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FACULTY OF ENGINEERING

Electrical Power and Machines Engineering

Combined power supply system and attitude control system for satellites

A Thesis submitted in partial fulfilment of the requirements of the degree of Master of Science in Electrical Engineering

(Electrical Power and Machines Engineering)

by

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Statement

This thesis is submitted as a partial fulfilment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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List of **Abbreviations**

ACFS : Attitude Control Flight Software
ACS : Attitude Control System
AOCE : Attitude Orbit Control Electronics
BMS : Battery Management System
CEACS : Combined Energy and Atitude Control System
CPACS : Combined Power and Attitude Control System
CR : Contractor Report
CMG : Control Moment Gyro
DTC : Direct Torque Cotrol
DC : Direct Current
EPS : Electrical Power Subsystem
FDIR : Fault Detection Isolation and Recovery
FES : Flywheel Energy Storage
FOC : Field-Oriented Control
GEO : Geostationary Orbit
GNN : Guidance Navigation and Control
GPS : Global Positioning System
GRC : Glenn Research Center
HEO : Highly Elliptical Orbit
HWIL : Hardware In the Loop
IPACS : Integrated Power and Attitude Control System
ISS : International Space Station
LCO : Lithium Cobalt Oxide
LEO : Low Earth Orbit
LMO : Lithium Manganese Oxide
MEO : Medium Earth Orbit
PMSM : Permanent Magnet Synchronous Motor
PSS : Power Supply System
PPSS : Primary Power Supply System
PTC : Positive Thermal Coefficient
PV : Photovoltaic
RTG : Radioisotope Thermal Generators
SA : Solar Array

List of **Symbols**

I^{*}_{charge}	Commanded charge current (A)
I_{DC}	DC bus cureent (A)
I_{Load}	Load current (A)
$I_{flywheel}$	Flywheel current (A)
i_{inv}	Flywheel inverter current (A)
$I_{s/a}$	Solar array current (A)
i^{r}_{dS}	Rotor d-axis current (A)
i^{r}_{qs}	Rotor q-axis current (A)
J	Rotor polar moment of inertia (kg • m2).
J_0	The total inertia of mechanical plant (Kg. m^2)
L_d	d-axis inductance (H).
L_d	q-axis inductance (H).
P	Number of poles
p_{ele}	Flywheel electrical power (W)
p_{inv}	Flywheel inverter power (W)
p_{mech}	Flywheel mechanical power (W)
T_d	Disturbance torque (N.m)
T_e	Electromagnetic torque (N • m)
V_{DC}	Voltage of DC bus (V)
λ_{af}	Rotor magnet flux linkage (V.s)
ω_r	Speed of rotor (rad/sec.)
$\omega_{r,mech}$	Mechanical rotor speed (rad/s)
$\omega_{r,elec}$	Electrical rotor speed (rad/s)
θ	The rotation angle of the air table (deg.)
Variable *	Commanded value of variable

Abstract

Flywheel power systems are now seen as a technology that can be used in various applications, including low-earth space satellite orbits, pulse transmission for hybrid electric vehicles and many other applications. In consideration of the energy storage feature, a flywheel device has great advantages over chemical batteries for Low Earth Orbit (LEO) satellites: lifespan, density of power, short charge time, wide operational temperature band, and deep depth of discharge. Flywheel systems have significant advantages over chemical batteries also it can be used to control the spacecraft attitude. The combination of energy and attitude control is a reasonable solution to improve space missions for satellites. Double counter-rotating flywheels mounted on an air table are introduced in this thesis to execute the control system of combined power and single axis attitude control. The system control technique of integrated power and attitude control could be implemented based either on a speed control mode or on a torque control mode. The control algorithm's method is field orientation control. This method offers the flywheel motor / generator with precise and high bandwidth torque control by controlling rotor reference frame currents that are dc in steady-state. The Permanent magnet synchronous motor/generator is controlled by the direction of the field. The current rotational frame of the d-axis is ordered to zero and the q-axis current component changes to maintain the required dc bus level and commanded attitude angle. MATLAB Simulink was used to model the combined power and single-axis attitude control system using two similar flywheels. Furthermore, different cases and different modes of operation are presented which showed that flywheels behavior changed according to different operation.