Optimization of Solar Energy Production using PLC & SCADA

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ABSTRACT

This paper focuses on the maximizing the solar energy produced by Solar cells through the development of such a Sun-Tracking system that can be implemented using PLC & SCADA.

The developed tracking system is innovative in relation to the usual sun tracking systems available in the market. In fact, the developed solution has many advantages in relation to similar existing devices, as this system can automatically work in order to optimize the energy production of photovoltaic cells as we know that in case of fixed Solar cells, the efficiency is very poor. This efficiency of power generation by Solar cells can be increased using this system, so that as the position of sun changes, the position of Solar cell is automatically adjusted by using stepper motors. An experimental prototype was built and field results have proven the good performance of the developed tracking system.

KEY WORDS: Solar Cells, Photovoltaic cells, Tracking Systems, Intelligent sensors and Supervisory Control.

1. INTRODUCTION

According to market economy, the increasing worldwide demand for energy, forces a continuous rise on the price of fossil combustibles. In fact, it is expected in the near future, that the demand for energy will grow faster than the finding out of new available fossil resources.

This market behaviour brings a positive challenge to the scientific community as more funds are allocated for the research and development of new alternatives to the usual main energetic sources (fossil combustibles). In this context, nowadays more effort is being done to conserve the fossil fuels and also to find alternative energy resources to meet the power demands.

In this paper a system for Optimization of Solar Energy generation using PLC & SCADA is developed. Nowadays, Solar power generation has very low efficiency in terms of availability, utilization and generation (ca. 12%).

Solar Energy is such an energy which is available to us in abundance and without any limits. The Solar Energy incident on Earth atmosphere is 10^{17} Watts. The Solar Energy that reaches the earth's surface is 10^{16} Watts. The total power requirements of whole world is 10^{13} Watt. If, 5% of the total energy received at the surface is fully utilized, it is still 50 times more than the actual requirement of the whole world.

This paper focuses on the optimization of the electric energy production by solar cells through the development of an intelligent sun-tracking system. The developed tracking system is innovative in relation to the usual sun tracking systems available in the market. The usual available solutions for tracking systems rely on the knowledge of the geographical position of the solar panel on the earth surface. With this knowledge it is possible to know the relative position of the sun, on a time basis, according to the well-known solar tables.

Modern solutions incorporate a GPS system to calculate the position of the solar panel on the Earth surface. The orientations to be followed by the photovoltaic panel, on a regular time-base, are then pre-programmed, on an open loop approach. There are significant efforts on the optimization of sun tracking systems as it is documented by several registered international patents. These solutions are based either on the above described principle either on

the quantification of the received solar energy, either on the maximization of the solar incident radiation through the use of light concentration lens.

The solution developed in this paper is innovative related to the above referred approaches as this system is autonomous regarding the information needed to process the optimal orientation and it is intelligent in a way that it monitors, on a real-time base, the photovoltaic energy production and it avoids systematic failures coming from changes on the assumed values (position, initial infrastructure orientation, cleanness of the photovoltaic cells, etc.).

2. SYSTEM DESCRIPTION:
A. Overall System Presentation
The overall system is presented in fig. 1. The complete strategy is composed by 5 sub-systems:
1. Electro-Mechanical Structure
2. Control Unit
3. Supervisory System
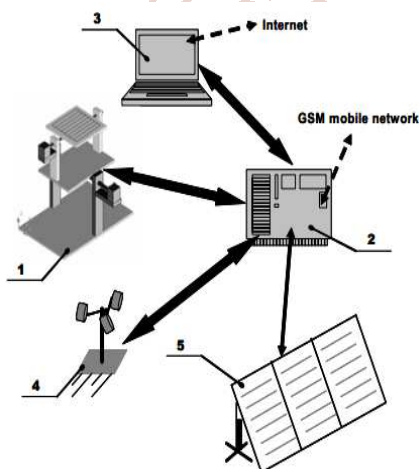4. Wind-meter
5. Photovoltaic Park.

Fig.1 overall system presentation

The developed tracking system searches the optimal orientation of a surface, related to the sun incident radiation. The global performance of the system is described below. The planar surface is composed by a photovoltaic cell which is motorized by 2-orthogonal axis. These two controlled DOF (Degrees of Freedom) are managed by a PLC (Programmable Logic Controller) according to a search program that compares the electric power produced by the photovoltaic cell in each correspondent orientation. The maximal power value is stored and the correspondent orientations on both motorized axis are stored. This new optimal orientation of the tracking system is then communicated to the industrial

photovoltaic park in order to transfer the new optimal orientation to all PV-production panels.

B. Electro-Mechanical Structure
The operational subset of the tracking system, named Electro-Mechanical System, is presented in figs 2 and 3. This structure has two DOF, motorized by stepper motors with incorporated encoders; in order to track exactly the prescribed path. The mechanical system was designed using standard industrial Aluminium profiles in order to obtain a simple and economic structure.

The mechanical structure is mainly composed by Bosch Profiles and Aluminium plates. The two motorized axis are composed by Step-motors assembled to Aluminium shafts. Figure 2 illustrates the several main components of the mechatronic system:
Part n. 6 = Step-Motor to control axis 1;
Part n. 7 = Step-Motor to control axis 2;
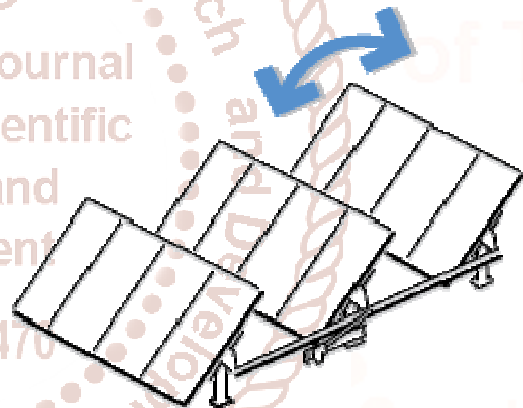Part n. 8 = Photovoltaic cell (150mmx150mm).
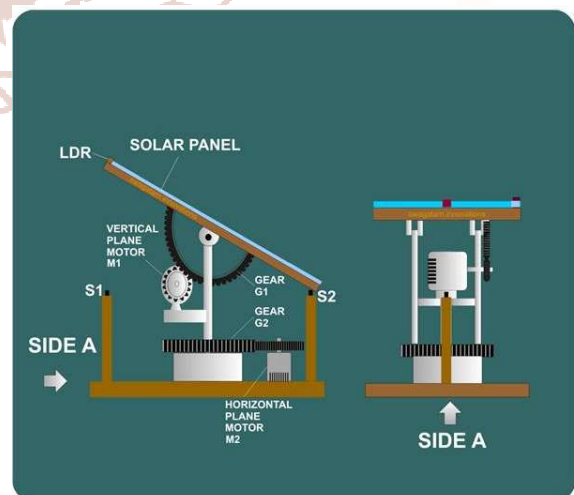

Fig 2 Electromechanical System for Solar Tracking

Fig.3 Design of Degree of freedom

Figure 3 details the two designed degrees of freedom (DOF).

C. Control Unit

The control unit consist of PLC Siemens S7-300 system (Programmable Logic Controller). This control system has the complete operational management of the tracking system. The main tasks performed by the system are:

➢ Controlling of the two stepper motors;
➢ Processing the data from both encoders;
➢ Processing the voltage signal coming from the Solar-Cell;
➢ Processing the data from the external proximity sensors that informs the system about the hard-home position reference.

This PLC controls directly the tracking system and commands all other Solar-Panels, from the solar Park, through a Profibus-DP network.

Figure 4 shows an example of a solar park with several PV-Panels. Figure 5 illustrates the Profibus network implemented in this study.

Fig 4 Solar Panel Power Plant

D. Supervisory System

A SCADA system (Supervisory Control and Data Acquisition) is implemented to monitor and supervise the tracking system. A Supervisory Control and Data Acquisition (SCADA) System is used as an application development tool that enables system integrators to create sophisticated supervisory and control applications for a variety of technological domains, mainly in the industry field. The main feature of a SCADA system is its ability to communicate with control equipment in the field, through the PLC network. As the equipment is monitored and data is recorded, a SCADA application responds according to system logic requirements or operator requests.

In the developed supervisory system, the SCADA application manages the overall system dynamics. The Communication flux between the supervisory system and the control unit is illustrated in fig. 5. The SCADA PC is simultaneously a SCADA server and an internet server, as the implemented SCADA application is web enabled.
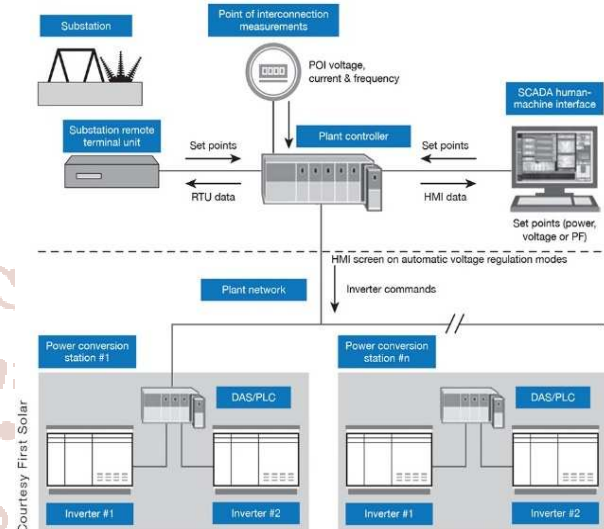

Figure 5 This Figure from a first solar white paper. "'Grid-Friendly' Utility-scale PV Plants," illustrates the basic architecture and components of a Plant-level Control system

3. EXPERIMENTAL PROTOTYPE

A. Physical Description

The prototype built followed the design presented in figure 2. This system incorporates a PV-cell150mmx150mm, $P_{max}=1,12W$, (Polycrystalline Silicon wafer) and the whole structure is made of Aluminium alloy. In fig. 6 the global developed prototype is shown.

Fig.6 Prototype assembly

The control unit was developed using an industrial Siemens S7-300 PLC (Programmable Logic Controller). The selected PLC system is a modular device that is constituted by the following modules:

Slot1 = Power supply PS 307-2A
Slot2 = Processor CPU 315-2DP
Slot4 = Communication module CP 342 -5
Slot5 = Digital card DI8/DO8xDC24V/0,5A
Slot6 = Analog card AI8 x12bit
Slot7 = Analog card AO4 x12bit
Slot8 = FM card – Counter Module (FM350)
Slot9 = FM card – Counter Module (FM350)
Slot10 = FM card – Stepper Motor (FM353)
Slot11 = FM card – Stepper Motor (FM353)

Additionally, the PLC-tracker has a modem for GSM communication that provides the system capacity to communicate through the mobile phone network.

The driving unit is composed by two motorized axis, with the following characteristics:
1. Axis 1
➢ Step motor: Nanotec ST4018L0804, 50Ncm;
➢ Opt. Encoder: HP HEDL-5540 A14, 500 Pulses
➢ Coupling unit: Oldham D5
➢ Proximity sensor: Omrom EA2 M8 PNP
2. Axis 2
➢ Step motor: Nanotec ST5918L1008, 170Ncm;
➢ Gear box: Nanotec PLE40-1S-4
➢ Opt. Encoder: HP HEDL-5540 A14, 500 Pulses
➢ Coupling unit: Oldham D25
➢ Proximity sensor: Omron EA2 M8 PNP

Figure 7 details the electro-mechanical structure of the developed sun-tracker system.

Fig 7 Prototype Assembly: Solar panel

B. Implemented Control Algorithm

The software used for the PLC programming was the Siemens Simatic Step 7, with the Simatic 7 ProdaveV5.5 needed for the communication between the Scada system and the PLC network. The designed control algorithm was implemented using the Ladder Diagram language.

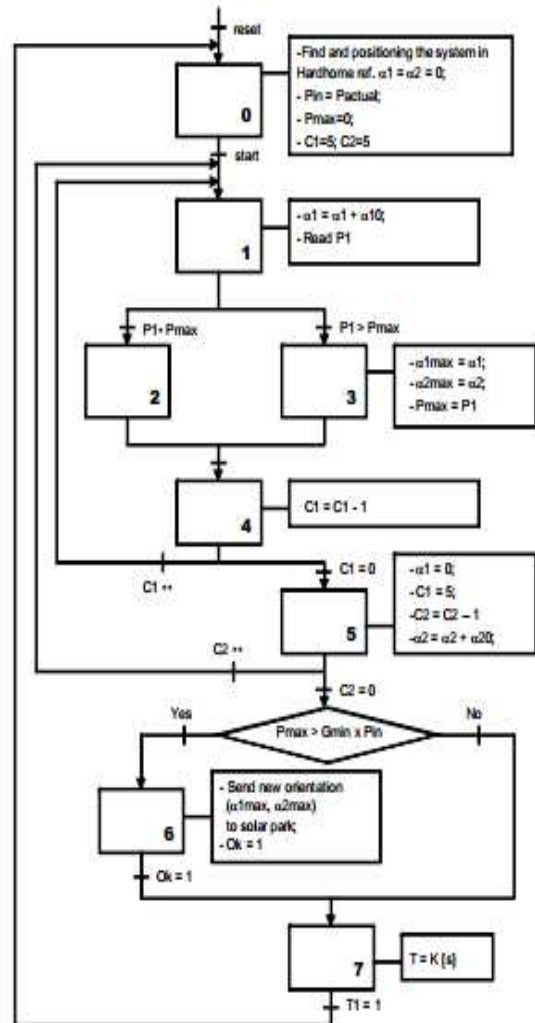The developed control algorithm is illustrated in fig.8.

Fig.8 Control Algorithm for the Tracking System

A short description of the tasks performed by the tracker controller, regarding the above referred algorithm, is described below:

Box0: After reset is activated, the system stores the PV-power generated in the actual position, P_{actual}, in the variable Pin. The system searches its reference-null position. It moves until it finds the hard-home position (both external proximity sensors on). In this position the system assumes the absolute orientation angles for both axis equal zero ($\alpha1 = \alpha2 = 0$). The maximal Power, Pmax is set to zero. Bothcounters, C1, C2, are loaded;

Box1: After start is activated, the system initiates the search for the maximal power generated in axis 1, with an angle increment α10. The system stores the power generated in variable P1.

Box2: If P1 < P max, the system goes to Box 4, and follows for a new position;

Box3: If P1 > P max, this position is stored in the variables: α1max, α2max. The max Power value,

P max is actualized with the new Power value P1;

Box4: Counter for axis 1 is updated;

Box5: After all orientations for axis 1 are evaluated, regarding a fixed orientation for axis 2, axis 2 is positioned in a new position, with an angle increment α20, and axis 1 returns to its initial position α1=0. The system re-initiates the search for the optimal orientation of axis 1, regarding the new position of axis 2. The information flux returns to box 1.

Box6: After all orientations for axis 1 are evaluated, regarding all different positions of axis 2, the system compares the maximal power found (P max) with the initial Power generated, before the search process had begun (Pin). If the new Power value is greater than a pre-defined gain, this new correspondent orientation (α1max, α2max) is sent to all park panels. If the power gain is not enough, the new found position is not to follow by the other PV-panels.

Box7: After a pre-defined time interval (K) the tracker system initiates a new complete search process in both axis. The information flux returns to box 0.

C. SCADA Supervisory System

The SCADA system used to implement this monitoring and control strategy permits the selective access to the application, depending on the user's responsibility degree. In this paper we developed three user levels: Operators, Supervisors and Administrators.

Several SCADA menus were built. The main characteristic of a SCADA Menu is to be simple, explicit and quick on transmitting the information to the operator or to the System administrator.

One of the developed Graphical User Interfaces (GUI) is shown in fig 9.
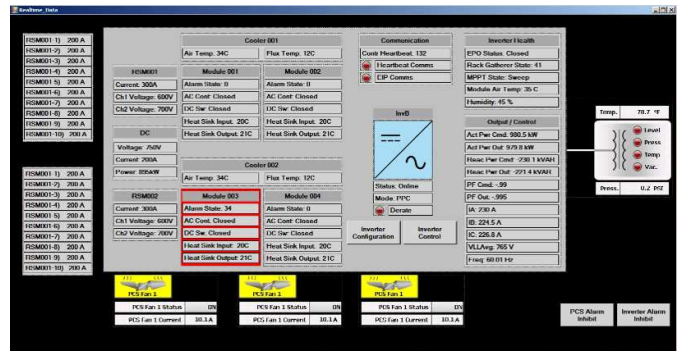

Fig 9 SCADA view of Solar Tracker

As this SCADA platform is web enabled, all the GUI displayed data is also on-line accessible through the internet.

In fig. 9 it is shown the developed main menu for the sun-tracker system. The on-line available information, referring actual data from the tracker unit is: actual position for both axis, actual PV-power generated, max. daily PV-power generated, actual efficiency ratio.

4. CONCLUSIONS

The developed tracker for sun radiation worked very well. The increase in power generation, in relation to other Solar Energy-systems, without tracking devices, is of similar magnitude (ca. 25%) as for other usual tracking solutions. However, this system has a relative advantage, as it measures exactly the controlled variable: the actual Solar power generation.

Note: If we can just utilize 5% of the total available solar energy on earth surface, it will be 50 times the energy which is required by the whole world. And in this way, there will never be any shortage of power supply except in case of non-availability of direct sunlight.

In such case, the other sources of power can be used so that we use as much less fossil fuels as possible.

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