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MATLAB Simulation of Traction Energy Storage System with Power Electronic Converters

VIJAYA LAKSHMI KONDEPUDI, GRANDHI RAMU
Electrical and Electronics Engineering Department,
Chaitanya Institute of Science and Technology,
Kakinada, A.P, India.

Abstract

With growing importance being placed on decarbonising the world economy and achieving energy security, electrified public transportation is playing a progressively greater role in society. Compared with personal transportation, a substantial energy saving is achieved with public transportation, particularly at peak commuter times. Further carbon savings may be made since the electrical network would allow renewable and low-carbon energy to provide motive power. The energy consumed in an electrified transit system can further be reduced by installing energy storage systems (ESSs) onboard vehicles. Energy storage devices can be used to regenerate energy during braking, energy which would otherwise be dissipated in either mechanical brakes or braking resistors. This energy can then be reused. This paper proposes a new power electronics topology that integrates the energy storage power electronics with those of the inverter drive system. This topology reduces weight and component count compared with previous topologies but still allows the use of standard machines.

1. Introduction

Ac motor has many distinct advantages, such as of simple structure, reliable operation and small volume of specific power [1]. With the constant perfection and development of high power variable frequency device and its control technique, the application of AC motor as the locomotive traction motor has become an important development direction of traction drive. Three-phase AC asynchronous traction motors and synchronous traction motors have their own strong points respectively, the comparison of them is still not clear yet. But on the motor itself, induction motor has the more simple-firm structure [2]. Now, High power inverter fed induction motors are widely used in high speed railway traction applications [3]. There are approximately three methods to change motor rotational speed. First one is changing slip ratio; second one is changing the number of motor poles; third one is change power supply frequency. The two former approaches cannot adapt to the requirements of locomotive traction. However, high velocity precision, wide speed range and step-less speed adjustment can be realized in the variable frequency speed regulation system [4-5]. Frequency control is an ideal speed regulation method. However, there are certain practical issues involved, like system harmonic increase, motor torque ripple, etc. which need to be taken care of and are addressed by various researchers [6].

Installing energy storage devices onboard vehicles is not a new idea. The bus was powered by a flywheel that drove an induction generator. Bombardier had developed the Mitrac Energy Saver, which has shown a 30% energy consumption reduction in Mannheim. Recent publications suggesting the implementation of an onboard energy storage use an arrangement based on that. Steiner, together with other authors, has published a number of papers on the Bombardier Mitrac system, which is a successful example of the implementation of ultra capacitor energy storage in light rail systems, which is based on this configuration using a bidirectional insulated-gate bipolar transistor (IGBT) chopper. Other authors have also proposed and analyzed systems based on this configuration. The energy storage converter employed in such systems is require to boost the energy storage unit voltage, ultimately meaning the converter requires bulky passive components. A solution has been proposed to overcome this issue, installing the ultra capacitors in series with the dc supply. Simulation results of this concept are promising, although practical tests performed to date have been unable to prove the concept. A weakness of the standard configuration is that the energy flowing to and from the energy storage devices passes through two power electronic converters:

1) The traction inverter and
2) The energy storage converter.

Connecting an energy storage inverter to the motor through an auxiliary transformer removes the requirement for the extra stage. This configuration requires additional transformers, which introduce additional mass and additional system losses, although these are smaller than that of a dc–dc converter. Laboratory tests have shown promising results. A cascaded two-level converter has been proposed as an alternative to four-level converter topologies using one dc link. This circuit can be adapted, using two separate dc sources, at different voltage levels for traction applications. In this paper, a new topology is proposed to use the ultra capacitors in the traction applications. Space Vector Modulation control based inverter is used in the proposed model.

2. Proposed Methodology

The new power electronic converter proposed in this paper combines two parallel inverters. The two parallel inverters work from two separate dc sources:

1) The traction supply source and
2) The energy storage source.

The first inverter is connected to the traction supply source. The second inverter is connected to the ESS. Bidirectional switches are employed to connect the ESS to the motor windings; this is required to prevent current flowing from the traction supply system to the ESS when the inverters are connected in parallel. Two IGBTs and anti parallel diodes are connected together to create a bidirectional switch. Both sets of inverters have switches connecting the motors to ground (IGBTs 2, 4, and 6 and IGBTs 13, 14, and 15). As they are in parallel, they can be replaced with a single set of switches, and therefore, IGBTs 13, 14, and 15 (shown by dashed lines) can be removed.

A. Operation

By switching between the two separate inverters, the power electronic converter can be used to interleave the two sources. The circuit clearly works best if the energy storage unit is designed to have a nominal dc voltage comparable with that of the normal dc traction supply. The three modes of operation, i.e., traction supply inverter, energy storage inverter, and interleaved operation, are subsequently described.

Standard Inverter Operation: The bidirectional switches are off (IGBT pairs: 7 and 8, 9 and 10, and 11 and 12), and a pulse width- modulation (PWM) signal is generated to control IGBTs 1, 2, 3, 4, 5, and 6. In this mode of operation, the circuit behaves as a conventional inverter.

Energy Storage Source Inverter Operation: IGBTs 7, 9, and 11 are turned on, and IGBTs 1, 3, and 5 are turned off. IGBTs 8, 10, and 12 and IGBTs 2, 4, and 6 are driven using a PWM signal, and the circuit behaves like an inverter with the energy storage device as the energy source. This mode also allows the induction motor to operate in a regenerative braking region of operation, braking the vehicle, and charging the energy storage device.

Dual-Source Inverter Operation: By switching between the standard inverter mode and the energy storage source inverter mode, the circuit can be used to drive the induction motor from either source. By rapidly switching between the two modes of operation, the novel power electronic converter can be used to interleave the two power sources. Examination of the circuit shows that IGBT 7 and D7, IGBT 9 and D9, and IGBT 11 and D11 are in parallel and could be replaced with a single IGBT and anti parallel diode. The operation of this circuit is possible using the simple switching control subsequently described and would result in a reduction in the switch count. However, independently switching the IGBTs could potentially allow a more advanced switching strategy should space vector modulation be employed.

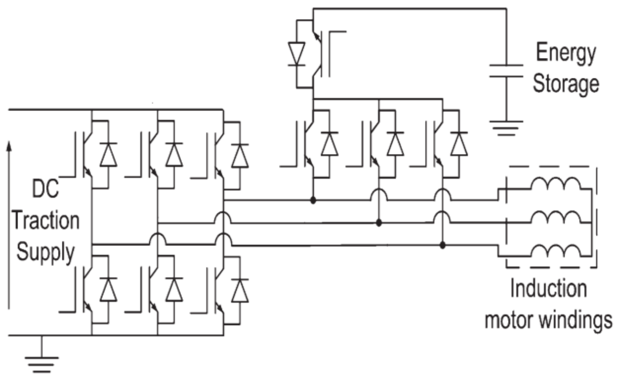

Fig 1. Circuit diagram of the proposed methodology

3. Space Vector Pulse Width Modulation

In this paper Space vector Pulse Width Modulation
(SVPWM) Z-source inverter based approach has been
proposed. It is an advanced, Computation-intensive PWM method which the best as compared to all the PWM techniques for ASDs. Its gaining more and more applications recently as it has the required performance characteristics. The implementation of PWM methods has been done only on a half bridge of a 3- phase bridge inverter. If the load neutral is connected to the center tap of the, dc supply, all three bridges can operate independently and give satisfactory PWM performance. The load neutral is normally isolated, in case of machine load due to which interaction among the phases is caused. In SVPWM this interaction of the phases is considered and harmonic content of the three phase isolated neutral load is optimized. The Space Vector modulation the can be understood, the concept of a rotating space vector. If the three phase sinusoidal and balanced voltages given by the voltages,

$$v_a = v_m \cos wt$$
$$v_b = v_m \cos \left(wt - \frac{2\pi}{3} \right)$$
$$v_c = (v_m \cos (wt + 2\pi/3))$$

are applied to a three phase induction motor. Using the following state equations,

$$v^{\rightharpoonup} = v_{qs}^{s} - j v_{ds}^{s}$$

$$= \left(\frac{2}{3} v_{as} - \frac{1}{3} v_{bs} - \frac{1}{3} v_{cs}\right) - \left(\frac{\sqrt{3}}{2} v_{bs} \frac{\sqrt{3}}{2} v_{cs}\right)$$

$$= \left(\frac{2}{3} v_{as} - \frac{1}{3} v_{bs} - \frac{1}{3} v_{cs}\right) - \left(\frac{\sqrt{3}}{2} v_{bc} \frac{\sqrt{3}}{2} v_{cs}\right)$$

Where a= $e^{j\frac{2\pi}{3}}$ and $e^{-j\frac{2\pi}{3}}$

It can be shown that, the space vector V with m magnitude V rotates in a circular orbit at angular velocity of ù where the direction of rotation depends on the phase sequence of the voltages. A circle is formed by the trajectory sketched by the space vector V* forms s circle for sinusoidal excitation and is shown in Fig. 2. The fabrication of PWM at the inverter output should be such that the voltages must follow these command voltages with minimum harmonic distortion when the sinusoid three phase command voltages are given. SVPWM allows z-source inverters to be operated at over modulation region which is not possible in other PWM techniques, since the inverter behaves as a square wave inverter when the modulation index exceeds one. In linear modulation (0<m<1), the V* of figure 4 can be resolved as

$$v_a = \frac{2}{\sqrt{3}} v^* \sin\left(\frac{\pi}{3} - \alpha\right)$$
$$v_b = \frac{2}{\sqrt{3}} v^* \sin \alpha$$

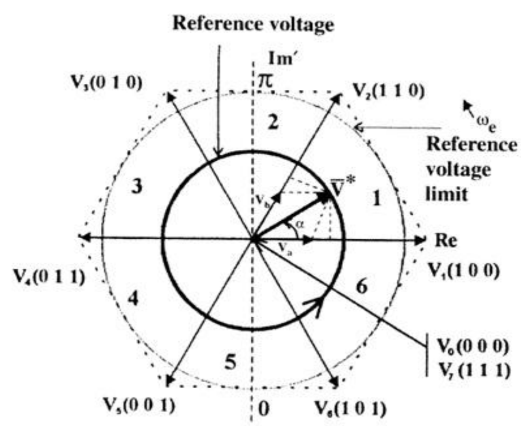

Fig:2 Space Vector Trajectory

Where Va and Vb are the components of V*aligned in the directions of V1 and V2 respectively.
Considering period Tc during which the average output should match the command, we can write the vector addition

$$v^* = v_a + v_b = v_1\frac{t_a}{T_c} + v_2\frac{t_b}{T_c} + (v_0 or v_7)\frac{t_{on}}{t_{off}}$$

V*T =V t +V t +(V or V)t_0

Where.

$$t_a = \frac{V_a}{V_1}T_c$$

$$t_b = \frac{V_b}{V_2}T_c$$

$$t_0 = T_c - (t_a + t_b)$$

time intervals t and t satisfy the command voltage, c but time to fills up the remaining gap for T with a null vector. Fig. 3 shows the construction of the symmetrical pulse pattern for two consecutive Tc intervals to satisfy the above equations. Here, T =2T =1/*f* (*f* =switching frequency) is the sampling

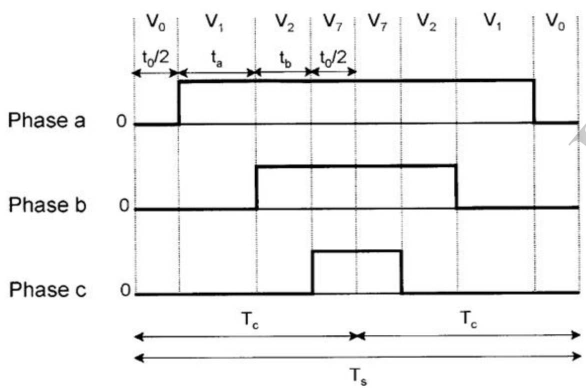

Fig:3 Output Voltage of Space Vector-I

time. Null time has been conveniently distributed betweenV_0 and V $_7$ V vectors to distribute the symmetrical pulse widths, which gives minimal output harmonics. The modulation index may be defined as the ratio between vector magnitude or phase peak value and fundamental peak value of the square phase voltage wave, varies from 0 to1at the square wave output.

Modified modulation factor

$$m' = \frac{\overrightarrow{V_m}}{\overrightarrow{V_{1sw}}}$$

From the geometry of the fig. the maximum possible value of at the end of the under modulation region can be derived. The radius of the inscribed circle can be given as

$$V_m^* \frac{2}{3}V_d \cos 30 = 0.577V_d$$

Modified modulation factor for SVM

$$m' = \frac{\overrightarrow{V_m^*}}{V_{1sw}} = \frac{0.577V_d}{\frac{2}{\pi}V_d}$$

It implies that, 90.7% of the fundamental at square wave is available in the linear region, compared to 78.55% in the sinusoidal PWM. In over modulation or non-linear operation, starts when the reference voltage V* exceeds the hexagon boundary. There are two modes in over modulation In mode 1, V crosses the hexagon boundary * at two points in each sector as shown in fig. 4. The fundamental voltage (peak) of the inverter output in Mode I of Space vector PWM because of quarter wave symmetry could be expressed as,

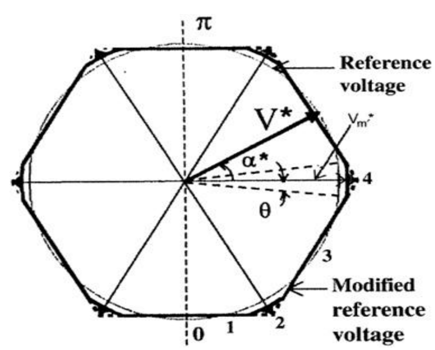

Fig:4 Space trajectory in Mode-I

$$V_1 = \frac{4}{\pi}\int_0^{\frac{\pi}{6}-\theta} V_1 \sin\theta_d\, d\theta_d + \int_{\frac{\pi}{6}-\theta}^{\frac{\pi}{6}+\theta} V_2 \sin\theta_d\, d\theta_d + \int_{\frac{\pi}{6}+\theta}^{\frac{\pi}{2}-\theta} V_3 \sin\theta_d\, d\theta_d \int_{\frac{\pi}{2}-\theta}^{\frac{\pi}{2}} V_4 \sin\theta_d\, d\theta_d$$

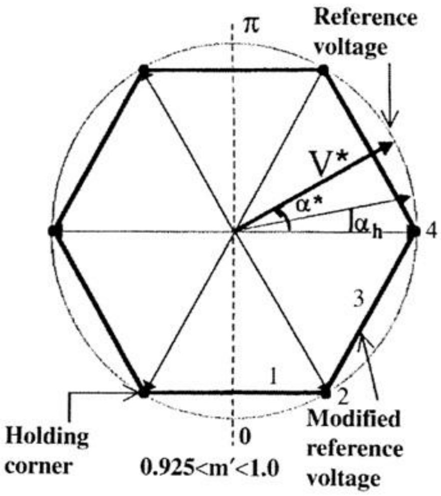

Fig:5 Space Trajectory in Mode- II

The fundamental voltage (peak) of the inverter output in Mode II of Space vector PWM because of quarter wave symmetry could be expressed as,

$$V_1 = \frac{4}{\pi}\int_0^{\frac{\pi}{6}-\alpha_k} V_1 \sin\theta_d \, d\theta_d + \int_{\frac{\pi}{6}-\alpha_k}^{\frac{\pi}{6}+\alpha_k} V_2 \sin\theta_d \, d\theta_d + \int_{\frac{\pi}{6}+\alpha_k}^{\frac{\pi}{2}-\alpha_k} V_3 \sin\theta_d d \, d\theta_d \int_{\frac{\pi}{2}-\alpha_k}^{\frac{\pi}{2}} V_4 \text{si}$$

4. Simulation Results

Different modes of operation of the proposed model are simulated and the simulation results for the dual mode of system operation are presented in figure 6 and figure 7. From the results shown in the figure it can be observed that the proposed configuration of the inverter gives the uninterrupted power supply to the traction drives even when there is a disconnection of the power supply from the main supply.

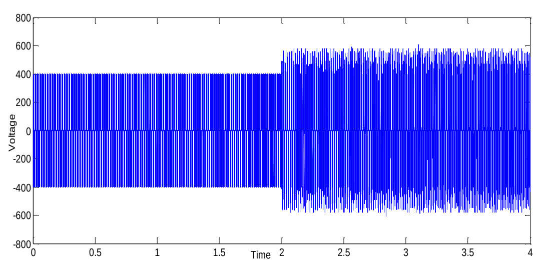

Fig 6. Supply voltage given by the dual converter configuration

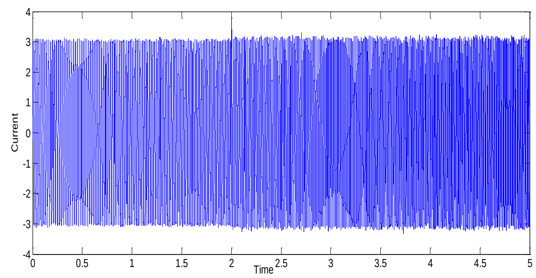

Fig 7. Supply current given by the dual converter configuration

5. Conclusions

This paper has presented a new converter topology for light rail traction. It has been shown that energy storage onboard can substantially reduce energy use per kilo meter. A new converter circuit has been presented. It has been shown that further energy savings per kilo meter can be achieved with the novel converter as opposed to a conventional power electronics topology. Space Vector Modulation control based inverter is used in the proposed model.

6. References

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