AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRICAL POWER AND MACHINES DEPARTMENT

Modeling and Control of PV – Battery Hybrid System

A thesis is submitted in partial fulfillment of the requirement of the M.Sc. in Electrical Power and Machines Engineering

by

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B.Sc. in Electrical power & Machine Department
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II. Statement

This thesis is submitted as partial fulfillment of M.Sc. degree in Electrical Power and Machines 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 degree or qualification at any other scientific entity.

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III. Abstract

The Electrical Power Subsystem (EPS) is significantly essential element for satellite. It gives the required power to the spacecraft to achieve its role. After the spacecraft demands have been found out, the EPS will be picked out. The satellites in Low Earth Orbit (LEO) are very fast and able to revolve Earth in about 100 minutes, these intervals are divided into two parts; two-third in light and one-third in dark. In other words, about 66 minutes in sunlight period and 34 minutes in eclipse period. Since the Sun is the only renewable energy source available in space and it has immense amount of solar energy, therefore, the photovoltaic (PV) has considerably the most widespread usage for space application. However, PV system needs another secondary storage system to be relied on it when PV system cannot generate adequate power.

The Chemical Battery (CB) is considered the most realistic choice for energy storage because its mechanism is well-known. In the last decade, Lithium-Ion Battery proved its performance and efficiency in space application and that led to be massively popular usage as rechargeable secondary power supply. It has long charge and discharge cycles, bulk energy density, high cell voltage, besides that, it has miscellaneous types. Recently, Ultracapacitor (UC) is used for space application and it has got space qualified license. It seems like being promising in spacecraft application especially in deep space exploratory / interplanetary application as it has extremely long number of cycles, speedy charging, and huge specific power.

This thesis focuses on designing, simulating the satellite power sources just after distinguishing the loads for each subsystem. Using primary source with auxiliary source as a complementary source so that the EPS can electrify the satellite's subsystems under any circumstances during the entire lifetime interval. PV is selected to be the primary source and it should carry out two duties; it supplies the subsystems with electric power during sunlight intervals and charges the auxiliary power source when it has extra power after supplying the loads. Lithium-Ion Battery (LIB) and / or Lithium-Ion Capacitor (LIC) are / is selected to be rechargeable secondary storage source and they have / it has to supply the loads during off light (eclipse) intervals. Software programs like Matlab and Satellite Tool Kit (STK) are used to establishing the mathematical model of satellite power sources. Then, after each design phase, there are a set of tests are executed to ensure power subsystem performance and capability. At first, the power system will implement PV – LIB hybrid power source. Then PV – LIC hybrid power system is implemented. Then, the system PV – LIB besides LIC hybrid secondary sources is executed. finally, a comparison between them including the pros and cons for each designed system is presented.

Keywords: Satellite, Photovoltaic, storage system, Lithium-ion battery, Ultracapacitor, Lithium-ion capacitor

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VIII. List of Nomenclature

i. Abbreviations

AOCS	Attitude and Orbit Control System
BCS	Body Coordinate System
BoL	Beginning of Life
CB	Chemical Battery
CdTe	Cadmium Telluride
CuInGaSe	Copper Indium Gallium Diselenide
DoD	Depth of Discharge
ECI	Earth Centered Inertial
ECEF	Earth-Centered Earth-Fixed
EDLC	Electric Double Layer Capacitor
EoL	End of Life
EPS	Electrical Power Subsystem
ESR	Equivalent Series Resistance
EMI	Electromagnetic Interference
GaAs	Gallium Arsenide
GCS	Ground Control Station
Ge	Germanium
GEO	Geosynchronous Orbit
GMSS	Global Mobile Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEO	High Earth Orbit
ICO	Intermediate Circular Orbit
LAN	Longitude of Ascending Node
LEO	Low Earth Orbit
LIB	lithium-ion battery
LIC	lithium-ion capacitor
Li-ion	Lithium-Ion
MEO	Medium Earth Orbit
MPPT	Maximum Power Point Tracking
NiCd	Nickel Cadmium
NiH_2	Nickel Hydrogen
OBC	On-Board Computer
OCS	Local Orbital Coordinate System
PCDU	Power Conditioning and Distribution Unit
PG	Power Generation
PV	Photovoltaic
RAAN	Right Ascension of Ascending Node
RTG	Radioisotope Thermoelectric Generator
Si	Silicon
TCR	Telemetry, Command, and Ranging
TMTC	Telemetry And Telecommand
TTC	Tracking, Telemetry, and Command
UC	Ultracapacitor
UPS	Uninterrupted Power Supply