POWER MANAGEMENT IN PM BLDC MOTOR DRIVEN ELECTRIC VEHICLE FED FROM HYBRID ENERGY STORAGE SYSTEM

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by

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CERTIFICATE

This is to certify that the dissertation titled **“Power Management in PM BLDC Motor Driven Electric Vehicle fed from Hybrid Energy Storage System"**, being submitted by **Mr. Phaneendra Babu Bobba** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy, is a record of bonafide research work carried out by him under my guidance and supervision.

Mr. Phaneendra Babu Bobba has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results obtained herein have not been submitted in part or in full to any other University or Institute for the award of any degree.

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ABSTRACT

Environmental pollution and energy crisis issues gave a big boost to the development of the electrical vehicles called green vehicles or battery driven vehicles has became an alternative choice for automotive industry compared to hybrid electric vehicles. In present days due to improvements in battery technology and motor technology, electrical vehicles are becoming more and more popular and governments of advanced and certain developing countries are giving subsidies to develop the electrical vehicle technology**.**

In electric vehicles, the challenges are to achieve high efficiency, ruggedness, and compactness and economical power converters and electrical machines, as well as associated electronics. The ideal characteristics of an electric motor drive used in fully electric and hybrid electric vehicle should satisfy the conditions like high torque at low speed region for fast acceleration and in hill climbing, and low torque at high speed for normal driving. Permanent magnet brushless DC motor is very efficient, compact and has good reliability and ease of control. This motor finds applications generally in two and three-wheelers electric vehicles. The bottleneck for the development of electric vehicle technology is the energy source. At present, the viable electric vehicle energy sources are batteries, fuel cells, ultra-capacitors and ultrahigh-speed flywheels. Batteries are relatively the most economical source for electric vehicle application. They offer either high specific energy or high specific power but not both. A high specific energy source is favorable for long driving range, whereas a high specific power source is desirable for high acceleration rate and high hill climbing capability. Ultra-capacitors are having high specific power and low time constant compared to any other energy source available for electric vehicle application. Since regenerative braking requires very fast response in recovering

energy, the combination of batteries and ultra-capacitors are ideal for electric vehicles.

The electric power source for most of the two and three-wheeler electric vehicles are batteries. As the power storage capacities of batteries are limited, these electric vehicles suffer from the problem of short range. In urban driving and hilly-terrain area driving, significant amount of energy is consumed in braking. It is possible to recover this energy lost in braking by employing regenerative braking in electric vehicles. This recovered energy can be used to increase the range of the vehicle, thereby improving the system performance and reducing the size of the system as well as the overall cost of the system.

In this thesis, permanent magnet brushless DC motor driven electric vehicle fed from hybrid energy storage system is designed and simulated. The operation of this motor in motoring mode with various control strategies, and in regenerative braking mode in three different braking methods have been simulated using the SIMULINK/MATLAB platform for the considered electric vehicle application. Factors like recovered energy, braking current, braking power are compared. Depending upon the results obtained from these simulations, it is suggested that a variable switch regenerative braking technique can be used to optimize the braking performance. By using variable switch regenerative braking technique, properties of all the three simulated braking methods can be utilized depending on the vehicle speed. All these simulated braking methods need not require any extra components or devices for this regenerative braking operation. Existing hall sensors positions are used to generate switching pulses to the inverter in both motoring and braking modes.

Hybrid Energy storage system is designed based on battery and ultra-capacitor in active combination. Active combination efficiently uses the properties of battery and ultra-capacitor. So as to facilitate the sharing of power among the two different sources, initially a bi-directional buck-boost converter based power management system is designed and developed specifically for lower power applications meant for two-wheeler electric vehicle. A simple controller is developed based on heuristic approach to share power between and battery and ultra-capacitor. Later on, a multiport converter based power management system for medium power electric vehicle such as three-wheelers have been designed and simulated. The designed three port converter takes power from both the sources simultaneously and shares it optimally to meet the load demand. Many simulation results are obtained and analyzed to show the power sharing and power management capability of designed converters under variation in load power demand & variation in available power in the basic source. The converter control is such that, it shares power from the two sources in a way that the battery gives constant power and the remaining power from or to the auxiliary power source, i.e. the ultra-capacitor. The hardware set-up for the electric vehicle in both the motoring and braking has been developed. Powder dynamometer test setup is used to feed the load characteristics of electric vehicle. Control algorithms have been implemented in hardware by using the TMS320F2812 DSP processor for the PM BLDC drive.

TABLE OF CONTENTS

Page No.

List of Figures

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols and abbreviations used in the thesis are defined at appropriate places.

However for easy reference, a list of symbols and abbreviations is given below:

ADC	Analog to digital converter
AES	Auxiliary energy storage
CCM	Continuous conduction mode
DCM	Discontinuous conduction mode
DOD	Depth of discharge
DSP	Digital signal processor
ECU	Electronic control unit
EDLC	Electric double layer capacitor
EMS	Energy management system
EVs	Electric vehicles
HESS	Hybrid energy storage system
HF	High frequency
HSP	High specific power
HSE	High specific energy
ICE	Internal combustion engine
MMF	Magneto motive force
MI	Multi-input
NNSMC	Neural network based sliding mode controller
Nd-Fe-B	Neodymium-Iron-Boran
PID	Proportional, integral and derivative controller
PI	Proportional and integral

PM BLDC	Permanent magnet brushless dc motor
PMSM	Permanent magnet synchronous motor
PV	Photo-voltaic
PWM	Pulse width modulation
SC	Supercapacitor
SOC	State of charge
TI	Texas Instruments
VSI	Voltage source inverter
C	Battery capacity
I	Discharge current
M	Mutual inductance
M	Mass
Q	Battery charge
T_e	Developed torque
ω	Angular rotor speed
T_L	Load torque
$\mathrm{W_r}$	Regenerative energy
$\mathrm{W_b}$	Battery energy
e_a, e_b and e_c	Balanced three phase back-EMFs
$\mathrm{e_{ab}}$,, $\mathrm{e_{bc}}$ and $\mathrm{e_{ca}}$	Balanced three line back-EMFs
i_a, i_b and i_c	Balanced three phase stator currents
I_p	Peak value of the phase currents
K_v	Back-EMF constant
$\mathrm{R_{EPR}}$	Parallel resistance
$\mathrm{R_{ESR}}$	Series Resistance

ω_e	Electrical rotor speed
θ_e	Rotor position
t	Time
T_e	Developed electromagnetic torque
F_{rl}	Road load
F_{rr}	Rolling resistance
F_{rw}	aerodynamic drag
F_{rc}	climbing resistance
δ	Rotational inertia coefficient
F_t	Tractive effort
η_t, η_m	Efficiency of transmission, Mechanical efficiency
ρ_a	Rotational Inertia Factor
C_d	Aerodynamic drag coefficient
A_f	Vehicle Frontal Area
V_{ucmid}	The intermediate voltage
$V_{uc\min}$	The minimum operating voltage
I_{cm}	DC-DC converter current capability
$V_{uc\min}$	Minimum operating voltage
r	Tire radius
ρ	Air density