A Novel DC Converter control for Induction Motor Drive in Electric Vehicle

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Abstract: Different kinds of electric motor drives are used in electric vehicle technology. Each motor drive shows diversity in numerous features like power density, efficiency, cost factor, reliability etc. Out of these Induction motors and Brushless DC motors are widely used in electric vehicle technology. In Induction motors, single phase, three phase and multi-phase motors are used for the propulsion system of the electric vehicle. But research reveals that multi-phase induction motors are more economical, efficient and reliable than the traditional three phase and single-phase motors. In Induction motors, as the number of phases increases the torque ripple will decrease which is a desirable characteristic in motor drives for electric vehicle. Due to the smooth operation, and uniform torque of a six-phase induction motor they are used in air-craft and submarine applications. But the application of six phase induction motor is limited in automotive due to the non-uniformity in loads. So here a current programmed controlled DC-DC converter is developed to check the reliability of six phase induction motor in automotive applications.

Key words: induction motor (IM), six phase induction motor (SPIM), DC-DC converter

I.INTRODUCTION

The electric vehicles are now a promising solution to curb the air pollution that uses pollution free battery power to produce clean energy for the vehicle. By 2040, there will be around 350 million electrical vehicles all over the world. Out of these 350 million will be cars, which is 15 % of the total cars. In India, two wheelers and three wheelers are constituting about 83% of total vehicles. 13% are economy cars. All together this costing less than one million, which is 95% of Indian vehicles. So, these small and affordable vehicles are electrified, it will keep the batteries small, charging at lower voltage and lower power [1]. Electric vehicles incorporate different electric motor drives like DC (Shunt or Series) motors, Induction motor (IM), Permanent magnet synchronous motor (PMSM), Brushless DC Motor (BLDC) and Switched reluctance motor (SRM) for their propulsion. The selection of different electric motor drives is influenced by the parameters like efficiency, reliability, cost, power density and torque to weight ratio. Power Density is the ratio of capacity-to-weight of any electric motor and is normally computed utilizing the motor apex power [2]. Power density for any motor is calculated by dividing the apex power yield (in kW) by mass (in kg). The most impressive power density is shown by Permanent Magnet motors and it is because of the presence of high-power density of permanent magnets. The PMS machine delivers the highest power thickness which allowing a powerful and smaller machine in the allowed frame. At that point PM brushless motor becomes the best which is followed by both IM and SRM. Again, dc motors possess the poor power density. Every single electric motor is expected to work at maximal efficiency at the measured output. Out of the different motors used in electric vehicle, it is observed that BLDC motor gives the best energy efficiency (greater than 95%) followed by the Induction Motors (greater than 90%). BLDC Motors have the better efficiency due to the absence of losses in rotor. As far as the energy efficiency is concerned, the most productive motors for the electric vehicle drives are the PM-BLDC motors. The induction being next, and then followed by SRMs which possess nearly indistinguishable efficiency.[3] Comparison based on fidelity of the electric motor drive that is breakdowns and support ought to be minimum, the most reliable ones are IM and SRM and which is followed by PM motors. The least dependable is the DC Motor. DC motor brushes and switches enter current in the armature, along these lines and hence are less decisive and ill-equipped for maintenance free task. Induction motors abide by the vital competitor due to their fidelity [4]. When considering the cost factor, the most desirable motor drive is the induction motor drive. And it is followed by the DC motor and switched reluctance motors. The induction motor engines are accepted by most of the manufacturers for the EV applications since they are more and more economical than any other motor drives. For large capacity motor, the price of DC motor is much higher than that of AC motor of the same capacity. If two motors are with the same power capacity are compared, a higher speed, lower torque motor will cost less than a lower speed, higher torque motor. A motor with a higher operating voltage and lower current requirement will have a lower cost than that with lower operating voltage and higher current. Rotor design is probably the most important factor in making the DC motor more expensive. PMDC motors contain permanent magnets which are not economic. The amount of magnet required is approximately proportional to the power [5]. Multi-phase induction motor has a better torque to weight ratio comparing with traditional single phase and three phase induction machines. In multi-phase induction motors, there is a trend between the number of phases and torque pulses. As the number of phases increases the torque pulsation will be decreased. And torque to weight ratio also increases. Among the group of multi-phase motors, the six-phase induction motor has received more and more attention due to the simplicity in converting a conventional three phase machine to six phase. This is achieved by splitting the stator winding into two sets of three phase winding with set 1 spanning 60 degrees electrical from set II having common magnetic structure. Multi-phase induction motor finds its application in electric aircraft, electric ship propulsion, electric vehicles

Advantages of multi-phase induction motors

• Enhanced system reliability.

• Reduced rotor harmonics current losses.

• Lowering the DC link current harmonics.

• Reduced torque ripples.

• Reduced harmonics power losses.

• Better power distribution per phase.

• Improves the power characteristics.

• Improved power efficiency. Application of six phase induction motor is limited in automotive due to the non-uniform nature in loads. So here a current program-controlled DC-DC converter is developed to check the reliability of six phase induction motor in automotive. The converter is operated in a CPM with a waveform representing the un-evenness's in roads.

II.LITERATURE SURVEY

[1] M. S. Pooja Naresh Bhatt, Hemant Mehar," Electrical motors for electric vehicle a comparative study," International Conference on Recent Advances in Interdisciplinary Trends in Engineering Applications, vol. 35, 2019.

In this paper, the Electric Vehicle is a vehicle controlled by an electric motor and is run utilizing the power put away in the batteries. Electric Vehicle was fabricated soon after the first DC power motor was introduced and consequently has longer history than a great many people figure it out. Pertaining to the growing innovation in Electric Vehicle system, it has turned out to be critical to get a far-reaching comprehension of the criteria connected in determination of electric motors. It is observed that the use of electric motor has been varied from manufacture to manufacture. An expanding biological mindfulness and the lack of non-renewable energy source assets are solid motivations to grow progressively effective vehicles, with lower fuel utilization however without lessening driving solace indicate references by Thanh Anh Huynh et Al, 2018. Hence, various types of electric motors are currently utilized depending upon the power requirement. **In this paper,** authors provide a comparison of the most popular classes of electric motors being used over the period of time in context with the efficiency, power density, reliability, and size.

[2] K. R. E. P. Usha Sharma, Abhishek Panchal, "An overview of electric vehicle concept and its evolution," International Research Journal of Engineering and Technology, no. 12, Dec 2018.

In this paper, Agrowing concern in today's world is environmental protection and energy conservation. Automotive manufacturers are developing alternatives to existing fossil fuel-driven vehicles. This has paved way for the development of Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV). **In this paper**an overview of basic concept of electric vehicle is explained. Also explained the all-possible types of eclectic vehicle such as (1) Plug-in Hybrid Electric Vehicle, (2) Battery Electric Vehicle, (3) Fuel Cell Electric Vehicle and (4) Hybrid Electric Vehicle. At last, we explained the brief evolution of electric vehicle.

[3] S. Li, "A review of electric motor drives for applications in electric and hybrid vehicles," March. 2017.

This paper reviews several types of electric motor drives and their features in applications for electric vehicles (EV) and hybrid electric vehicles (HEV). The main driving forces for researching and producing EVs and HEVs are fast depletion of fossil fuels and deteriorating atmospheric conditions. Currently, with rapid development of power electronic devices and improved material quality, high performance electric machines employing induction motor (IM), permanent magnet (PM) motor, switched reluctance motor (SRM) or other novel motor design have been intensively researched. Various HEV/EVs have already been manufactured incorporating these motors to compete the conventional internal combustion engine (ICE) vehicles in the automotive market. In this paper, basic configurations for EVs and HEVs are introduced. Then the discussion of diverse types of electric motors including DC, IM, PM, SRM, and SynRM machines is presented. Moreover, future trend of EVs as well as electric machine developments are also envisaged.

[4] M. L. F. A. Baltatanu, "Multiphase machines used in electric vehicles propulsion," International Conference on Electronics, Computers and Artificial Intelligence (ECAI), pp. 1–6, 2013.

The paper presents the modelling and simulations of an induction motor with 3 and 5 phases. Multi-phase (more than three-phase) motor drive systems have attracted much attention in recent years due to some inherent advantages which they offer when compared to the three-phase counterpart. Presently the grid power available is only limited to three-phase so the supply to multi-phase motors is invariably given from power electronic converters. For applications operating with electric cars, multiphase system could satisfy potential demand for electric drive systems of power, which are both robust and energy efficient.

III.PROPOSED SYSTEM

a) System description

The complete system representing the test set up to check the reliability of six phase IM can be figured as follows. It consists of a three-phase supply which is converted in to six phase supplies by the special connection of transformers. The six-phase supply is given to the SPIM. A DC generator is mechanically coupled with the induction motor. And a current programmed converter emulating the road load profile is connected as the load to the generator system.

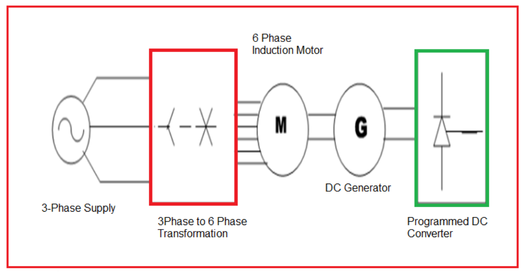

Fig. 1: Block diagram representation of complete system

b) 3φ to 6φ Transformer

Multi phase induction motor requires multi-phase electric supply. So, six phase power supply is required for SPIM. A special connection of a single three phase transformer or three single phase transformers can be used for this particular purpose. Here three identical single-phase transformers with a centre tap at the secondary of transformers is used. For each single-phase transformer there are three windings, one primary winding and two secondary windings. The primary windings of the three single-phase transformers can be connected in star or in delta connection. In secondary winding of the transformers, each half is considered as a separate single phase. The circuit diagram representation of the windings of this special transformer connection scheme is shown in Figure 2.

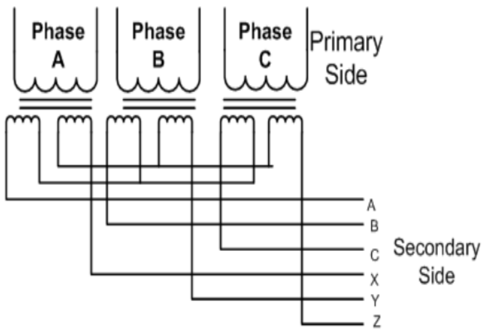

Fig. 2: Special transformer connection for six phase voltage system

In primary windings which is star connected, the star point is developed by connecting one end of each single-phase transformer and star point in secondary is produced by connecting the centre-point of each secondary windings i.e., centre tap connection of the secondary windings. Half windings of the secondary connection of each single-phase transformers produces 180-degree phase shifted voltage phasors. So ‘A’ phase and ‘X’phase of six phase supply is obtained from the secondary of the first transformer. Similarly, ‘C’ phase and ‘F’phase is obtained from secondary of second transformer and output phase ‘Y’ and ‘B’ is formed from third transformer connections. The output voltage magnitude is decided by turns ratio of the winding of the single-phase transformers. The primary windings can also be connected in delta configuration. The secondary side voltage will be 30-degree phase displaced when comparing with the primary side voltage. The two voltages at the secondary of each single-phase transformers are 180-degree phase displaced and it can be used to form two phases of six-phase voltage output. In this way, six-phase outputs are produced which are equal in magnitude and 60-degree phase shifted [6].

c)Six Phase Induction Motor

In a multi-phase induction motor,more than three windings are fitted in a same stator. There by the motor per phase Current is reduced. To begin with, an m-phase symmetrical induction machine, such that the spatial displacement between any two consecutive stator phases equals

$$a = 2n/m \quad \textbf{(1)}$$

is considered. Stator winding is considered as m-phase and the sinusoidal distribution of windings are assumed, hence every higher spatial harmonic of the mmfis neglected. The number of phases which is denoted by m can either be odd or even. When m is six, two 3-phase windings are there, which are displaced by 60° in symmetrical fashion. So there arise magnetic circulating current a problem. To eliminate this problem an asymmetrical fashion is designed in which the 3-phase windings are phase shifted by 30°, so that we can eliminate (6n +1) order harmonics, where n= 1,3,5........... A 6-phase electric machine is formed by dividing the phase belt of 60° in to equal half sections which are spanned by 30° each. By split belt connection the winding distribution factor become 1 for 6-phase machine which is about 0.965 for 3- phase connection. The stator slot number is an important factor during the design of stator. General expression for stator slots number is given by

$$S_s = m/2.p[2+K] \quad (2)$$

d)Current Programmed DC -DC Converter

The Current Programmed DC-DC converter can be used to emulate the road load profile. When a wave form representing the road load is given to the converter, it will work in such a way that the input current will follow exactly the same waveform that given. The converter here used is conventional boost converter which integrated with self-lift Sepicconverter [9].

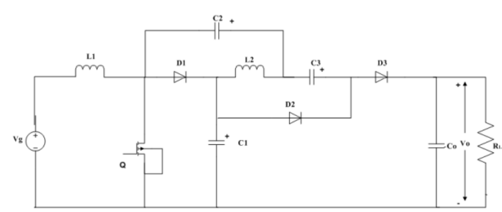

Fig.3: Circuit Diagram of Boost-Sepic DC-DC Converter

IV.CURRENT PROGRAMMED CONTROL

In conventional DC-DC converter the output is controlled by controlling the duty ratio of the switch. In CPM, converter output is controlled by choice of the peak transistor switch current. The control input signal is a current signal. The control network switches the transistor ON and OFF such that peak of the transistor current follows the control input. Duty cycle is not directly controlled but depends on control input, inductor currents, capacitor voltage and input voltage. The current programmed control block diagram is shown in figure 4.

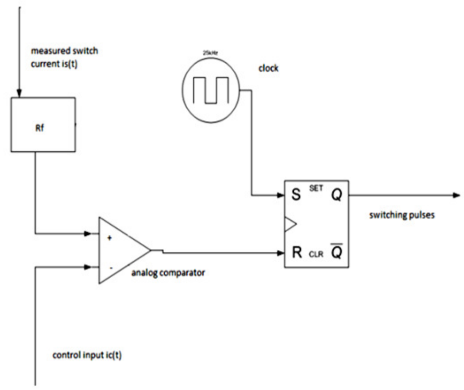

Fig. 4: current programmed control

V.SIMULATION RESULTS

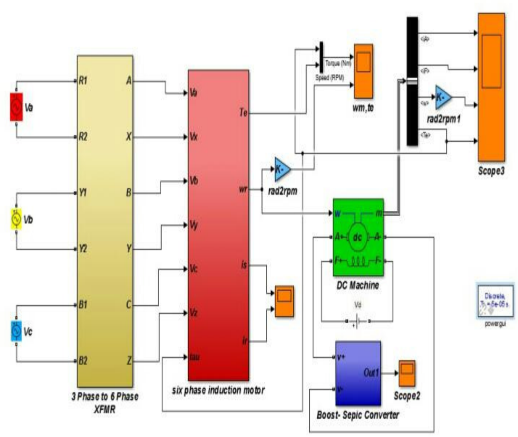

Fig .5 Simulation diagram of the system

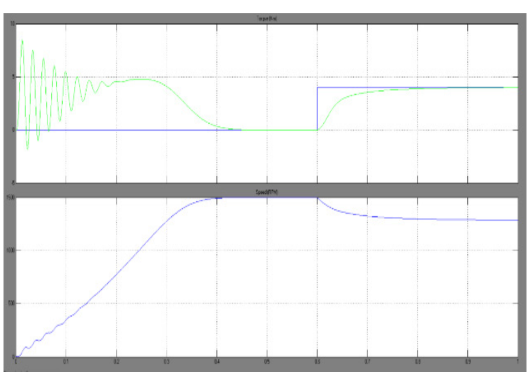

Fig. 6: Torque and Speed waveforms of SPIM

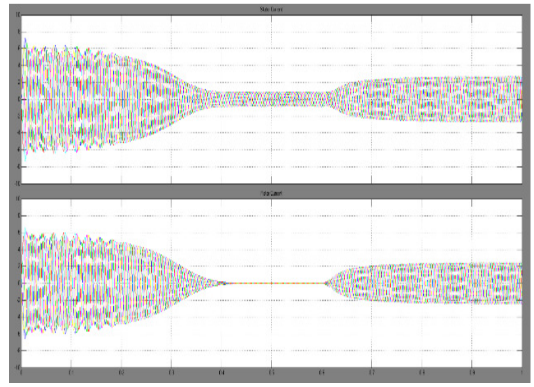

Fig. 7: Stator and Rotor current waveforms of the system

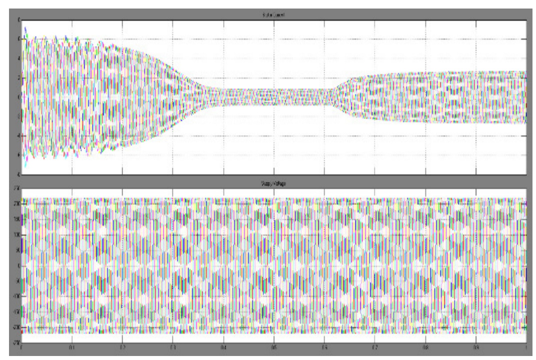

Fig 8: Stator current and Six phase voltage waveform

For the reference waveform of amplitude 3, the motor torque and speed waveform follow the same and maximum value of torque is 0.4Nm and speed is reduced to 1480rpm. For the reference waveform of amplitude 10, the motor torque is about 1.5Nm and speed is approximately 1450rpm and both the waveform follows the reference waveform. For an amplitude of 25, motor torque is about 3.5Nm and speed reduced to 1370rpm and wave forms are almost the same waveshape.

The simulation results are not valid for an amplitude greater than 35. So up to 35A, we can conclude that the motor torque and speed waveforms follows the same wave shape of the given reference waveform. And the torque is increased and speed is reduced as the magnitude of the given wave increases.

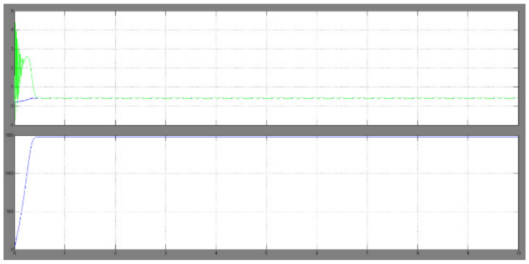

Fig. 9: Torque and Speed waveforms of SPIM: sample 1

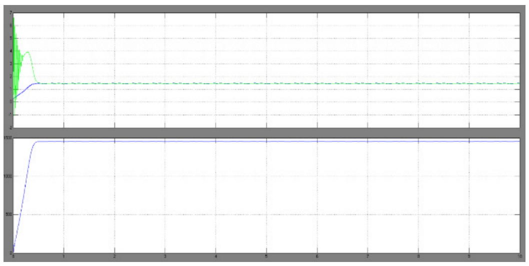

Fig.10: Torque and Speed waveforms of SPIM: sample 2

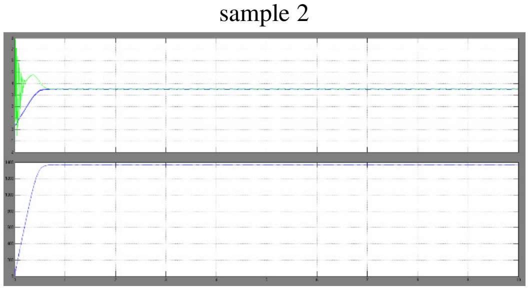

Fig. 11: Torque and Speed waveforms of SPIM: sample 3

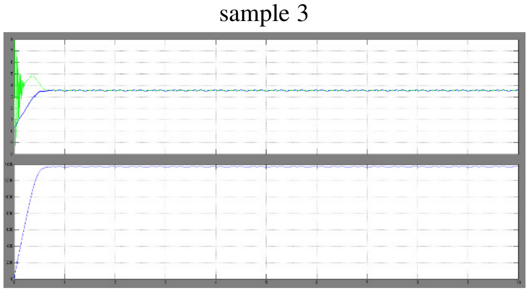

Fig. 12: Torque and Speed waveforms of SPIM: sample 4

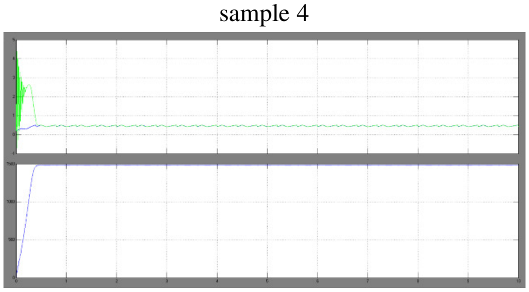

Fig.13: Torque and Speed waveforms of SPIM: sample 5

CONCLUSION

Six phase induction motor has better torque to weight ratio than conventional motors. SIM has a wide application in aircraft and submarine vehicles. Simulink model for a six-phase induction motor is developed and simulated and different waveforms are plotted No load and blocked rotor tests are done and equivalent circuit is drawn for the same. Current programmed control is designed and simulated and input current is following the reference waveform as desired. The entire test setup representing the test model of SPIM for automotive developed and simulated. Hardware set up for current controlled boost-sepic converter is implemented and tested the same for the designed voltage. From the simulation results it is found that, the motor torque and speed is varying instantaneously as the reference waveform given. As the magnitude of the reference waveform increases, the torque of the motor also increases and speed of the motor decreases. The road-profile representing the roadload in highways is almost smooth and steady, so the motor torque and speed in such cases having less ripple. The roadprofile representing the road-load in village and remote places are very rough and unpredictable, so in such cases motor torque and speed having high ripple. From the above analysis it is found that six phase induction motor can be used in electric vehicle which has almost uniform road load. In village roads and un-even road SPIM are not preferred. Simulation results are valid to reference waveforms having maximum magnitude of 35A. In future this project can be extended by developing additional equipment's to make the SPIM suited to any road profiles.

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