

Permanent Magnet Traction Module with an Enhanced Fault-Tolerant Capability for Subway Application

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Abstract: A fault-tolerant permanent-magnet traction module is proposed for subway application, which has three different operation modes: normal, isolation, and fault-tolerant mode. In normal mode, 2 three-phase permanent-magnet synchronous machines (PMSMs) are controlled by 2 three-leg voltage-source inverters (VSIs), respectively. The proposed module can output maximum torque and reach the maximum velocity. When one leg fails, the corresponding PMSM is isolated from the fault VSI and the fault subway train operates in isolation mode, in which the traction effort is reduced but the maximum velocity can be maintained under light load. However, the fault subway train will stop if the load is heavy. To avoid the stop, the fault subway train is switched into fault-tolerant mode, in which the healthy VSI and fault VSI are reconfigured to 1 five-leg VSI by a fault-tolerant bridge. Due to lower phase-phase voltage apportionment ratio, the fault-tolerant mode is not used until the velocity is decreased to half of the maximum velocity. In fault-tolerant mode, the non-adjacent selection principle is proposed to prevent the common leg from over current damage. The subway train equipped with the proposed module can maintain basic operation performances if any leg fails. The performances are analyzed and the effectiveness is verified by experimental results.

Keywords: PMSM, VSI.

I. Introduction

The conventional five-leg topology without using the non-adjacent selection principle[1]. The over current phenomenon is dangerous for the subway traction system by using the nonadjacent selection principle, the over current problem does not exist in the proposed module is safer than the conventional one. In the existed method to overcome the over current damage to use the control method of vector control it consist of two level control[2].

- i) System level control
- ii) Machine level control

But in this method one leg fails to add an redundant leg[3], which complicates the system structure and increases the cost[7],[8]. Therefore, the proposed module is safer, simpler and more cost-effective than the available methods. In the existing system reference paper “FAULT TOLERANT VSI FOR PM DRIVES “gives the disadvantages about the system the cost is very high compare with the proposed module. The software result will be given in below, the software results are obtained both are give similar conclusion.

Block Diagram

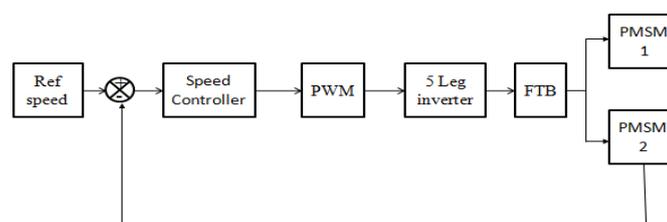


Figure1.1block diagram

Permanent-magnet-synchronous-machine (PMSM) drives have been increasingly applied in a variety of industrial applications which require fast dynamic response and accurate control over wide speed ranges. However, there still exist challenges to design position-sensor less vector control of PMSM operating in a wide speed range, which covers both constant-torque and constant-power region. Thus, two control techniques are proposed in this dissertation for PMSM drives, namely flux-weakening control incorporating speed regulation and sliding mode observer with feedback of equivalentControl. The research objectives are to extend the

operating speed range of the PMSM drive system and improve its control robustness and adaptability to variations of operating conditions as well as dynamic performance.

II. Permanent Magnet Synchronous Motor (PMSM)

Permanent Magnet Synchronous Motor (PMSM) is commonly known as permanent magnet ac (PMAC) motors. They are classified according to the nature of voltage induced in the stator as sinusoidal excited and trapezoidal excited.

Constant-torque operation

In a PM machine, torque control can be achieved, similarly to that of a dc machine. As presented previously, the electromagnetic torque consists of: 1) magnet torque, which is proportional to the product of the magnet flux linkage (i.e., rotor flux in the rotor reference frame) and the quadrature-axis stator current (i.e., torque-producing stator current component); 2) reluctance torque only for PM machines with saliency, which is dependent on the saliency ratio and the product of the direct-axis and the quadrature-axis stator current component. Hence the electromagnetic torque of PMSM can be controlled instantaneously through controlling the stator currents in the rotating reference frame, to meet load torque requirements.

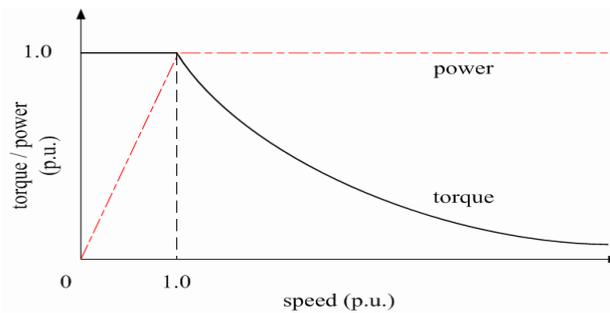


Figure 2.1: Typical Characteristics Curve of Torque/Power vs speed of PMSM.

III. Fault –Tolerant Bridge (Ftb)

In this proposed module consist of fault-tolerant bridge; it will reconfigure the fault and healthy voltage source inverter. The fault-tolerant mode is tested. Leg 4 is assumed to fail. According to section III Tables I and II, nRT is 43, which means the phase C1 and phase C2 are connected together to share leg 3. The maximum velocity in this mode is halved to 40 km/h. The waveforms are illustrated; the subway train also can successfully pass through both the upslope and the down slope[4]. As compared with the normal mode, the lower maximum velocity results in nearly double operation time. An important feature must be pointed out that the common leg current is significantly lower than any phase currents. This feature can prevent the common leg from over current damage. The leg reconfigured figure is given below. The fault-tolerant bridge consist of 12 triode. It is the anti-parallel connection of two SCR. The 12 anti-parallel pairs of SCR are used in the switching operation, if one leg fails in the inverter it is reconfigured by FTB into five leg inverter the current shared by the other leg of the inverter

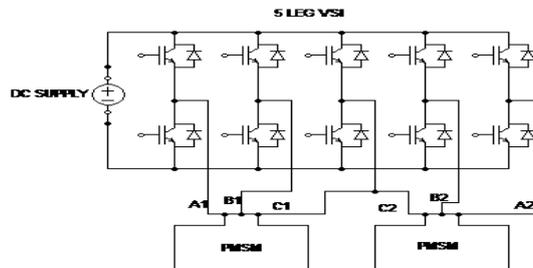


Figure 3.1 Reconfigured five leg inverter

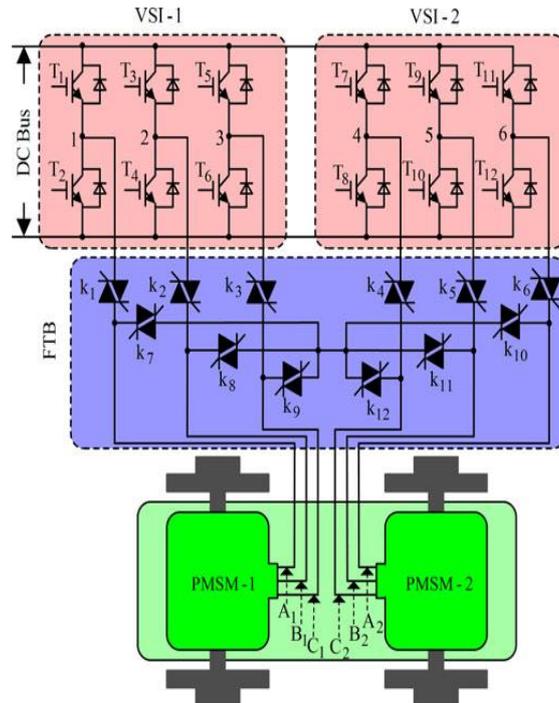


Figure 3.2 Reconfigured five leg inverter with FTB

Non Adjacent Selection Principle

The non-adjacent selection principle is used for avoid the common leg over current damage. In the fault-tolerant mode, such as Figure.3.1, the proposed module is reconfigured to be a five-leg topology and the common leg must bear the summation of two connected phase currents. Because each leg has the same rated current, the common leg may operate in the over current condition[5]. To protect the common leg from over current, a “nonadjacent selection principle” is proposed in this section

n_{RT}	n_{FL}	k_{FTB}	n_{FL}	n_{RT}	k_{FTB}
1	16	011 111 100 100	4	41	111 001 100 001
	15	011 111 100 010		42	111 011 010 001
	14	011 111 100 001		43	111 011 001 001
2	26	101 111 010 100	5	51	111 101 100 010
	25	101 111 010 010		52	111 101 010 010
	24	101 111 010 001		53	111 101 001 010
3	36	110 111 001 100	6	61	111 110 100 100
	35	110 111 001 010		62	111 110 010 100
	34	110 111 001 001		63	111 110 001 100

Relationship between fault leg and redundant leg table I

It is seen in Table I that three legs in another VSI can be selected as the common leg to replace the fault leg. The problem is how to find the optimal leg from the three candidates to minimize the common-leg current. The common-leg current i_{com} can be denoted by

$$I_{com} = I_{com_1} + I_{com_2}$$

$$I_{com_1} = I_{pms} \sin \theta_1$$

$$I_{com_2} = I_{pms} \cos \theta_2$$

Three Phase Voltage Source Inverter

The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable[6]. Although most of the applications require

sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators). As shown in above Figure (3.9) circuit there are six power MOSFETs, $S_1, S_2, S_3, S_4, S_5, S_6$. Observe that upper three MOSFETs are S_1, S_3 and S_5 . Similarly lower three MOSFETs are numbered as S_4, S_6 and S_2 .

Depending upon the drives applied to MOSFETs, there are two types of 3ϕ inverters:

- 180° conduction and
- 120° conduction mode

In 180° , each MOSFET conduct for 180° and in 120° , each MOSFET conduct for 120°

In our project work deals with 180° conduction mode so we discuss about this.

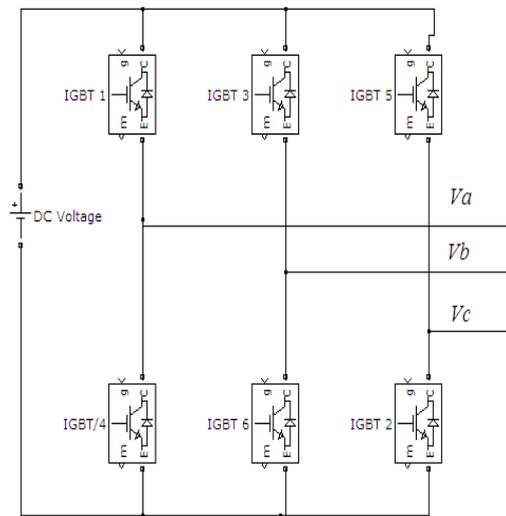
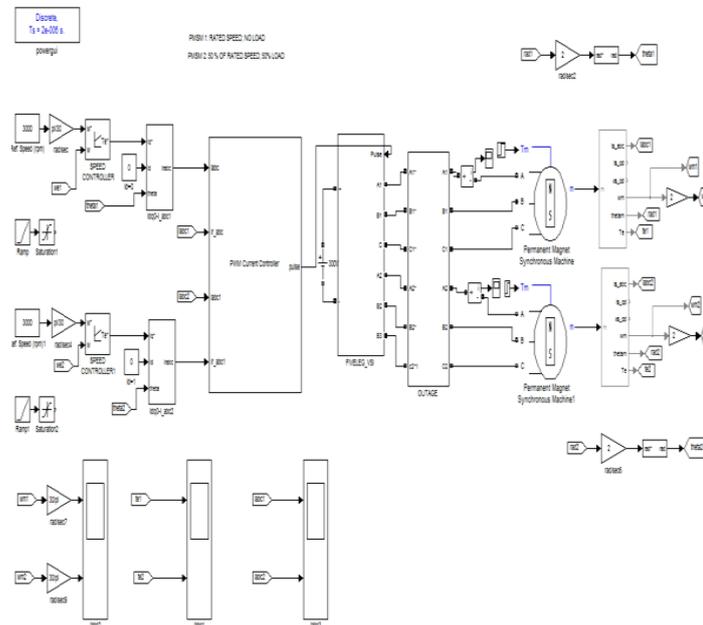


Figure 3.3 Basic circuit diagram of VSI inverter

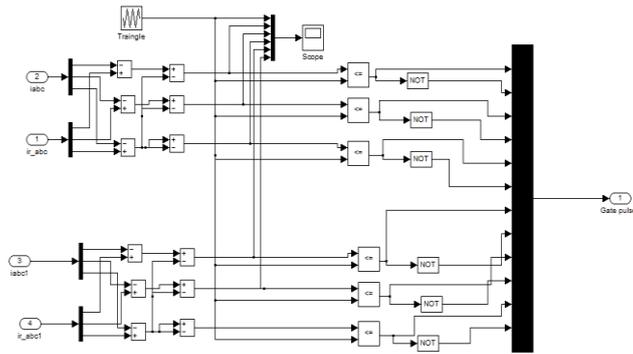
IV. Mat lab

Simulation has become a very powerful tool on the industry application as well as in academics, nowadays. It is now essential for an electrical engineer to understand the concept of simulation and learn its use in various applications. Simulation is one of the best ways to study the system or circuit behavior without damaging it. The tools for doing the simulation in various fields are available in the market for engineering professionals.

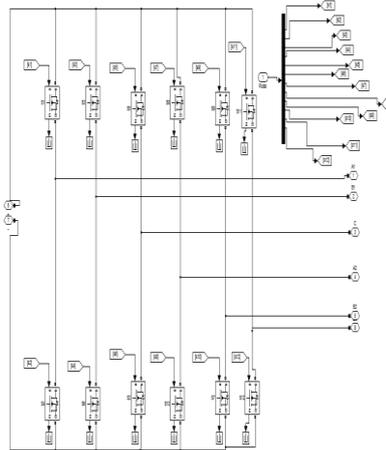
Mat lab Circuit



Pwm Circuit

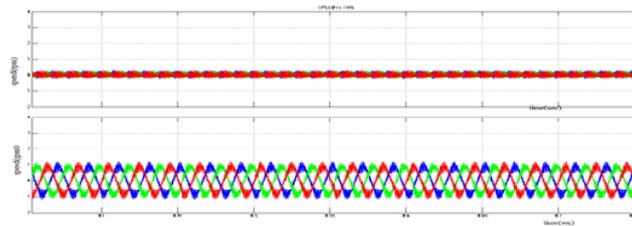


Inverter Circuit

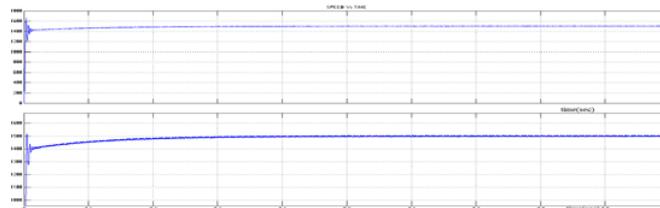


V. Results

Three phase current of PMSM 1 & 2



Actual Velocity of PMSM 1 & 2



VI. Conclusion

To realise the five leg inverter output. The effect of the traction module is not reducing in the five leg inverter with 2 three phase permanent magnet traction system. The five leg inverter current are analysed with compare to the six leg inverter current the output current are same.

The fault-tolerant capability of the traction module is improved by using the fault-tolerant bridge. The proposed module can output maximum torque and reach the maximum velocity.

In the fault-tolerant mode, the non-adjacent selection principle is proposed to prevent the common leg from over current damage. The subway train equipped with the proposed module can maintain basic operation performances if any leg fails. The performance are analysed and the effectiveness is verified by experimental results.

The priority of the three mode is normal mode> isolation mode> fault- tolerant mode. If all legs are healthy the subway train operates in normal mode .If one leg fails in one traction module, the subway train must transfer to isolation or fault-tolerant mode. If the reduced traction effect is enough for the operation of the fault subway train, the isolation mode should be selected. Otherwise, the fault-tolerant mode is adopted.

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