Status Monitoring and Performance Evaluation of Photovoltaic Energy Systems

BY

Mohammed Adel Eldreny

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
Electrical Power and Machines Engineering

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Status Monitoring and Performance Evaluation of Photovoltaic Energy Systems

Key Words:
Grid connected PVES, Isolated PVES, Status Monitoring of PVES, Evaluation of PVES

Summary :

This work presents the design concept, operating principles and the performance analysis of two photovoltaic energy systems installed for educational and research purposes at the faculty of Engineering - Cairo University. These systems are designed and fully monitored using two simple monitoring systems that provide increased flexibility if it compared to traditional schemes that need particular data logging system and special hardware design. The first system with total capacity of 5.1 *kwp* is feeding the utility via grid tie inverter who plays an essential in monitoring the health of the system. The second system with total capacity of 1 *kwp* is feeding standalone loads via a separate isolated inverter.

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Nomenclature

BOS: Balance Of System Equipment

CF: Capacity Factor

DCS: Distributed Control Systems

EETC: Electricity Transmission Company

EPME: Electrical Power and Machines Department

IEA: International Energy Agency

L_c: Capture Losses

L_S: System Losses

MPPT: Maximum Power Point Tracking

NREA : New and Renewable Energy Auth

PPA: Power Purchase Agreements

PR: Performance Ratio

PVES: Photovoltaic Energy Systems

PV-SIs: PV-System Integrator(s)

RE - FiT: Renewable Energy Feed-in Tariff

STC : Standard Test Conditions

THD: Total Harmonic Distortion

YA: Array Yield

***Y*f:** Final Yield

Y*r:* Reference Yield

η sys: System Efficiency

Abstract

Egypt has put an ambitious plan for diversifying its energy sources for electricity generation based on renewable energy technologies. Although, the existence of many solar projects in the country in previous years, it is evident that the lack of long – term experience in operational behavior/performance and reliability of such systems in Egypt may hinder the successful implementation of this plan.

This work presents the design concept, operating principles and the performance analysis of two photovoltaic energy systems installed for educational and research purposes at the faculty of Engineering - Cairo University. These systems are designed and fully monitored using two simple monitoring systems that provide increased flexibility if compared with traditional schemes that need particular data logging system and special hardware design. The first system; of 5.1 kwp is connected to the utility via grid tie inverter which plays an essential rule in monitoring the state of the system. The second system with total capacity of 1 kwp feeds standalone loads via a separate isolated inverter. Additional global radiation and ambient temperature sensors for recording the climatic conditions on the PVES site are installed to communicate with the grid tie inverter software. First, the grid tie PVES was operated since June 2016 and was subjected to periodical cleaning since September 2016. Data are monitored, collected and analyzed following the international standards of IEC 61724 for a period of 9 months however the energy losses and the key performance indices of the system are only calculated for 6 months period after applying the cleaning routine. A comparison of the performance of the system under study with other monitored PV systems reflects good matching and high potential of new installed systems in the subsequent years.

Chapter 1: Introduction

1.1. Back ground

Photovoltaic (PV) energy systems convert sunlight into electricity. A residential PV power system enables homeowners to generate some or all of their daily electrical energy demand on their own roof. The house remains connected to the electric utility at all times, so any power needed above what the solar system can produce is simply drawn from the utility. Egypt has an average solar insolation of over 2000 KWH/m^2 that is higher than the energy produced from the sun in a square meter in Germany.

In February 2008, the Egyptian Supreme Council of Energy has put his ambitious directive to satisfy 20% of the generated electricity by renewable energy by 2020. This was followed by approving the Egyptian Solar Plan in July 2012 with a target to install 3500 MW by 2027. To be in line with these directives that will certainly lead to drastically change in the Egyptian power system and the energy market, Automatic control group in Electrical Power and Machines Department (EPME) – Cairo University – Egypt took actions to stimulate the new power system environment and understand the operational behavior of the two basic renewable energy based generation systems. A research project has been funded by STDF – Egypt in late 2015 to install two photovoltaic energy systems to work in two separate modes; grid connected and standalone at the top roof of the library building (Latitude: 30° 4' 58", Longitude: 31° 16' 58"). This project, aims to promote research in the area of PV Energy System monitoring, operation and control with special consideration to the grid integration. The gained experience during the project stages in the design, installation and operational monitoring will allow showing the benefits of this technology and evaluating its impact on both utility and autonomous scale.

The hardware setup includes PV arrays - Grid Tie inverter - standalone inverter - charge controller - battery pack - PLC - RTU- local loads -switches - measuring transducers and smart energy meters. These units are assembled in a control panel as shown in Figure 1.1, except the PV arrays which are mounted on the top roof, local loads and the Battery pack which are placed inside the lab, Figure 1.2.

Back surface temperature, front surface, cells' mismatch and losses are reported in this work as they have direct influence on PVES operational performance. The losses mechanism for any PVES can be split into capture losses which are mainly due to the attenuation of the incoming solar radiation and system losses which mainly due to wiring and inverter losses.

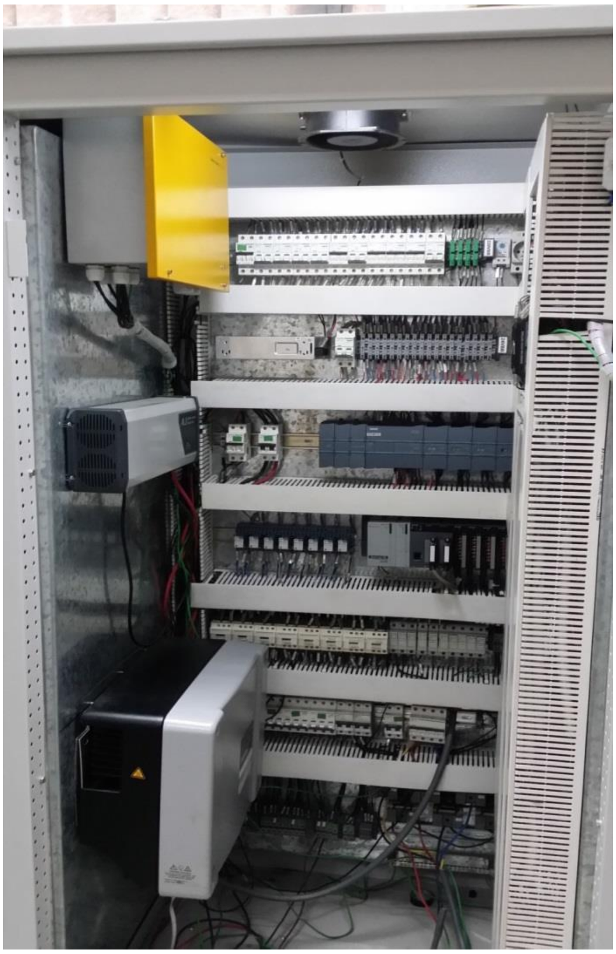

Figure 1.1: Control Panel Figure **Figure 1. 2: Battery Pack**

The calculations performed in this work are mainly based on three essential parameters on understanding the behavior characterizing the performance of the installed PVES under Egypt climatic and environmental conditions. The base parameters used are the array, reference and the final yield. These parameters are calculated according to the data collected for the energy injected into the grid, the energy output of the inverter and energy generated by the PV array.

The capture and the system losses are computed and hence the performance ratios are produced. Other numerical calculations are also performed that enable to determine the efficiencies of each component and judge the health of the system. In general, the work in this thesis provides a technical description of grid tie and the off grid PV systems and an initial evaluation for the performance of the grid tie PV system for the period of 6 months.

1.1.1 Typical Grid-Tie System Design

PV Electrical System models: There are three general models of electrical designs for PV energy systems for residential building; systems that are connect with the utility power grid and have no battery backup ability and systems that are connect to utility power with battery backup.

1.1.1.1. Grid-connected without Battery

This type only operates when the utility is available. This system will normally provide the greatest amount of bill savings to the customer of investment. However, in the event of an outage, the system is designed to shut down until utility power is restored. This research presents a review of small scale of this system.

From Figure 1.3, the inverter works in the same time with the grid supply with the power to the local load supplied from the solar input by the inverter. Any excess PV energy will be flow to the grid. In the event when enough PV energy is not available to supply the local load the grid will make up the shortfall.

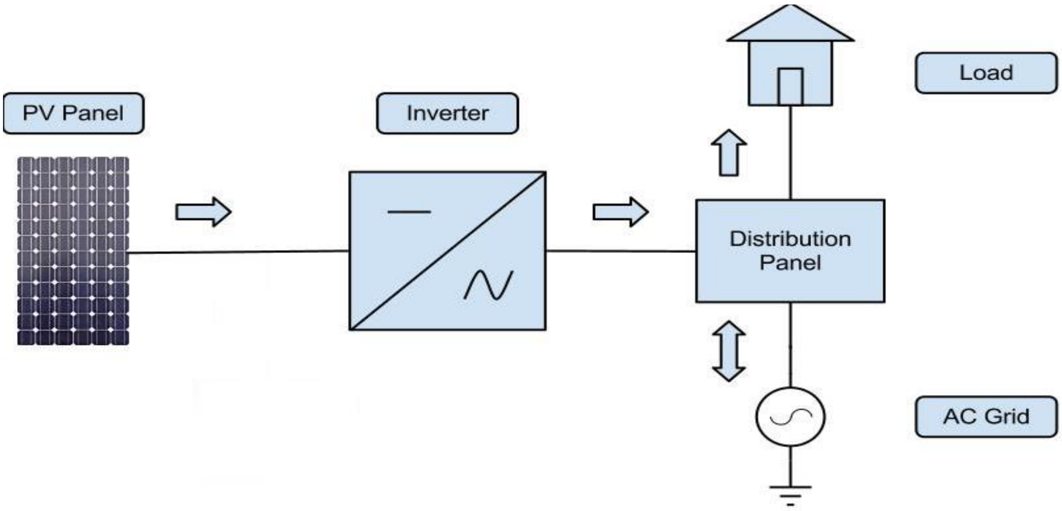

Figure 1.3: General schematic block diagram to on grid system without battery backup

Typical System Components:

A. Solar PV Array

Solar system uses solar cells to transform energy from sun radiation to electricity. PV Array consists of PV modules, there are different types of solar cells such as poly crystalline cells, monocrystalline cells and thick film silicon. The most general PV panel that is 1.2-to-3 M^2 in area and weighs around 14-25 kg.

Solar panels collect energy in the form of sunlight and modify to electricity which can be used to generate power for electrical loads. Solar panels are contain of several individual solar cells which are themselves composed of layers of silicon (which provides the negative charge), and boron (which provides the positive charge). [7]