A PV Based Automation System for Fish Farms: An Application Study

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Abstract

Nowadays, generating electricity from solar energy is used for many applications. Especially in rural areas, PV based applications have been a great importance for generating electricity. In this study, a PV based application study presented for fish farms. An off grid PV system designed to supply the systems' required electrical energy and a pump used for taking cold water from the depth of the dam lake to cool the cage. Temperature sensors are used for measuring the cage's water temperature and according to the cage temperature a motor driver is used to adjust the speed of pump. A PLC controller and an HMI system for monitoring designed for the system. All the energy requirement of the system is supplied from designed PV system. Thanks to developed system, the temperature of fish cage is stabilized to 17 °C so from May to September, fish can be growth sustainably during the year.

1. Introduction

Solar energy is clean, renewable and plentiful in the nature and the energy needs and costs have increased in recent years. These conditions have made solar energy more important. On the other hand, due to rapidly developing photovoltaic (PV) technology, PV based applications have been developed recently.

Off-grid PV systems have been used in many applications just like remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing, and protection of pipelines. Also there are some applications in power stations, in buildings, in transport, in standalone devices, in rural electrification and solar roadways. A stand-alone photovoltaic power system for remote villages using pumped water energy storage is one of these applications [1]. In this study, regards the implementation of a stand-alone photovoltaic plant in which battery storage is partially replaced by a micro-hydraulic system in the Aegean Sea, to cover basic electricity needs of the remote village.

Another study is focus on a solar photovoltaic powered ice-maker which operates without the use of batteries and is therefore environmentally friendly and may be used in truly autonomous applications in remote areas. The operation of the refrigeration compressors by the PV panels is ensured by the use of a novel concept dedicated controller [2]. Pande, presented designing and testing of a solar PV pump based drip system for orchards [3]. Narvarte et al. introduced a PV pumping analytical design and characteristics of boreholes. [4].

Besides these studies, also PLC controlled and PV based studies have been studied. One of them is hydraulic water level monitoring system monitored via SCADA and based on PV power supply and PLC controller [5]. A micro-DC power distribution system for a residential application energized by photovoltaic–wind/fuel cell hybrid energy systems is another application study based on PLC controller [6].

User acceptance of diesel/PV hybrid system in an island community is investigated to understand the off-grid PV systems' success by Phuangpornpitak and Kumar [7]. Yamegueu et al. developed an experimental study of electricity generation by solar PV/diesel hybrid systems without battery storage for off-grid areas [8]. A case study for a remote location in Tunisia investigated by El Mnassri by developing a stand alone photovoltaic solar power generation system [9]. Fragaki and Markvart is also designed a stand-alone PV system using a new sizing approach [10]. An experimental validation of autonomous PV-based water pumping system optimum sizing is studied by Kaldellis and others [11].

PV based studies have several application areas like solar racing cars [12], solar buildings [13] and PV pumping systems [14]. Especially, due to increasing fish farms rapidly in Turkey, PV based applications for fish farms have been required to achieve for several works in these areas. A small application about this subject is studied to monitoring the fish farms with a remote control system [15]. Bayrak and Cebeci are also investigated an 1.1 kW off grid power system for a fish farm for supplying farm's fundamental electricity demand [16].

Fig. 1. Application area of the project on Keban Dam Lake

In this study, an experimental research project for fish farms is introduced. Designed off grid PV system consists of 8 PV panels, 8 batteries, 2 solar charger, 1 inverter and 1.1 kW three phases pump as load and PV system supplies the electrical power of load, motor driver and controller structure. PV system is controlled via PLC and monitored by developed SCADA program and to measure the average temperature of fish cage, four PT-100 sensors which are the inputs of PLC are used. Motor driver is controlled according to average temperature of fish cage and the speed of pump adjusted via analog output of

PLC. Pump takes from the 30 meters depth of dam lake's water has approximately 10 °C into the fish cage and cool it. Thanks to designed system, the temperature of fish cage is stabilized to 17 °C so from May to September, the fish can be growth sustainably during the year and an important problem was solved via the automation system.

Fig. 3. Developed PV array constructed on the fish cage

2. Designed Off Grid PV System

The stand-alone PV system shown general structure in Figure 2, operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources [17].

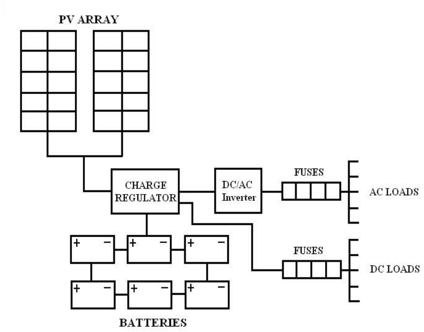

Fig. 2. Schematic diagram of a stand-alone photovoltaic system

2.1. System Components

The main system components are the photovoltaic array power conditioning and control equipment, storage and load equipment. It is particularly important to include the load equipment for a stand-alone system because the system design and sizing must take the load into consideration. The most common system components and their role in the system operation given below:

2.1.1. The Photovoltaic Array

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current.

In this project, a PV array consists of 8 PV panels which have each one 205 Wp, 32.47 V open circuit voltage and 8.39 A short circuit current technical specifications was designed. Developed PV array shown in Figure 3 was constructed on the fish cage to supply the system's required electrical energy.

2.1.2. Power Conditioning

It is often advantageous to include some electrical conditioning equipment to ensure that the system operates under optimum conditions. In the case of the array, the highest output is obtained for operation at the maximum power point. Since the voltage and current at maximum power point vary with both insolation level and temperature, it is usual to include control equipment to follow the maximum power point of the array, commonly known as the Maximum Power Point Tracker (MPPT).

It is also usual to include charge control circuitry where the system includes batteries, in order to control the rate of charge and prevent damage to the batteries. In studied system 2 charge controller were used which have 30 A maximum current to control the charge and switching between PV array and batteries.

2.1.3. Inverter

If the PV system needs to supply AC loads, then an inverter must be included to convert the DC output of the PV array to the AC output required by the load. As with PV systems, inverters can be broadly divided into two types, these being stand-alone and grid-connected.

The stand-alone inverter is capable of operating independently from a utility grid and uses an internal frequency generator to obtain the correct output frequency (50/60 Hz). The input voltage depends on the design of the PV array, the output characteristics required and the inverter type. Stand-alone systems commonly operate at 12, 24 or 48 V, since the system voltage is determined by the storage system.

2200 W, 24 V DC input voltage and 230 V AC output voltage sine wave inverter was used in this project.

2.1.4. Storage (Batteries)

For many PV system applications, particularly stand-alone, electrical power is also required from the system during hours of darkness or periods of poor weather conditions. In this case, storage must be added to the system. Typically, this is in the form of a battery bank of an appropriate size to meet the demand when the PV array is unable to provide sufficient power. In this project, amount of 8 batteries have 12 V, 110 Ah shown in Figure 4 were used for storing the energy.

Fig. 4. Used batteries to store the electrical energy

2.1.5. Load Equipment

In developed system, a three phase 1.1 kW pump (has induction motor's specifications) was used as load. PV pump shown in Figure 5 was used to take the deep cold water into the fish cage. Also PLC, HMI, motor driver and sensors were other loads of the PV system.

The critical temperature is 20 ^{o}C for the system. The convection heat transfer parameter of the water can be determined from Newton's law of cooling [18]. Total heat gain related to all surfaces of the cage was calculated as 45125 kW by considering heat gain comes to surface from the sun. The selection of PV pump was realized according to criterions of the system below:

The required time for pumping water has 10 ^{o}C temperature of degree was determined as 9,65 hours and the volume of fish cage 125 m^3 so required flow rate: 125 / 9,65 = 12,95 m^3/h = 3,6 L/m and the power of PV pump it was calculated from the Equation 1:

$$P = \frac{Q.H.q}{367.n} = 0.232 \text{ kW} \qquad (1)$$

P: Required motor power (kW), Q: Flow rate of the pump (m^3/h), H: Height of pumping (m), (r_o): Efficiency of the pump, q: Liquid density (kg/dm^3).

Safety factor is 1.1 until 15 kW of power so; P= 0.232x1.10= 0.255 kW and required power of PV pump was detremined as 0,5 kW (0,67 HP) and selected pump is suitable for this system.

Fig. 5. Mounting pump to the fish cage

2.1.6. Cabling and Switching Equipment

The array cabling ensures that the electricity generated by the PV array is transferred efficiently to the load and it is important to make sure that it is specified correctly for the voltage and current levels which may be experienced. Since many systems operate at low voltages, the cabling on the DC side of the system should be as short as possible to minimize the voltage drop in the wiring. Switches and fuses used in the system should be rated for DC operation. In particular, DC sparks can be sustained for long periods, leading to possible fire risk if unsuitable components are used.

In PV system, 4 mm^2, 6 mm^2 and 10 mm^2 special solar cables, automatic fuses and waterproofed switching boxes were used for connections and switching.

3. Developed Automation System

After finishing PV installation, it was started to improve the automation system. The main structure of the automation system is shown in Figure 6. For improving automation system, a PLC controller, PLC analog and RTD modules, an HMI touch panel, a motor driver and temperature sensors were used to control the all system. These elements were detailed explained below:

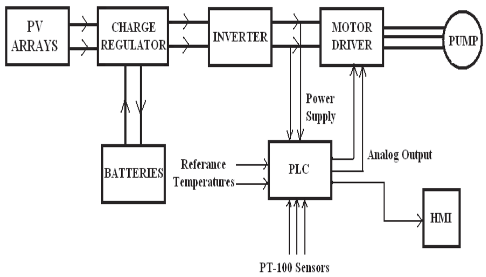

Fig. 6. Designed PV based automation system

3.1. Programmable Logic Controller (PLC)

In this study, a PLC controller unit was designed and this unit contained an S7-200 CPU, an EM-235 analog extension module and an RTD module. RTD module had four analog inputs and these inputs were used for getting RTD sensors to measure temperature of fish cage. EM235 analog output was used for the analog input of motor driver to control the speed of pump. Developed PLC unit is shown in Figure 7. The reference temperature is taken via PLC and it is compared with measured temperature. Then analog output evaluated by PLC and pump is controlled according to developed PLC program. Also digital outputs of the PLC are used to indicate pumps' working conditions.

3.2. Human Machine Interface (HMI)

In the industrial design field of human–machine interaction, the user interface is the space where interaction between humans and machines occurs. The goal of interaction between a human and a machine at the user interface is effective operation and control of the machine, and feedback from the machine which aids the operator in making operational decisions. Examples of this broad concept of user interfaces include the interactive aspects of computer operating systems, hand tools, machinery operator controls, and process controls.

According to the improved PLC program, the connection between PLC and HMI unit was completed. DOP B05S100 touch panel was used to design the desired HMI system. SCADA program was also developed shown in Figure 7 and automation interface completed.

Fig. 7. Improved automation interface program with SCADA

3.3. Motor Driver

Variable frequency drive controllers are solid state electronic power conversion devices. The usual design first converts AC input power to DC intermediate power using a rectifier or converter bridge. The rectifier is usually a three-phase, full-wave-diode bridge. The DC intermediate power is then converted to quasi-sinusoidal AC power using an inverter switching circuit.

The inverter circuit is probably the most important section of the variable-speed drives (VFD), changing DC energy into three channels of AC energy that can be used by an AC motor. These units provide improved power factor, less harmonic distortion, and low sensitivity to the incoming phase sequencing than older phase controlled converter VFD's.

1.1 kW MM-420 series motor driver used for controlling speed of pump in the project. Parameter settings of motor driver were done according to technical specifications of the pump.

3.4. Temperature Sensors

PT-100 is called a RTD element, meaning Resistance Temperature Detector. An RTD or PT-100 sensor is connected with two, three or four wires to the measuring device and its resistance helps to determine the temperature.

Four PT-100 sensors were used to measure the temperature of the fish cage and these connected to RTD module of PLC unit.

4. Experimental Study

A PV based automation system was developed for fish farms to stabilize the temperature of fish cage is to 17 °C temperature which allows to growing fish. The whole automation system elements are shown in Figure 8. This control panel was mounted to fish cage for controlling the all system. PLC unit, charge regulators, motor driver, relays and other devices can be seen in this figure.

Fig. 8. Temperature and energy control system of the fish cage

Developed control panel was mounted to fish cage after test studies. It is shown in Figure 9 and HMI touch panel is also mounted to facade of control panel. Inverter was also placed into the panel shown below the control panel.

Fig. 9. A view of the designed control panel system

When the system is on, measured temperature from PT-100 sensors are monitored and average temperature of fish cage is evaluated. According to this temperature, PLC unit determines the appropriate analog output signal and sends it to analog input of motor driver. Then motor driver adjusts the frequency of the pump. All these values can be shown in Figure 10.

PV array supplies all required energy of the system and voltages and currents of the PV array and batteries are monitored via developed SCADA system. These values also can be seen on the touch panel screen just like the temperatures of PT-100 sensors, average temperature of fish cage and frequency of motor driver. The system can be selected manual or automatic mode from touch panel to select the appropriate running mode of the system.

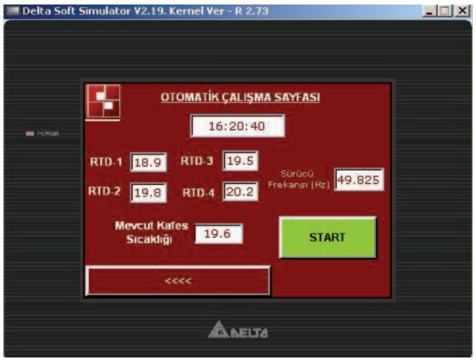

Fig. 10. HMI program outputs when the system is run mode

Developed automation and energy generating system on the Keban Dam Lake is shown in Figure 11.

Fig. 11. A view of completed automation system on the lake

5. Conclusion

A PV based automation system was developed for fish farms to stabilize the temperature of fish cage to 17 °C temperature which allows to growing fish. Thanks to this application study, the growing fish can be enhanced from May to September and the fish can be growth sustainably during the year. Manufacturers will not to be transport the fish to another cold areas between these hot months will generate own required electrical energy from PV system.

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