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Integrated Inverter/Converter Control circuit of a 30kW Interior Permanent Magnet Synchronous Motor Used in Electric Vehicles

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Abstract:-- **The pollution of environment is increasing due a very large numbers of conventional cars present today. To reduce pollution the electric hybrid electric vehicle are very beneficial. As the era of cheap fuel is also coming to an end the hybrid electric or electric vehicle is a good alternative to the conventional cars. In the paper, the optimization design and analysis of a 30kW interior permanent magnet synchronous motor (IPMSM) used in electric vehicles are fulfilled by finite element analysis (FEA). In order to satisfy good control performances, low cost and high reliability ,Simulation and experimental verification of the prototype are compared deeply, and the final comparison results indicate the prototype essentially satisfies the design In this project the survey of Electric car is done, also a new design of integrated circuit of inverter/converter is introduced to increase the efficiency of the hybrid electric cars & comparison of this technique with other control methods for HEV/EVs is being done. In this system it is given that at starting we need high starting torque for HEVs so we will use two PMSM (permanent magnet synchronous motor) motor feeding by two distinct Inverters sources. After staring we need high acceleration so we will use one of the Inverter & PMSM motor set as a DC-DC boost converter to assist other Inverter to increase the DC link voltage of that inverter to increase the output voltage & power. This integrated circuit allows the Permanent magnet synchronous motor (PMSM) to operate in motor mode or acts as a boost inductor of a boost converter, thereby boosting the output torque coupled to the same transmission system. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type converter, while using the motor windings as the boost inductors to boost the converter output voltage. Therefore, the proposed integrated circuit can significantly reduce the volume and weight of the system.**

Keywords: **Permanent magnet synchronous motor (PMSM), Hybrid electric vehicle (HEV), Boost converter.**

I. INTRODUCTION

Based on the research of the electric buses background, in this paper, the author designs a 30kW IPMSM; the electromagnetic design methods and the choice of permanent magnet rotor structure will be analyzed; the optimal design of the IPMSM is carried out by the FEA using Magnet electromagnetic field software ,the optimal analysis of the structure parameter and the inherent parameter of the IPMSM prototype is detailed to simulate; finally, a prototype experiments were conducted.

In urban area, due to their beneficial effect on environment, electric and hybrid electric vehicles are an important factor for improvement of traffic and more particular for a healthier environment as electric vehicles are zero emission vehicles, as we are quite rapidly reaching to the end of the cheap oil era. Electric and electric hybrid vehicles are offering the best possible chances for the use of new energy sources, because electricity can result a transformation with high efficiency of these sources and is always used with the highest possible efficiency in systems with electric drives or components. The integrated inverter convert control circuit is used to boost the torque coupled to same transmission and also has the ability to increase the dc link voltage of inverter circuit. This helps in increasing the efficiency of the electric or hybrid electric vehicle.

II. TYPES OF ELECTRIC VEHICLES

I. Plug in Electric vehicle

Plug in electric vehicle has the simplest construction of all it has components such as battery, converter, motor, gear system as show in fig.1 Battery is used to store energy, which is converted to in to dc or ac according the drive used to drive the vehicle. The motor may be asynchronous motor i.e. induction motor, dc motor, brushless dc motor synchronous motor in which permanent

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magnet synchronous motor has very good efficiency. It is also possible to place more than one motor for splitting the torque. The motors are placed in wheel hubs. But in this case, each motor needs a separate converter with speed and torque control, which guarantees the necessary torque splitting in each condition. An electric vehicle is an emission free, environmental friendly vehicle. However, the electric vehicles remain unpopular among the consumers due to their lack of performance and their inability to travel long distances without being recharged. So, vehicle that embraces both the performance characteristics of the conventional automobile and the zero-emission characteristics of the electric vehicles are greatly being anticipated by the general consumers and the environmentalists alike.

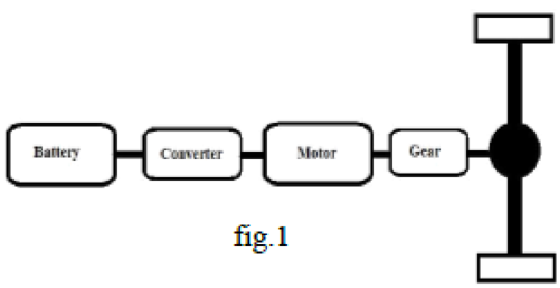

Fig.1

1. Hybrid Electric Vehicle (HEV)

The electric vehicle with an additional energy source such as internal combustion engine, or a group of fuel cells is called as hybrid electric vehicle where both electrical and other energy system are integrated together to drive the vehicle. Hybrid electric vehicles powered by electric machines and an internal combustion engine are a promising means of reducing emissions and fuel consumption without compromising vehicle functionality and driving performances. Leading car manufacturers like Toyota and Honda have already started mass producing Hybrid electric cars, Prius and Insight respectively, which are now becoming very popular among the consumers for their incredible mileage and less emissions. Aside from that, a number of automotive manufacturers are marketing hybrid vehicles for the general population, examples are Daimler Chrysler, Mitsubishi, Nissan, Fiat, Renault, Ford, GM, and Subaru.

TYPES OF HEV

1. Series HEV

In series HEV configuration, only the electric motor is connected to the drive train and thus the vehicle is entirely driven by the electric motor. The Internal Combustion (IC) engine drives an electric generator (commonly known as alternator), which then supplies the electric power to the motor and battery pack. The IC engine turns off if the battery is fully charged. In some cases, the electric power supply for the electric motor can come both from the battery and the engine generator set. As only the electric motor is connected to the drive train, the IC engine can run at an optimum speed to run the generator thus greatly reducing the emissions. The batteries can either be charged off-board, by external DC power link from the electric-grid, or on-board, with the help of an alternator and an IC engine.

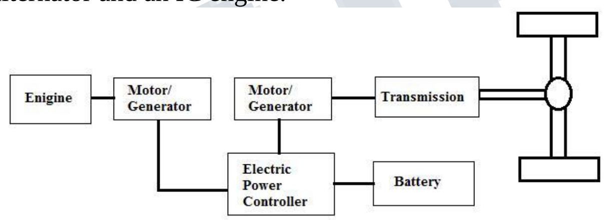

Fig.2

The fig.2 shows the schematic diagram of series HEV. It consist of IC engine, motor generator set electric power controller to control the power flow in circuit battery to store the energy further the transmission system also.

Advantages of Series HEV:-

1. Engine runs more efficiently as not directly coupled to transmission drive & maintains the constant output.
2. Low emission of gases as efficiency of engine increases.
3. Flexibility of location of engine & motor set.
4. Good stability for short trips.

Disadvantages of Series HEV

1. HEV requires full size motor as it drives the vehicle, thus the generator & engine also needs to be of full size.
2. As vehicle is totally driven by motor the battery size required will be more as continuous energy will be required by motor.
3. All the equipment's such as IC engine & generator must have good output efficiency as for long distancebatteries will soon exhausted & all the power will have to supply by the engine generator set.

2. Parallel HEV

In the parallel HEV configuration there are two power paths for the drive train, while one comes from the engine the other comes from the electric motor. During short trips the electric motor can power the vehicle, while during long drives the IC engine can power the vehicle. The vehicle can thus have engine only, motor only, or a combination of engine and motor mode of operation. The electric motor can also assist the engine during hill climbs and vehicle accelerations, thus the rating of the IC engine can be reduced.

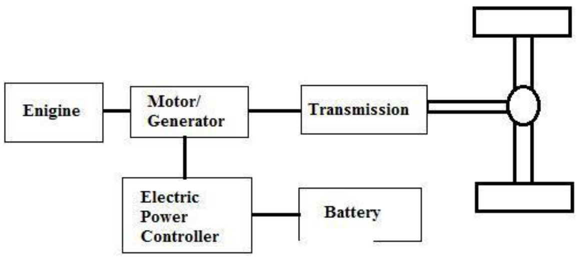

Fig.3

The fig.3 shows the schematic diagram of Parallel HEV. It consists of IC engine, motor, electric power controller to control the power flow in circuit battery to store the energy. These types of HEV do not require generators and they can be connected to an electric grid for recharging the batteries.

Advantages of Parallel HEV:-

1. The battery size can be small, as both the engine and motor are connected to the drive train.
2. The performance is very good as compared to conventional vehicles as dual power sources are present.
3. Constraints on battery packs are relaxed in this configurations.

Disadvantages of Series HEV:-

1. HEV cannot get full acceleration power when battery is low.
2. Control becomes complex as mechanical power is supplied by motor & engine in parallel.
3. To synchronize the power coming from motor & the engine necessitates the complex mechanical device.

3. Dual mode HEV (Series-Parallel mode)

Dual mode hybrid vehicles are parallel hybrids, but differ from them in the aspect, that an alternator (generator) is coupled to the IC engine that charges the battery. During normal operation, the IC engine turns both the drive train and the generator, which in turn feeds the battery pack through the electronic control unit. During full-throttle acceleration, the electric motor gets power from the battery and assists the IC engine to attain the requested acceleration. Choosing a full size electric motor, which uses the IC engine only for charging the battery and occasionally for turning the wheels, can reduce tail pipe emissions and this can be achieved with the help of a mechanical clutch. This configuration exhibits dual capability and hence the name dual mode HEV configuration.

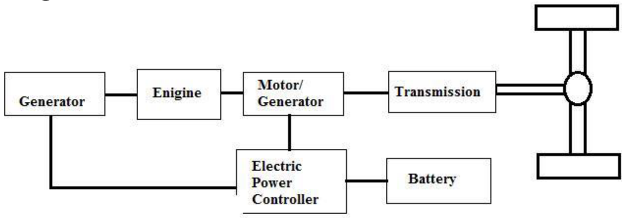

Fig.4

The fig.4 shows the schematic diagram of Dual mode HEV. It has only disadvantage that,it needs more components such as an electric motor, an electric generator, an IC engine and a battery pack, for its operation which makes it more expensive.

Barriers In Hybrid Electric Vehicles

Three important barriers include the high cost and cycle life of batteries, complications of chargers, and the lack of charging infrastructure. Another drawback is that batteries chargers can produce deleterious harmonic effects on electric utility distribution systems & thus increases the ripple in current & also reduces the efficiency this can be reduce using the integrated inverter/converter circuit & control technique of motor dive with dual mode operation. There are few more issues in Hybrid cars which are listed below:-

Currently more expensive than conventional

Heavier than conventional, due to battery pack and electric motors weight.
Limited battery life.
Low torques for hill climbing.
Expensive battery packs if you want to replace it.
Safety issues, high voltage battery and fuel.
Reliability, still under study.
More complex computer controlled systems.
May have drivability issues.
Needs heavy duty power plug terminal (high current) everywhere: home, parking and street with metering device.
Electric energy infrastructure (generation, transmission and distribution) must be expanded to provide extra energy for this type of cars.

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Travels short distances, inner city
Low speed.
Battery charging takes time.
Need new regulatory standards.

So as to increase the efficiency, a new integrated circuit for motor drives with dual mode control is proposed. The proposed integrated circuit allows the permanent magnet synchronous motor to operate in motor mode or acts as boost inductors of the boost converter, and thereby boosting the output torque coupled to the same transmission system or dc-link voltage of the inverter connected to the output of the integrated circuit. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type boost converter, while using the motor windings as the boost inductors to boost the converter output voltage.

III. SCOPE OF WORK & CONCLUSION

A new integrated inverter/converter circuit & a control technique for motor drive with dual mode operation is selected where the integrated circuit allows the permanent magnet synchronous motor to operate in motor mode or acts as boost inductors of the boost converter, and thereby boosting the output torque coupled to the same transmission system or dc-link voltage of the inverter connected to the output of the integrated circuit. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type boost converter, while using the motor windings as the boost inductors to boost the converter output voltage. The control technique for the integrated circuit increases the efficiency of the converter.

Old Techniques

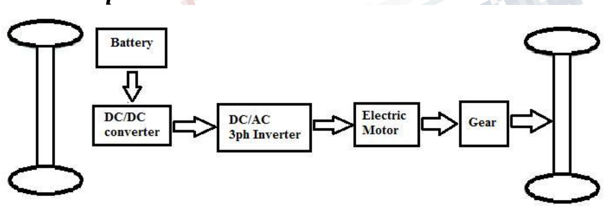
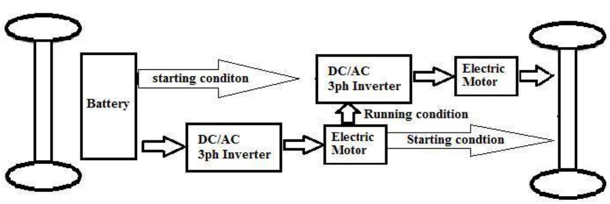


Fig .5 shows use of converter also for boosting of dc link voltage for a Electric vehicle.[1]

New Techniques



As in Fig.6 a new technique is shown which is a integrated circuit for motor drive with dual mode control this integrated circuit allows the Permanent magnet synchronous motor (PMSM) to operate in motor mode or acts as a boost inductor of a boost converter, & thereby boosting the output torque coupled to the same transmission system or dc-link voltage of an inverter connected to the output of the integrated circuit. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type boost converter, while using the motor windings as the boost inductors to boost the converter output voltage. Therefore, the proposed integrated circuit can significantly reduce the volume and weight of the system. The circuit shown Fig.7 can act as an inverter & a boost converter depending upon the mode of operation. For the integrated circuit, it not only can reduce the volume and weight but also boost torque and dc-link voltage for motor/ converter modes, respectively. Moreover, a new control technique for the proposed integrated circuit under boost converter mode is proposed to increase the efficiency.

Table I
Technichal Specifications of The Prototype

Parameters	Unit	Specifications
Rated power	KW	30
Peak power	kW	70
Power supply voltage (DC)	V	307
Rated speed	rpm	2500
Maximum speed	rpm	6000
Rated torque	Nm	115
Peak torque	Nm	240
Phase number		3

Conventional Circuits

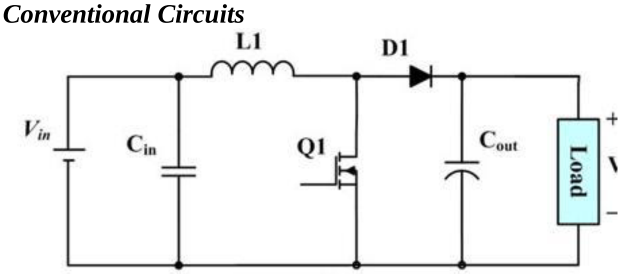


Fig.7 shows a single phase boost converter has been widely used for boost control due to its simplicity. However, for higher power applications, an interleaved

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boost converter can reduce the current ripple and components stress and thereby reducing the losses and thermal stress.

The single phase interleaved boost converter Based upon the interleaved control idea, a boost-control technique using motor windings as boost inductors for the proposed integrated circuit will be proposed. Under light load, the integrated circuit acts as a single phase boost converter for not invoking additional switching and conduction losses, and functions as the two-phase interleaved boost converter under heavy load to significantly reduce the current ripple and thereby reducing the losses and thermal stress. Therefore, the proposed control technique for the proposed integrated circuit under boost converter mode can increase the efficiency.

New Circuit Designs

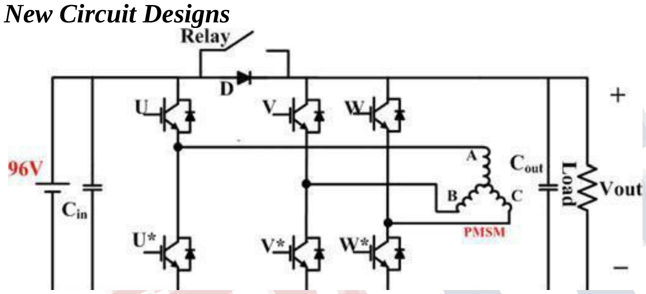


Fig 8 shows the integrated circuit for dual-mode control In Cin and Cout can stabilize the voltage when input and output voltages are disturbed by source and load, respectively. Diode (D) is used for preventing output voltage impact on the input side. When the integrated circuit is operated in inverter (motor) mode, relay will be turned ON and six power devices are controlled by pulse width modulation (PWM) control signals. When the proposed integrated circuit is operated in the converter mode, relay is turned OFF. And a single-phase or interleaved control method will be applied to control of the power devices depending upon the load conditions.

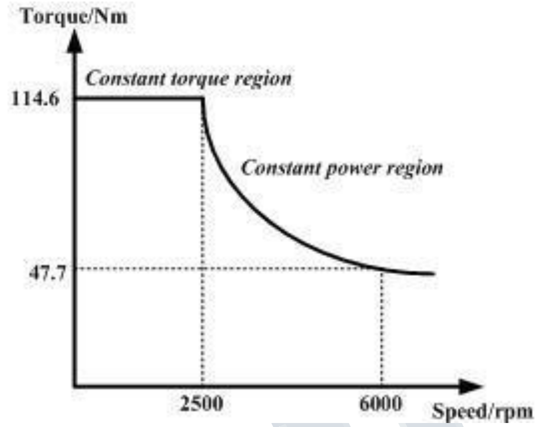
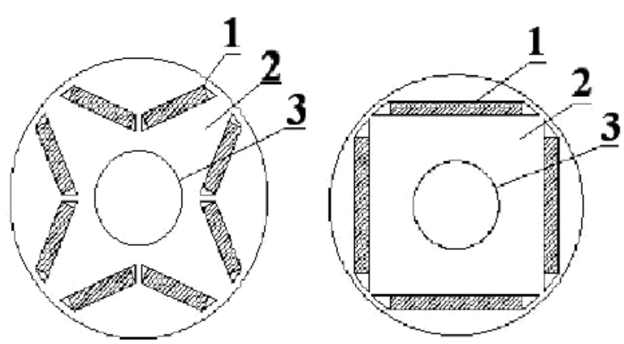


Fig.9. Torque versus speed curve of the 30kW IPMSM

In order to keep the long-time high efficient operation, the 30kW IPMSM is designed for a rated operating point at a corner speed. Rated power of the motor is 30kW, and its rated output torque is114.6Nm at 2500 rpm. Corner speed is 2500 rpm, and constant power speed range is from 2500 to 6000 rpm. The characteristics shows the torque versus speed curve of the 30kW IPMSM in different operation mode.

A. IPMSM Structure

It is very important to choose the appropriate rotor structure for the IPMSM design. In this paper, the 30kW IPMSM rotor structure choose the V type because V type of rotor structure can increase permanent magnet excitation dosage effectively than the traditional straight type rotor structure (fig.10 (b)), the different rotor structures of IPMSM are shown in Fig.10.The determination of stator structure refer to the stator structure of the same power grade asynchronous motor. In this paper, the stator structure is the type of parallel tooth 36 slots uniform distribution, and the stator windings adopt the double layer distribution winding type.



(a) V type (b) traditional straight type

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1. permanent magnet 2. rotor core 3. shaft Fig. 9.Rotor structures of IPMSM
Fig.10. Preliminary design structures of the 30kW IPMSM

In order to satisfy the characteristics requirements of the IPMSM design, the stator structure will be optimized in the basis of the original 2 and 4 design structures, the length of yoke is increased, and the angle of V type PM will be increased to 133°, the PM width reduce 0.4 mm, the width of PM is 37.3mm, and the PM thickness remains the 8mm, and the air-gap length is increased to 0.6mm. Finally, the final optimization design structure of the 30kW IPMSM is shown in the fig.11.

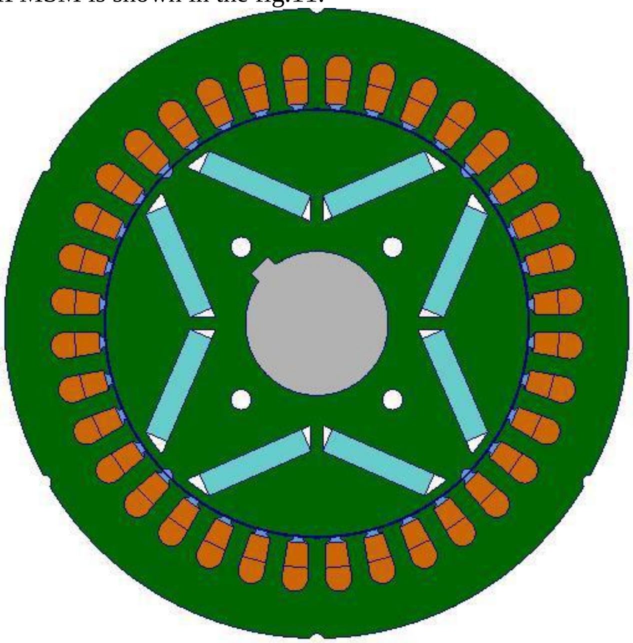

Fig. 11.The final design structure of the 30kW IPMSM

Through the finite element simulation analysis, the flux distribution of the final design structure at rated speed is shown in fig,6.From the simulation results analysis, the average air-gap flux density value of the final design structure is 0.54T,the tooth average flux density is 1.5T, the yoke average flux density is 1.7T, the yoke average flux density is not saturate. All the changes present.

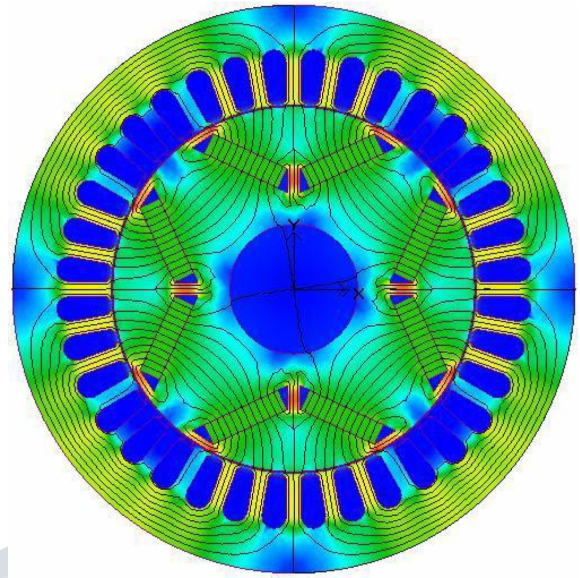

Fig.12. Plots of flux line and flux density of preliminary design structures the results of the optimization is desired.

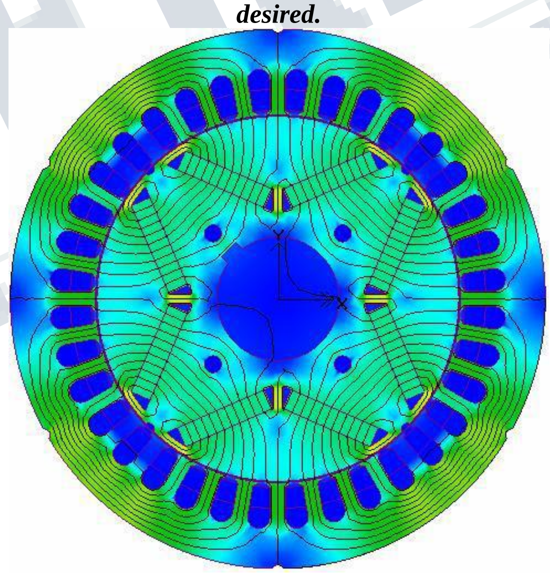

Fig.13. Plots of flux line and flux density of the final design structure

Although the average air-gap flux density of the 2 and 4 design structures reach 0.5 T or so, but the yoke average flux density are very high, the values are 1.85T

III. PERFORMANCE ANALYSIS

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In this paper, the final design structure of 30kW IPMSM parameters is analyzed by finite element analysis (FEA). The performances were shown as follow:

A. Cogging torque and no load back-EMF

According to the control characteristic requirements of the IPMSM, the cogging torque of IPMSM should be as small as possible, and cogging torque is an oscillatory toque, which occurs even when there is no current in the stator. The waveform of cogging torque with time of the 30kW IPMSM at rated speed of 2500 rpm is shown in Fig.13.

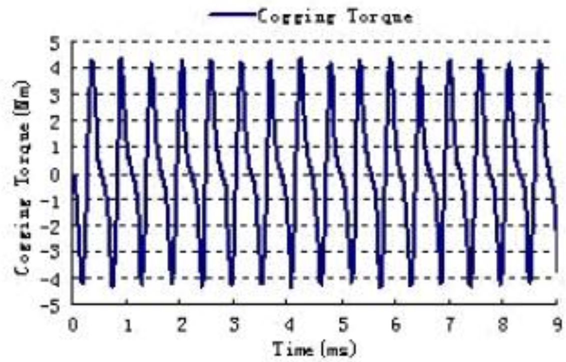

Fig.13. The waveform of cogging torque of the 30kW IPMSM

From the fig.13, It can be seen that the value of cogging torque is 4.12Nm of the IPMSM, and the cogging torque of the 30kW IPMSM is 3.03% ratio of the rated load torque.

IV. EXPERIMENTAL RESULTS

In this paper, the experiments of the 30kW IPMSM prototype is carried, the experimental platform for prototype is shown in fig.14.

Fig.14. Experimental Platform for 30kW IPMSM Prototype

According to the no load experimental results, the no load back-EMF waveform is illustrated in the Fig.14.Contrasting the simulation results and the experimental results of the no load back-EMF, it can be seen that the simulation results and the test results agree well.

V. CONCLUSION

In this paper, a 30kW IPMSM used in electric vehicle was designed and analyzed. Firstly, the optimization design for the different structures of the 30kW IPMSM were simulated by FEA; and the performances in details of the final design structure 30kW IPMSM were analyzed. Finally, the experiments of the 30kW IPMSM prototypes were made, the experimental results of the prototypes show that the designed 30kW IPMSM not only have the lowest magnet mass, but also a wider range of constant power speed operation and excellent flux–weakening performance. What is more, the cogging torque and harmonic distortion of no load back–EMF are smallest. Therefore, the good performances of the optimization design 30kW IPMSM can satisfy completely the characteristic requirements for electric vehicle applications.

Acknowledgment

This work is supported by the General Project of National Natural Science Foundation of China (51177135), and the Key Project of Natural Science Foundation of Shaanxi Province (2011GZ013). performance of the motor, as the same time, the holes will be helpful for increasing heat dissipation condition and improving the long-time operation stability of IPMSM.

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