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Simulation For Axial Flux Permanent Magnet Motor Drive

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Abstract— The Axial Flux BLDC motors are relatively new, especially at higher power ratings over 10kW. Therefore the designers face a lot of difficulties in designing and optimizing the motor for a given application. The brushless DC motors are permanent magnet motors where the functions of commutator and brushes were implemented by solid state switches. The brushless DC motors are distinguished not only by the high efficiency but also by their no maintenance. The permanent magnet motor used in this case is a three phase motor. When operating with poly phase motor, the inverter plays the role of the commutator. In this paper three-phase inverter is considered. The objective of the project is to analyze the performances of the Axial Flux Permanent Motor(AFPM) BLDC motor with three-phase winding. To study the motor operation, a mathematical dynamic model will be proposed, which became the basis for simulations that will performed using MATLAB/SIMULINK software package.
Keywords- *PWM,BLDC, inverter,hall sensors*

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I. NOMENCLATURE

a) e_A , e_B , e_C - Back emf of Axial flux PM motor

b) T_l - Load torque

c) T_{em} - Electromagnetic torque

d) i_A , i_B , i_C - Source current of a, b ,c phases

e) R_A , R_B , R_C - Resistances of the phase winding

f) L_A , L_B , L_C - Inductance of the phase winding

g) V_{SA}, V_{SB}, V_{SC} - Inverter phase voltage

h) ω_m - Angular speed of machine

II. INTRODUCTION

Environmental concern and legislative pressure are leading to significant interest in electrical and hybrid vehicles.Many different drive topologies are under consideration including traditional brush type dc motor and ac topologies such an induction, permanent magnet synchronous and reluctance drives. The availability of high speed, low cost MOSFET's and IGBT's has lowered converter cost sufficiently so that cost of ac drives compare favorably with dc system. While offering reliability reasons, many electric vehicles in thedevelopment stage are using induction motor technology. Brushless permanent magnet machines offer the advantage of high power density, reduced weight and higher efficiency giving longer ranges for a given battery size.

There are different types of AFPM, they are differentiated based on application, methodology, and construction. AFPM motors can be designed as double sided or single sided machines, with orwithout armature slots, with internal or external rotors and with surface mounted or interior type permanent magnets (PMs). Low power AFPM machines are usually machines with slot less windings and the surface mounted PMs. Rotors are embedded in power transmission components to optimize the volume, mass, power transfer and assembly time .Double-sided motor with internal PM disc rotor has the armature windings located on the two stator cores. The disc with the PM rotates between the two stators. [1].PMs are embedded or glued in a non-ferromagnetic rotor skeleton. When the stators are connected in parallel the motor can operate even when one stator windings break down. The stator cores are wounded from electro technical steel strips and the slots are machined by shaping or planning [3, 4].

Several axial-flux machine configurations can be found regarding the stator(s) position with respect to the rotor(s) positions and the winding arrangementsgiving freedoms to select the most suitable machine structure into theconsidered application. Another common type of AFPM motor is torus type motor which has found numerous applications, particular, in gearless drives for electrical vehicles. The stator however has slotless core and the Gramme' s type winding. The stator core is made of laminated iron. The rotor's discs are made of solid iron contain the high energy permanent magnets glued to their surfaces.

In Brushless DC motors, instead of mechanical commutators there is an electronic commutator which is implemented by solid state switches. The controller performs the same power distribution found in brushless DC motor without using a brush commutation system. Because the Controller must follow the rotor, the controller needs some means of determining rotor positions. To determine the rotor position two different methods are used sensor based control and sensor less control.

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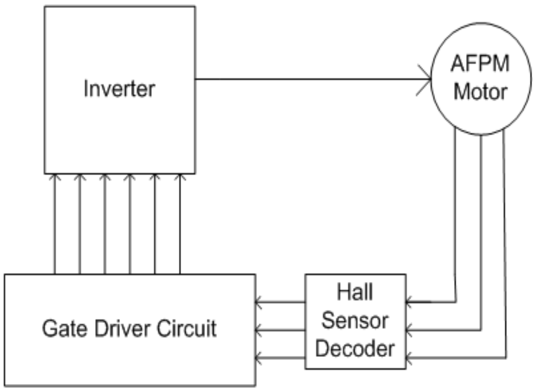

Figure 1.Block Diagram of Control Scheme

In our paper we are going to use sensor based method, in this method a Hall sensor is used which detects the position of rotor magnet which is used to give excitation to the appropriate stator winding.

III. Dyanmic Model Of AFPM

The AFPM motor is connected to the output of the inverter, while the inverter input terminals are connected to a constant supply voltage, as was shown in Figure.1. The equivalent circuit model that refers to this circuit diagram is shown in Figure2. Another assumption is that there are no power losses in the inverter and the 3-phase motor winding is connected in star.

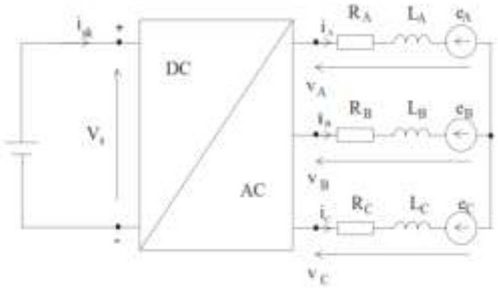

Figure 2. Equivalent circuit of 3-phase PM BLDC motor

The equivalent circuit shown in Figure 2 can be represented by the circuit diagram in Figure. 3. The equations that govern this model are as follows

$$V_A = V_N + V_{SA} \; V_B = V_N + V_{SB}$$
$$V_C = V_N + V_{SC} \qquad (1)$$

V_{SA}, V_{SB}, V_{SC} are the inverter output voltages that supply the 3 – phase winding.

V_A, V_B, V_C are the voltages across the motor armature winding.

V_N – Voltage at the neutral point.

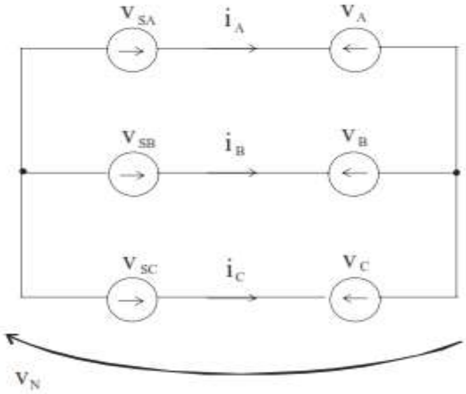

Figure 3. Schematic representation of equation 1

For a symmetrical winding and balanced system, the voltage equation across the motor Winding is as follows:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} R_A & 0 & 0 \\ 0 & R_B & 0 \\ 0 & 0 & R_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_A & L_{AB} & L_{AC} \\ L_{BA} & L_B & L_{BC} \\ L_{CA} & L_{CB} & L_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \qquad (2)$$

$$V_A = R_A * i_A + \frac{d}{dt} L_A * i_A + e_A \qquad (3)$$

Since $R_A = R_B = R_C = R_A$, the resistance takes the following vector form:

$$R = \begin{bmatrix} R_A & 0 & 0 \\ 0 & R_B & 0 \\ 0 & 0 & R_C \end{bmatrix} \qquad (4)$$

As for the inductances, since the self and mutual inductances are constant for surface mounted permanent magnets on the cylindrical rotor and the winding is symmetrical, the inductance takes the form

$$L = \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \qquad (5)$$

Voltage takes the following form

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} R_A & 0 & 0 \\ 0 & R_B & 0 \\ 0 & 0 & R_C \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_S & 0 & 0 \\ 0 & L_S & 0 \\ 0 & 0 & L_S \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \qquad (6)$$

The electromagnetic torque for this 3-phase motor is dependent on the current (*i*), Speed and electromotive force (e). The equation is:

$$T_{em} = \frac{e_A i_A}{\omega_m} + \frac{e_B i_B}{\omega_m} + \frac{e_C i_C}{\omega_m} = K(fa(\theta_e) * i_A + fb(\theta_e) * i_B + fc(\theta_e) * i_C) \qquad (7)$$

IV. Logic BehindHall Sensor Signals

Hall sensors identify the position of the rotor magnet and generate a particular sequence. Based on this sequence, a controller generates an output to operate the switches (T1-T6).Depending on the output sequence a particular combination of switches are fired. The Scheme is shown as below figure.4

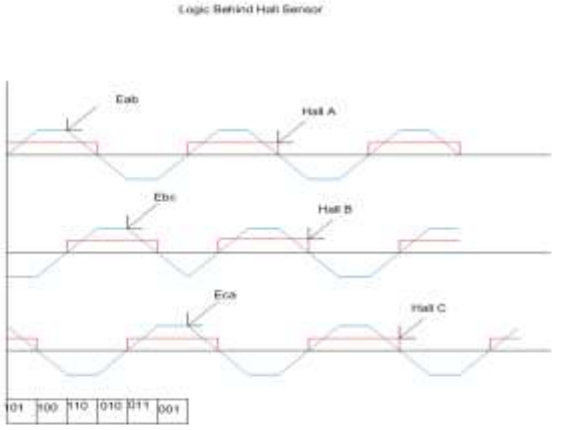

Figure 4. Hall sensor Signals Generating particular Sequence

V. SimulationStudy

The simulation of the AFPM motor was done using the software package MATLAB/SIMULINK. For this purpose, the PM synchronous motor taken with trapezoidal waveform from MATLAB library, asshown in Figure 5.

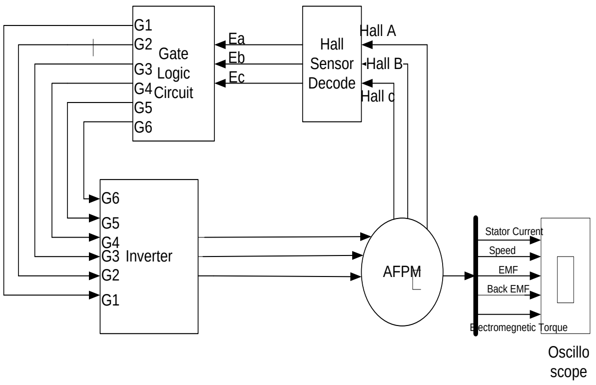

Figure.5 Basic Simulink Model of AFPM

The inverter is fed from the voltage source of 325V DC and the motor loaded with a rated torque of 1.5 N·M and then change to 2N-M after 1 sec. Phase R voltage is a square wave of 312.5V DC. The current waveform is distorted and having shape in between square wave and sine wave. The electromagnetic torque depends on phase currents, constant K, speed and electromotive force.

In this the three phase Y connection winding with six switches is employed in this motor. Hall sensors identify the position of the rotor magnet and generate a particular sequence. Based on this sequence, a controller generates an output to operate the switches (T1-T6).Depending on the output sequence a particular combination of switches are fired .In this scheme two phases are exited, one with positive by entering the current and second with negative by leaving the current and third winding is in non-energized state. Torque is produced by the interaction of magnetic fields produced by the stator fields and permanent magnets, the torque is maximum when the flux is 90 degree to each other and starts decreasing as the fields moving parallel, in order to keep the motor running, the magnetic field produced by the winding should change position, as the rotor moves to catch up with the stator fields.

A. Hall Sensor Decoder

In this the hall sensor signals are decoded as per the signal generated by the machine. These signals are derived from the EMF of the machine.

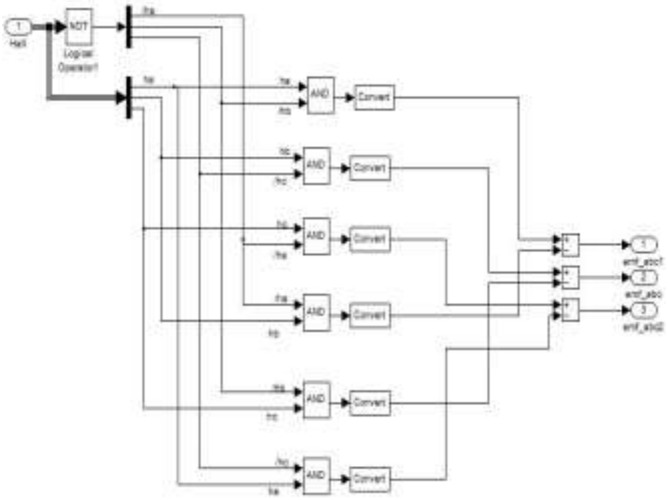

Figure 6. Simluink Model of Hall Sensor Decoder

B. Gate Logic Circuit

Based on the hall sensor decoder circuit, gate logic circuit generates 6 pulses to control the switches from T1 to T6.In this special care should be taken that not both switch of same leg should be on at any time.

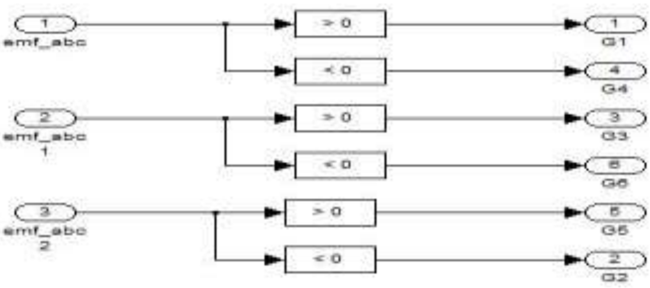

Figure 7. Simluink Model of Gate Logic Circuit

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VI. Simulation Results

In the simulation results different models are simulated on different operating condition.

1) Free Acceleration Condition
2) Step Change in load condition

A.Free Acceleration period

In this period we analyzed the model based on speed, electromagnetic torque and source current

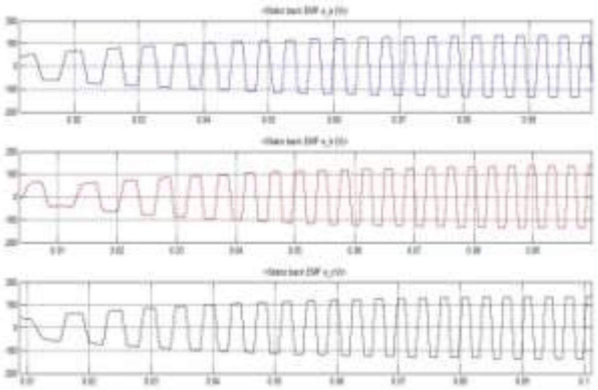

Figure.8 Simulation Results of EMF

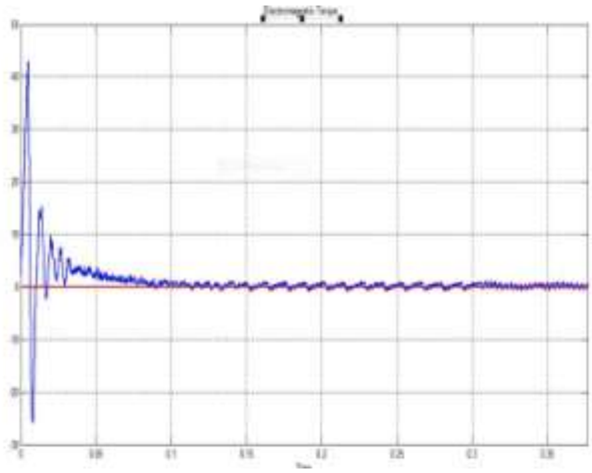

Figure.9 Simulation Results for Electromagnetic Torque

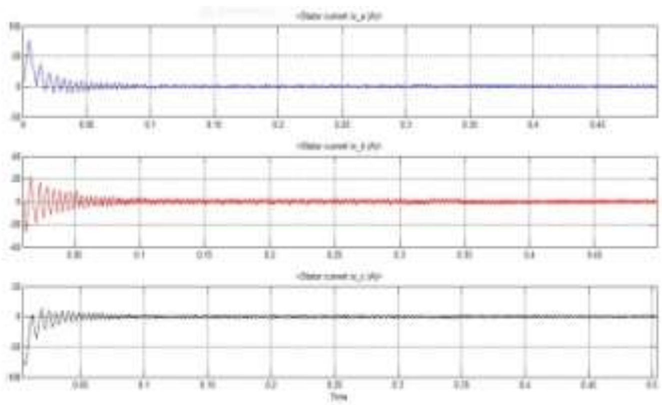

Figure.10 Simulation Results for Source currents for phase A, phase B, phase C

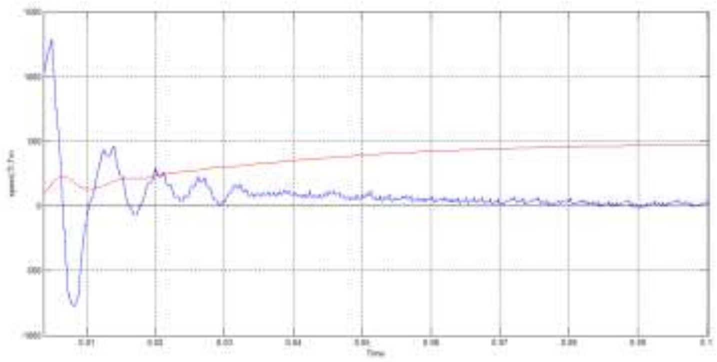

Figure.11Simulation Results for Speed, T_l , T_m

B.Step Change in Load Condition

After analyzing the motor performances in free acceleration period, we analyzed the performances on load basis. In this we observed that as the load changes the speed decrease and electromagnetic torque decreases, also we see some variation in others waveforms as we suddenly apply the load to the motor.

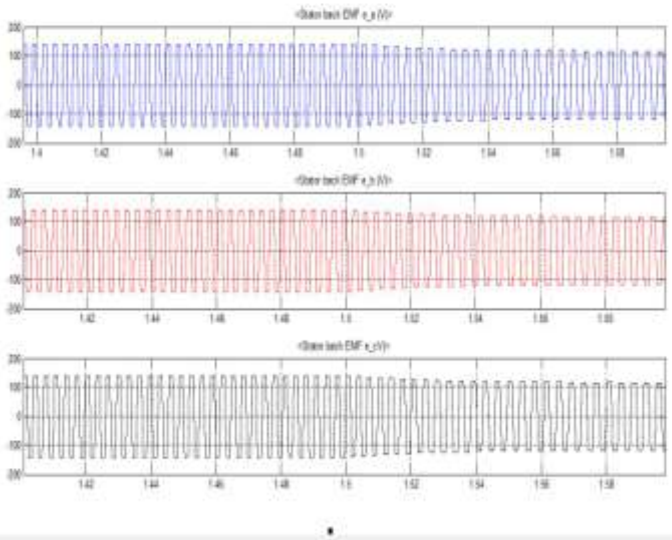

Figure.12 Simulation Results of EMF on load conditions

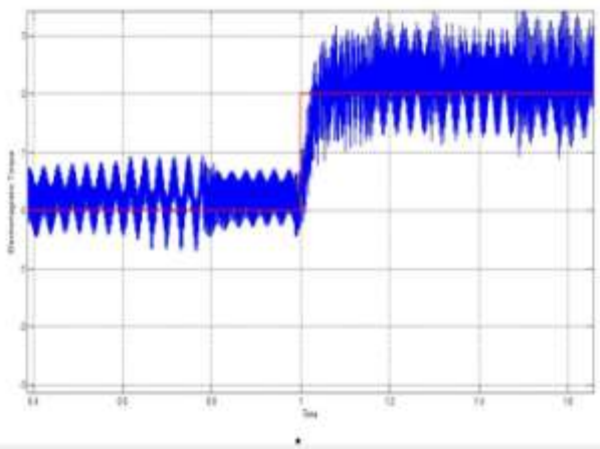

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Figure.13 Simulation Results for Electromagnetic Torque on Load

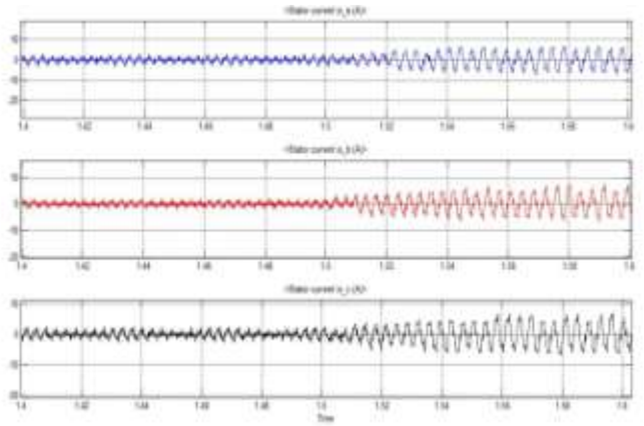

Figure.14 Simulation Results for Source currents for phase A, phase B, phase C on change in load condition

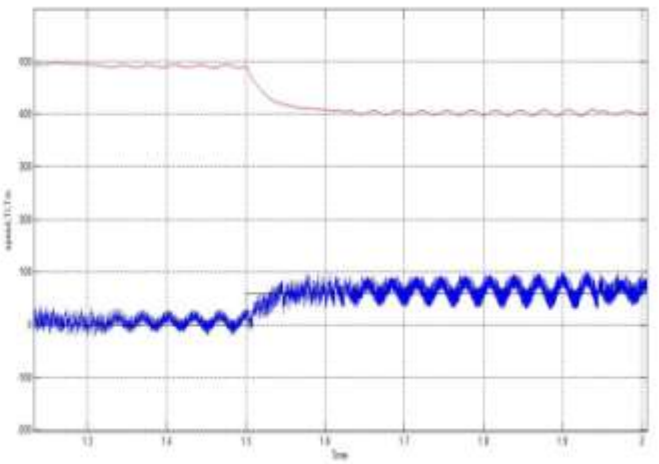

Figure.15Simulation Results for Speed, T_l and T_m on load Condition

VII. Appendix

Supply Volatge-325V
Stator resistance-0.18 ohms
Stator phase inductance-8.5e-3 H
Flux linkage-0.712 vs
Torque constant-0.5716Nm/A

VIII. Conclusion

In this paper mathematical model of AFPM is presented detailed focus on the simulation of AFPM gives an idea about the behaviour of motor and gives the information how machines will responds for a particular application. In this paper different waveforms of motor is studied.

The simulation also gives the idea about the design of controller. In future, based on the simulation work we will design a controller for open loop control or speed.

References

[1] W. N. Fu and S. L. Ho, "A novel axial-flux electric machine for in-wheel gearless drive in plug-in hybrid electric vehicles," *14th Biennial IEEE Conference on Electromagnetic Field Computation (CEFC.), 2010., p. 1, May 2010.*

[2] J. W. K. K. Jayasundara and D. A. I. Munindradasa, "Design of Multi Phase In-Wheel Axial Flux Permanent Magnet Motor for Electric Vehicles," *First International Conference on Industrial and Information Systems, pp. 510–512, Aug. 2006.*

[3] Y. Duan and R. G. Harley, "Present and future trends in wind turbine generator designs," *IEEE Power Electronics and Machines in Wind Applications, 2009. PEMWA 2009, pp.* 1–6, 2009.

[4] R. L. Ficheux, F. Caricchi, F. Crescimbini, and O. Honorati, "Axial-flux permanent magnet motor for direct-drive elevator systems without machine room," *IEEE Transactions on Industry Applications*, vol. 37, no.6, pp. 1693–1701,2001.

[5] K. M. Rahman, N. R. Patel, T. G. Ward, J. M. Nagashima, F. Caricchi, and F. Crescimbini,"Application of Direct-Drive Wheel Motor for Fuel Cell Electric and Hybrid Electric Vehicle ***12 13*** Propulsion System," *IEEE Transactions on Industry Applications, vol. 42, no. 5, pp. 1185–1192,2*