Ain Shams University
Faculty of Engineering

Optimal Design and Management of Photovoltaic and Energy Storage Systems

By

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A Thesis Submitted in partial fulfillment of the Requirement of the Degree of Master of Sciences in Electrical Power Engineering

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Cairo 2018

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Statement

This dissertation is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Sciences in Electrical Engineering.

The work included in the thesis was carried out by the author at the department of Electrical Power and Machines, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Acknowledgement

I would like to thank **Prof. Dr. Almoataz Youssef Abdelaziz,** one of the two thesis supervisors, for the valuable help in seeing this thesis through to successful completion. Prof. Almoataz has always shown professionalism, dedication and enthusiasm. I am grateful for having had the opportunity to study and to work under his supervision. I would like to thank him for suggesting the research topic, helpful advices, patience, encouragement, reviewing the drafts of the thesis and the time he offered me during supervision.

Also, I would like to thank **Dr. Nabil Mohamed Hamed**, the other thesis supervisor, for the guidance and advices during the research and for his continuous patience in reviewing the drafts during the preparation of this thesis.

Thanks, are also extended to the members of the examiners committee, **Prof. Dr. Mohamed A. Badr and Prof. Dr. Ashraf Mohammed Hemaida**, for their guidance and valuable advices.

To my father, mother, sisters, wife and daughter thanks a lot for your continuous support and encouragement during the research period have meant a lot to me. I could have not done this thesis without you.

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Abstract

This thesis presents the Optimal Design and Management of Photovoltaic and Energy Storage Systems. As the renewable energy has become one of the best replacement for oil energy and the non-sustainable energy. Among all renewable energy sources. Solar energy has been selected for its benefits. Solar energy increased in the generation level for the utilities level, but in residential level it is still in the growth phase. The consumers have the right to hesitate about using the solar energy due to the lack of studies that prove its profitability and minimize the total annual cost.
So, this thesis tries to find the optimal solution to cover the average of residential load through three optimization techniques:

- Cuckoo Search (CS)
- Mixed integer linear programming (MILP)
- Particle swarm optimization (PSO)

The system used two types of batteries which supply the load when the sun sets. The two selected batteries are:

- Absorbed Glass Mat (AGM)
- Lithium Ferro Phosphate (LFP)

The result of applying each method with each type of batteries for the residential load and Cairo, Egypt irradiance data shows that:
The system with AGM battery, MILP optimization method has the least total annual Cost. While the system with LFP battery using CS optimization techniques has the least total annual cost. But still the system with AGM battery is better than the system used LFP battery.

Keywords: Photovoltaic, Energy Storage, Optimization, Cuckoo search, Mixed linear integer programming, particle swarm.

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List of Abbreviations

CS	Cuckoo Search
MILP	Mixed integer linear programming
PSO	Particle swarm optimization
AGM	Absorbed Glass Mat
LFP	Lithium Ferro Phosphate
PV	Photovoltaic
CSA	Cuckoo search algorithm
EGS	Enhanced geothermal systems
CSP	Concentrated Solar Power
STC	Standard Test Condition
RE	Renewable Energy
NiMH	Nickel–metal hydride
Ah	Ampere Hours
DC	Direct Current
AC	Alternating current
PWM	Pulse width modulation
MPPT	Maximum power point tracking
MIP	mixed-integer programming
TAC	Total Annual Cost
$\boldsymbol{C_{ipv}}$	total initial cost of PV
$\boldsymbol{c_{ipv}}$	the initial cost of PV per m^2
$\boldsymbol{A_{pv}}$	the total Area of PV
$\boldsymbol{C_{opv}}$	the total operating cost of PV

c_{opv}	the operating cost of PV per m^2
e	Escalation rate
i	interest rate
N	the system life time (25 years)
C_{spv}	the total salvage value of the PV
c_{spv}	the salvage value of PV per m^2
f	Inflation rate
C_{iB}	the total initial cost of battery
c_{iB}	the initial cost of Battery per KW
PB	Battery capacity
nb	the number of battery replacement over lifetime
NB	the life span of storage battery
c_{OB}	the total operating & maintenance cost of Battery per KW
c_{OB}	the operating & maintenance cost of battery per KW
C_{inv}	the total initial cost of the inverter
c_{iinv}	the initial cost of inverter per KW
p_{inv}	the needed inverter power
C_{cont}	the total initial cost of charger controller
c_{icont}	the initial cost of charger controller per KW
p_{cont}	the needed charge controller power
I_C	the total Initial cost of the system
O_C	the total operating cost of the system
S_V	the Salvage Value
B	Budget
$P_{B\ Max\ cap}$	Battery maximum power

$\mathbf{N_{pvs}}$	Photovoltaic panels in series connection
$\mathbf{V_{oc}}$	Photovoltaic panel open circuit voltage
$\mathbf{V_{con}}$	Charger controller voltage
P_{PVSTC}	the max power STC of the PV
N_{pv}	total number of PV modules
P_{ctrl}	max output power of the charger controller
N_{ctrl}	total number of charger controller
SAM	System Advisor Model
NERL	National Renewable Energy Laboratory
KW	Kilowatts