AMI=\|\vec{V}_{ref}\|/(\sqrt{6}/\pi V_{dc}) = 2\, M_i^{new}\sin(\theta_1-\theta_2)/2) \qquad (7)$$

$$\theta_t=\theta/2+(\theta_1+\theta_2)/2$$

The desired output-voltage parameters, $Vpeak$ and θt, are conventionally demanded from dual-VSI controller. In the proposed method, above-mentioned parameters result in single nonlinear equation as

$$V_{peak}=12Vdc/\pi^2\cos(\theta_t-\theta_1) \qquad \text{where } \theta_t-\theta_1=\pi/2-\Delta\theta/2 \qquad (8)$$

5. SIMULATION THEORY

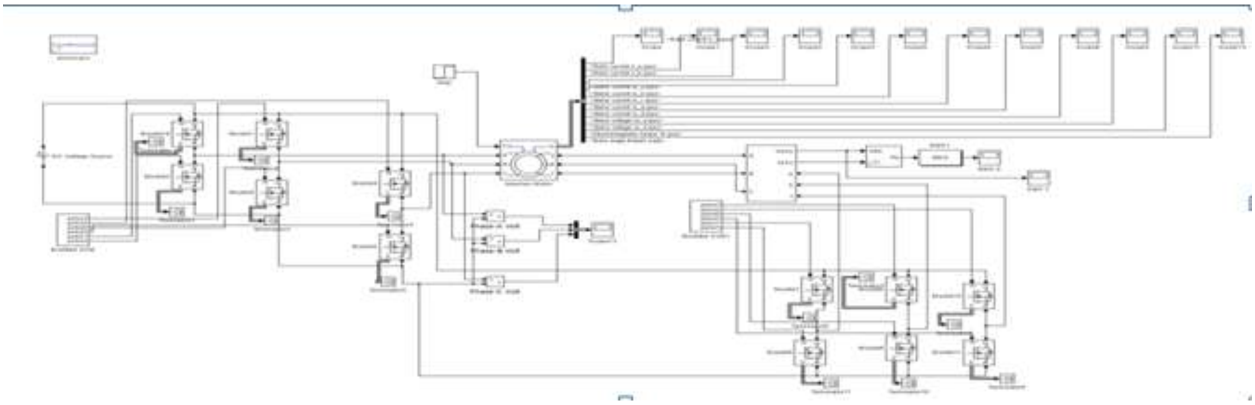

Fig.3.Simulation

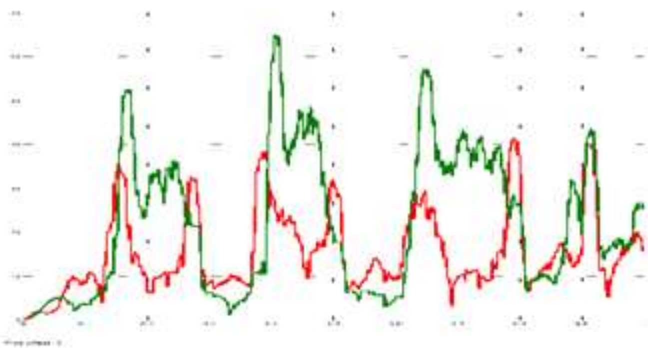

Fig.4.Waveform Output

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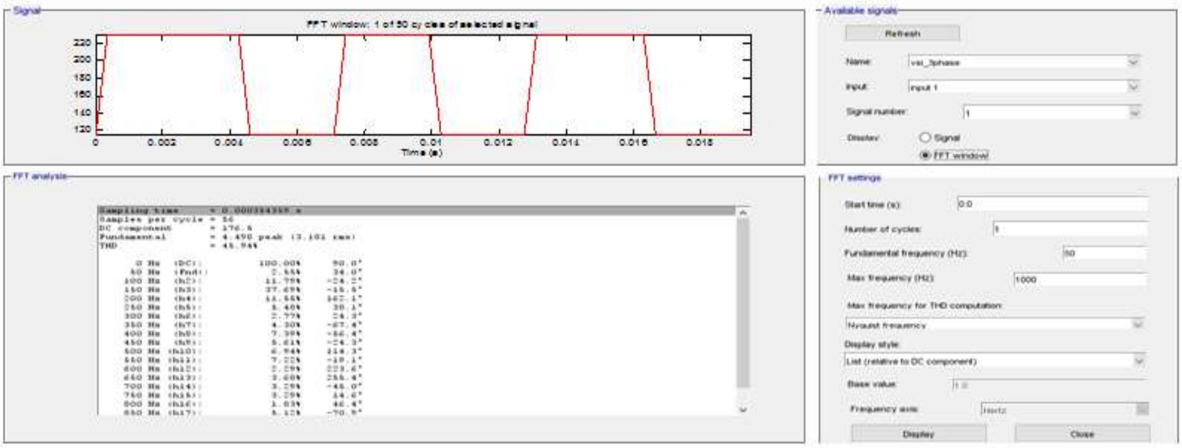

Fig.5. Output

CONCLUSION

The system deals with AMI controlling method for dual-VSI configuration, while each VSI is modulated by the modified CSVM. The benefits of the proposed approach are theoretically and experimentally evaluated in this paper, by showing that the desired reference space vector has capability of being generated with adjusting appropriate phase angle displacement between two references instead of forcing these to be in opposite direction. this paper introduces a promising solution to enhance efficiency, especially for electrical/hybrid vehicle applications by achieving at least 50% reduction in switching losses. This paper offers the pioneering approach to accurately extract voltage/current THD for dual-VSI structure. Not only simulation and experimental results but also analytical approaches have proven that peak value of CMV meets reduction by 66% in dual-VSI modulated by the proposed method. Also, THD of the low-order phase voltage takes lower values. These features make the proposed method a strong candidate to be used in dual-VSI without adding extra hardware, expenses, or complex calculation.

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