DESIGN AND CONTROL ASPECTS FOR SOLAR PHOTOVOLTAIC SYSTEMS

By

Mohamed Amin Yahia Abd El-Azeem Mohamed

A Thesis Submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

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Title of Thesis: DESIGN AND CONTROL ASPECTS FOR SOLAR PHOTOVOLTAIC SYSTEMS

Keywords: Photovoltaic, Load Patterns, Grid-Tie Inverter, Control Strategy, Net Investment

Summary: This research aims to demonstrate the importance of renewable energy systems in general and solar energy in particular, where there is a severe shortage of non-renewable energy resources from natural gas, petroleum and others. The methodology of this research including a full study of the components of the photovoltaic solar system containing the characteristics and factors to determine the design requirements of any solar system, and the restrictions on the design and operation of the system. The study focused on the design of solar energy systems connected to the electricity network with spare batteries operating as an alternative source of energy in the case of network out of service. A study w conducted on the different load patterns on which the capacity of the solar system will be built. The design and control strategy of the system was discussed with number of technical, mathematical, and software methods that aimed to achieve the best efficiency in the design, operation of the system, and to find the error percentage between each method.
The simulation of this system was carried out in two integrated parts using the PV_{syst} (6.43) package, as the technical and financial parts.
The results showed the extent climate in Egypt in the implementation of such projects, and showed decent technical efficiency of the system with some observations during some months of the year. In addition, the feasibility of economic study is acceptable with some reservations on the sale tariff of the energy to the public electricity network.

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GLOSSARY OF SYMBOLS

a-Si:	Amorphous Silicon.
A_Z:	The azimuth angle of the sun.
AC:	Alternating Current.
Ah:	Ampere Hour.
AGM:	Absorbed glass mat (Type of batteries).
AM:	Air Mass, used to define the spectrum of the sun (AM0, and AM1.5).
BBI:	Battery-Based Inverter.
BOS:	Balance of System.
BTS:	Battery Temperature Sensor.
c:	Speed of light.
CdTe:	Cadmium Telluride.
CIGS:	Copper Indium Gallium Selenide.
C_p:	The ampere-hour capacity at 1A discharge rate.
DC:	Direct Current.
DOD:	Depth of Discharge.
E_{gap}:	Band gap energy.
EEHC:	Egyptian Electricity Holding Company.
f:	Frequency of the incoming photon.
FF:	Fill Factor.
GTI:	Grid Tied Inverter.
h:	Planck Constant.
H:	The average daily irradiation on a horizontal plane at the Earth's surface.
I_λ:	Spectral Irradiance.
I_{mpp}:	Maximum Power Point Current.
I_{sc}:	Short Circuit Current.
k:	Peukert Coefficient.
K:	Boltzmann Constant.
K_T:	The clearness index.
KWh:	Kilo Watt Hour.
KWp:	Kilo Watt Peak Power.
L_C:	The collector length.
LCE:	Life Cycle Emissions.
MPPT:	Maximum Power Point Tracking.
NOCT:	Nominal Operating Cell Temperature.
P:	The profile angle of the sun.
PCC:	The point of common coupling.
PF:	The power factor.
PLL:	Phase locked loop control system.
P_g:	The utility grid power.
P_{lt}:	Long-term flicker, used to define the voltage fluctuations in a time of 2 hrs.
P_{ref}:	Reference value of the active power (Watts).
P_{st}:	Short-term flicker, used to define the voltage fluctuations in 10 min.
PF:	Power Factor.
PSH:	Peak Sun Hours.
PV:	Photovoltaic.
Q:	Reactive power (Var).

Q_{inj}:	The reactive power injection.
q:	Electron charge.
RE:	Renewable Energy.
RMS:	Root Mean Square, used to define the voltage or current of an AC wave.
S_{max}:	Maximum apparent power (VA)
SI:	Solar Irradiance.
S_C:	Spacing between solar collectors to avoid shading.
SG:	Smart Grid.
SLF:	System Losses Factor.
STC:	Standard Test Conditions.
SWE:	Staebler-Wronski Effect.
T_{cell}:	The absolute cell temperature.
TOF:	Tilt and Orientation Factor.
TSRF:	Total Solar Resource Fraction.
V_{mpp}:	Maximum Power Point Voltage.
V_n:	Nominal Voltage.
V_{oc}:	Open Circuit Voltage.
α:	The elevation angle, which describes the height of the sun.
β:	Tilt angle for the solar panel.
$\Delta u(t)$:	Voltage fluctuations as a function of time.
θ_Z:	The zenith angle of the sun.
θ_i:	The incidence angle of the sun.
θ_{RF}	The regulation factor
$\emptyset$:	The latitude of the site.
$\emptyset_i$:	The amplitude of the built-in potential.
σ:	Conductivity ranges for conductors, semiconductors, and non-conductors.
σ_Q:	The reactive voltage sensitivity.
σ_P:	The active voltage sensitivity.
ω:	The hour angle of the sun.
δ:	The declination angle.

GLOSSARY OF TERMS AND ABBREVIATIONS

Anti-Islanding: The case in which the continuity of driving power from the solar system occurs despite the power outage on the public electricity grid. Therefore, the anti-islanding protection must be done. This situation appears in the solar systems connected to the electricity grid.

C-rate: The rate at which a usage battery is discharged comparative to its maximum capacity. C-8 means that the battery will be fully discharged in 8 hours.

Depth of Discharge: DOD is the other method to specify a battery's state of charge (SOC).

Energy: The capacity to do work (Joule), and can be used to transfer charges over an electrical conductor (Current) from a power station to the commercial or residential applications.

Energy Density: The total energy stored in a system per unit mass ($\frac{J}{m3}$).

Fill Factor: The ratio of maximum available power to the product of the open-circuit voltage (V_{oc}), and the short-circuit current (I_{sc}).

Kilo Watt Peak Power: KWp value states the output power accomplished by a solar array under STC.

Load Patterns: The distribution of electric loads throughout the day in terms of use and time to deduce the value of the actual consumption.

Life Cycle: The number of complete charge/discharge cycles that the battery is capable to backup before that its original capacity drops under 80%.

Maximum Power Point Tracking: MPPT is a method used usually with PV solar systems to maximize the production power with respect to all presence conditions. The MPPT appears clearly in I-V curve.

Meteo File: The file contains all available climate and weather conditions for most of the geographical locations in PV_{syst} software program. In addition, meteo is an Italian word that means weather.

Mismatch Factor: This factor occurs due to the losses caused by the interconnection of solar modules, which do not have identical properties. PV module mismatch recognizes that manufacturing does not produce equivalent PV solar modules. I-V characteristics have little variations from module to other. PV WATTS recommends a default value of mismatch as 0.98. Also, it is one of the aspects that produce overall DC-AC de-rating factor.

Nominal Operating Cell Temperature: The NOCT is representing the temperature reached by open circuit cells in a module when the value of irradiance is equal 800 W/m^2.

P-N Junction: Related to the border between p-type and n-type material in a semiconductor device.

Power: The rate at which electric energy is transferred, and measured in watt (Joule/sec).

Power Threshold: Commonly defined as the highest average power can be endured for an hour.

Pulse Width Modulation: PWM is a procedure used in most solar charge controllers for converting the amplitude of a certain signal into a pulse width of another signal.

PV Performance Efficiency: The efficiency refers to the share of energy in the form of sunlight that can be converted thru photovoltaic into electricity. Energy transferred through the components of the solar system that cause loss of energy absorbed by the sun. The most lost components of energy and less efficient are the solar panels. The energy loss of the system as a whole is estimated at 20% to 30% depending on the configuration of the system.

Self-Discharge: A phenomenon in batteries in which inside chemical reactions decrease the stored charge of the battery without any linking between the electrodes. In other words, the battery original capacity is assumed to be 100% but after a period of time the total capacity becomes 90% due to the self-discharge which reduces the life of batteries.

Solar Irradiance: The power per unit area arrived from the sun as the electromagnetic radiations (w/m^2).

Specific Gravity: Generally, the specific gravity is the ratio of the intensity of any material to the intensity of some other standard material. For batteries, it is represented as the ratio of the density of a battery sol to the density of water.

Standard Test Conditions: STC used to conduct persistent comparisons of solar arrays by different manufacturers. The STC are known as irradiation: 1000 W/m^2, temperature: 25°C, and AM1.5.

Temperature Coefficient: This coefficient describes the relative change of a physical property that is related with a given change in temperature (dt).

Total Harmonic Distortion: The ratio of the sum of the powers of all harmonics occurred in voltage or current for a signal to the sum powers of the fundamental signal.

Transposition Factor: The ratio of the global incident irradiance on the collector, to the global horizontal irradiance.

System Voltage: The DC electrical voltage that works through the solar system as a whole. So that this voltage corresponds to the characteristics of solar panels, voltage regulators, batteries, and electrical inverter. Typically, the system voltage is 12V, 24V, or 48V.

Shading in PV Applications: An important phenomenon occurs from near objects, such as trees, buildings and nearby clouds in the sky. It has a clear and strong effect which producing major losses for the solar system, and decreases the output power of the designed system.

Active Power (P): The useful power or the working power that utilizing by loads (Watts).

Reactive Power (Q): The power consumed in an AC circuit that does not perform any useful work, but has a great effect on the phase-shift between the voltage and the current waveforms, and measured in (Var).

Apparent Power (S): The relationship between the active and reactive power (VA).

LIST OF FIGURES