Comparative Analysis of Solar Photovoltaic Monitoring Systems

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Abstract: This paper is focused on comparative analysis of photovoltaic (PV) monitoring system for observing the performance and stability of the system. The cost and complexity of existing PV monitoring systems restricted their use to large scale PV plants. Over the past decade, different aspects of the PV monitoring systems were reported in the wide range of literature. In this paper, a comparative analysis of various PV monitoring systems is presented for the first time. It is based on analyzing six main characteristics of PV monitoring system, such as data transfer mechanism, controller, monitoring parameters, sampling interval, program development software and monitoring methods. The comparison of methodologies and the description of implementation process are discussed in this context. The key findings of this study will contribute to the development of a new PV monitoring system. The acquaintance of all these aspects is crucial for the development of effective, low cost, and viable PV monitoring systems for the small and medium scale PV plants without compromising on the desired performance.

Keywords: Photovoltaic system, Monitoring, Data acquisition.

Introduction:

The energy demands of almost all the countries around the globe are on rise due to its large scale industrial expansions, increasing population, and continuous growth in energy consumption per capita. It should be noted that major portion of energy requirement is in form of electricity. On the other hand, use of fossil fuel based electricity generation came to saturation levels due to increased environmental concerns and limited resources. Thus, the gaps between the demand and generation in future are to be met by renewable energy sources. In line with this objective, renewable energy sources such as solar, wind, biomass, micro-hydro, and geothermal are being converted into electrical energy and delivered either to demand centers or utility grids [1]. In tropical countries, solar energy is deemed as the most reliable and viable among all renewable energy sources [2]. Owing to the developments in photovoltaic (PV) technologies and various

financial subsidies being provided by the government bodies to electrical energy generation sector using PV technology has seen a rapid evolution during the past decade. More recently, urban population and industrialists have shown their interests in PV energy generation in view of sustainable development. This will ultimately make the PV technology overcome their set back of lower power density by expanding its foot print to urban/populated areas. Therefore, a steep rises in PV systems/plants are expected in the years to come. At this verge, it is very much essential to develop the technologies, which keep track on PV energy production from a given PV plant and keep up its production in every possible dimension A comprehensive solution for the problems is being termed as PV monitoring system, whose job is to maximize the operational reliability of PV system with minimum system costs.

The PV monitoring systems are aimed to provide/report information about the energy potential, energy extracted, operating temperature analysis different of faults that have occurred, and energy loss associated with them. Over the past decade, different aspects of PV monitoring systems were reported. This paper presents an comparative analysis of six main characteristics of PV monitoring system, such as data transfer mechanism, controller, monitoring parameters, sampling interval, program development software and monitoring methods. The information gathered and compiled in this paper will be helpful for further research in this area.

2.1 Data transfer mechanism

Both wired and wireless systems have been introduced for data transfer mechanism in the past. In [3], RS232 cable is used for wired system or RS485 cable [4], with the monitoring system being PC based. But it suffers with several limitations. It increases the installation and maintenance cost as well as physical constrains during the laying of the data cables. Hence this type of data transmission is considered less favorable than the wireless system for monitoring of a solar PV system. Variety of wireless data transmission has been reported in literature. In [5], satellite, GSM [6], Zigbee [7], and other unspecified FR devices are used for data transmission. Amongst these, satellite based data transmission system is slow transfer rate (8 to 12 min), costly and requires high installation cost. On the other hand GSM has high data transfer rate and low data loss but its operating cost is high, as the users need to pay for the data transmission service. RF data transmission was quite popular in sending and receiving huge amount of data at low

cost. Its main disadvantage is the difficult to obtaining permission for the transmission frequency and the high price of its installation. Bluetooth, Zigbee and Wi-Fi are another option; however its coverage Bluetooth covers short distance and the cost of Wi-Fi device relatively high compared to Zigbee and Bluetooth. Zigbee signals will usually interfere with the local household Wi-Fi signal near to the plant. Hence, it is found that most prefer technology for data transmission is power line communication (PLC). It is an adequate communication technology.

2.2 Controller

Controllers play a vital role in all the monitoring systems and are used to handle the output data of sensors. Therefore, appropriate selection of suitable controller is of utmost important. Many researchers have used microcontroller, data logger, data acquisition card (DAQ) and module as controllers to gather signals from sensors and digitize the signal for storage, analysis and presentation on a personal computer (PC). Depending on the type of PC technology, a variety of data acquisition systems provides flexibility for test, automation and measurement applications. Common examples of such systems are- PCI, PCI Express, PXI, PCMCIA, USB, Ethernet, and wireless data acquisition. Microcontroller and data logger are cheaper in comparison to DAQ cards and modules. These are easily programmable, and have been used in earlier works. A commercially available data logger controller has been used to acquire a set of operational and metrological parameters of a hybrid photovoltaic–diesel system. But compared to data acquisition card, a data logger unit has lack of flexibility and cannot be used for renewable energy system control. Hence, it is found that for small size and low cost PV systems, a microcontroller with 8-bit ADC was found to be sufficient. However, for large and long time period PV systems, better microcontrollers such as a 10-bit and 12-bit ADC were used.

2.3 Monitoring parameters

Due to intermittent nature of solar energy the power output of a PV system may increase or decrease drastically, which leads to increased stress on the grid or sometimes causes power outages. Since PV achieves high penetration levels on utility grid, compelling it to monitor the parameters for ensuring reliability. An important cogitation of any monitoring system is the choice of parameters to be measured. These parameters are selected according to the British Standard BS IEC 61724 [8]. Depending on the type of PV system configuration, a list of

parameters is given in Table 1. It can be distinguished as grid-connected and stand-alone PV system.

Table 1: Parameters to be measured

PV system type	**Parameters**		
	Metrological	Electrical	
Grid connected	(i) Total irradiance, in the plane of array G_T (ii) Ambient temperature (iii) Module temperature (iv) Wind speed (v) Wind direction (vi) Humidity (vii) Barometric pressure	*Photovoltaic array:* (i) Output voltage (ii) Output current (iii) Output power (iv) Output energy	*Utility grid:* (i) Grid voltage (ii) Current to utility grid (iii) Current from utility grid (iv) Power to utility grid (v) Power from utility grid (vi) Utility grid impedance
Stand alone			*Load:* (i) Output voltage (ii) Output current (iii)Output power

After studying previous works on PV monitoring systems, it is noticeable that the most eminent operational and metrological parameters are solar radiation, temperature, PV voltage and current, while other parameters are configuration dependent. The monitoring system consists of numerous sensors which provide information of different assets under various conditions. This information can be used by the operators in making decisions related to utilization, replacement, and system reliability.

2.4 Sampling interval

In earlier works, different sampling period have been used to measure the monitoring parameters ranging from seconds upto hour. However, according to IEC61724 standard, the sampling interval of different parameters should be selected based on its type recorded. The parameters which vary directly with solar radiation shall be less than 1min. Sampling interval for parameters have large time constants that are module temperature can be around 1 to 5 min.

2.5 Program development software

Data analysis is essential for drawing conclusions from research. Hence, different methods have been used for quantitative data analysis to determine the performance of various PV system configurations. C language and ASSEMBLY language have been used for program microcontroller, at the same time MPLAB are popular choices. For programming PLC in developed SCADA system autobase software is used. LABVIEW and MATLAB are commonly used for numeric calculations and system control tools with measurement in a single application package respectively. HTML, PHP, CSS and JavaScript on the other hand, are favored for web-based implementations. Hence above mentioned methods require operator with one laptop to collect acquired data for analysis, requirement of power supply and the use of commercial software, which increases the price of the system and limited its spread and use. With this background and under the current technical development, there is a need to develop a low-cost data logger serves different basic purpose including, free from software and hardware, design is accessible to everybody.

2.6 Monitoring method

In monitoring system, it is important to choose which type of method which user can efficiently access the monitored parameters data. For the monitoring of PV system, users should have easy and prompt access to the data, in order to provide timely evaluation on the system performance, as well as to provide counter measures should any failure is detected. Based on the previous works surveyed, it is found that web-based monitoring system can be an attractive monitoring method. It can distribute the data among remote users and users can view data from any device with internet connectivity.

Discussion:

In order to sense the operational and metrological parameters of a PV system, different sensors should be used. But it is very difficult to identify due to system size variation, working principles, structure of sensors, hardware used, and differences in installation sites. An effective data transmission system is very essential in order to transmit the data. To facilitate the communication between the sensors and the data acquisition system various mediums are used such as wired, wireless and power line communications systems. WLAN can cover only a small

area approximately 20 km2 compared to GPRS-GSM and can transmit data over distances of hundreds or thousands of kilometers through internet where as PLC carries the information about hundreds or thousands of meters by using existing wired infrastructure without any additional installations which reduces the cost of the system. PLC can reach the maximum data transmit capability of 200 Mbps. The installation cost and process of wired data transmission system is very high. As a result, wireless and PLC are best candidates for communication since do not need any additional cables between the sensor and data acquisition system for data transmission. Due to severe radio interference effect wireless technology has limited applications. As a result, PLC technology can be considered as better choice for data transmission. Generally, data analysis is used to find out useful information in order to implement the successful computer-aided decision-making support system in PV monitoring systems. Few of these methods are complex, while the others are simple. Hence, there is a need to develop a low-cost data logger serves different basic purpose including, free from software and hardware, design is accessible to everybody. To understand this more clearly a summary of the convergence of various techniques for important six characteristics is presented in Table 1.

Table 1: Characteristics of previous monitoring techniques.

Characteristic		**Significant differences in quality**
Data transfer mechanism	Wired	Low error, good bandwidth and high cost
	Wireless	Lower quality of service, lower band width and high cost
	PLC	Low error, good bandwidth and low cost
Controller	NI DAQ	Increase performance but high cost and depend on software
	DSP	Highly integrated device but high cost and depend on software
	μC	High performance, low cost and independent of software
Parameters	G, T_a, T_m, V_{pv} $V_{ac,} I_{ac}, E_{pv}, E_{ac}$	–––
Software language	LabVIEW	1.One operator with one laptop is required to run these software's. 2. Requirement of grid supply. 3. High cost.
	MATLAB	
	Java	
	C, Turbo C++	1.Independent of PC, grid supply and low cost
Monitoring methods	PC	Difficult to access the monitored data from remote PV plants
	Web	User can access the data from anywhere at any time

Conclusion:

This paper provides comparative analyses of various PV monitoring systems based on analyzing six main characteristics are presented. It is very difficult to discuss each and every sensor used because it becomes really complex and every sensor has its own benchmarking. The section of data acquisition systems covers the controllers being used for data acquisition system, types of data transmission methods, data storage and data analyses. All the necessary comparisons were discussed and tabulated. It is believed that the acquaintance of information provided in this review is crucial for the development of an effective, low cost PV monitoring system viable for even small and medium scale PV plants, without compromising on the desired performance.

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