VERIFICATION OF PHOTOVOLTAIC SUPERVISORY CONTROL AND DATA ACQUISITION (PVSCADA) KIT

Ainun Mardiah Binti Jafar
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: cikainuneye@gmail.com

Abstract - **Data acquisition systems are widely used in Photovoltaic (PV) system applications in order to collect data regarding the PV system performance. In general, the development of a photovoltaic supervisory control and data acquisition (PVSCADA) kit can be described as a system to monitor PV system performance. It can monitor hardware and software performances. The proposed PVSCADA kit consists of a set of sensors for measuring both meteorological (such as temperature and irradiance) and electrical parameters (voltage and current at PV arrays, batteries and load). PVSCADA kit has an analytical monitoring system called datalogger and it needs to be verified. In this paper, using precision electronic devices is used and then compared with data from datalogger by the calculating accuracy of full scale or percentage of error for each parameter.**

Keywords-photovoltaic system, PVSCADA kit, datalogger,real data.

I. INTRODUCTION

PVSCADA kit is a robust datalogger featuring universal analog input channels which can automatically select measurement range based on the signal level. In order to provide reliable and efficient monitoring in PV system, PVSCADA kit is isolated and overvoltage protected. PVSCADA kit is connected by sensors to observe the performance solar irradiance, PV arrays, batteries and a load. PVSCADA kit function is to measure include temperature, DC and AC voltage and DC and AC current. This PVSCADA kit can measures a comprehensive set of data in 15 minutes intervals.

PVSCADA kit can be remotely control through internet, GSM modem, USB memory (up 512MB) and personal computer [1].

The photovoltaic system is composed of a PV module, PV junction, solar charge controller, generator, inverter, batteries and a load. In the process to verify the PVSCADA kit using the precision electronic device, there are several parameters that need to be measured as per indicated in Figure 1.

For outdoor measurements, the 9 parameters data were obtained. The different measures realized are as follows:

- Solar irradiance (Garray_plane)
- Array temperature (Tcell_temp)
- Battery temperature (Tbattery)
- Maximum Power Voltage at array 1 (Vmp_array1)
- Maximum Power Voltage at array 2 (Vmp_array2)
- Maximum Power Current at array 1 (Imp_array1)
- Maximum Power Current at array 2(Imp_array 2)
- Battery voltage (Vbattery)
- Load AC voltage (Vload_ac)

The best management of a PV system requires deep knowledge on the variation of different parameters. The acquisition of voltages is obtained directly on each under-system while the currents are measured with shunts with energy consumption. These shunts allow the conversion voltage current. [2]

The measurements for real data used a various devices including hand pyranometer, Megger AVO300 series (digital multimeters), Extech AC/DC Power (Clamp-on Meter), and Raytek MiniTemp MT4 (Non-Contact InfrarRed Thermometer).

Meanwhile, in order to analyze the vast function available in PVSCADA kit, we need to analyze all the sensors located at PVSCADA kit. In example for the data acquisition of solar irradiation incident (Wh/m^2), the data were measured using pyranometer sensor.

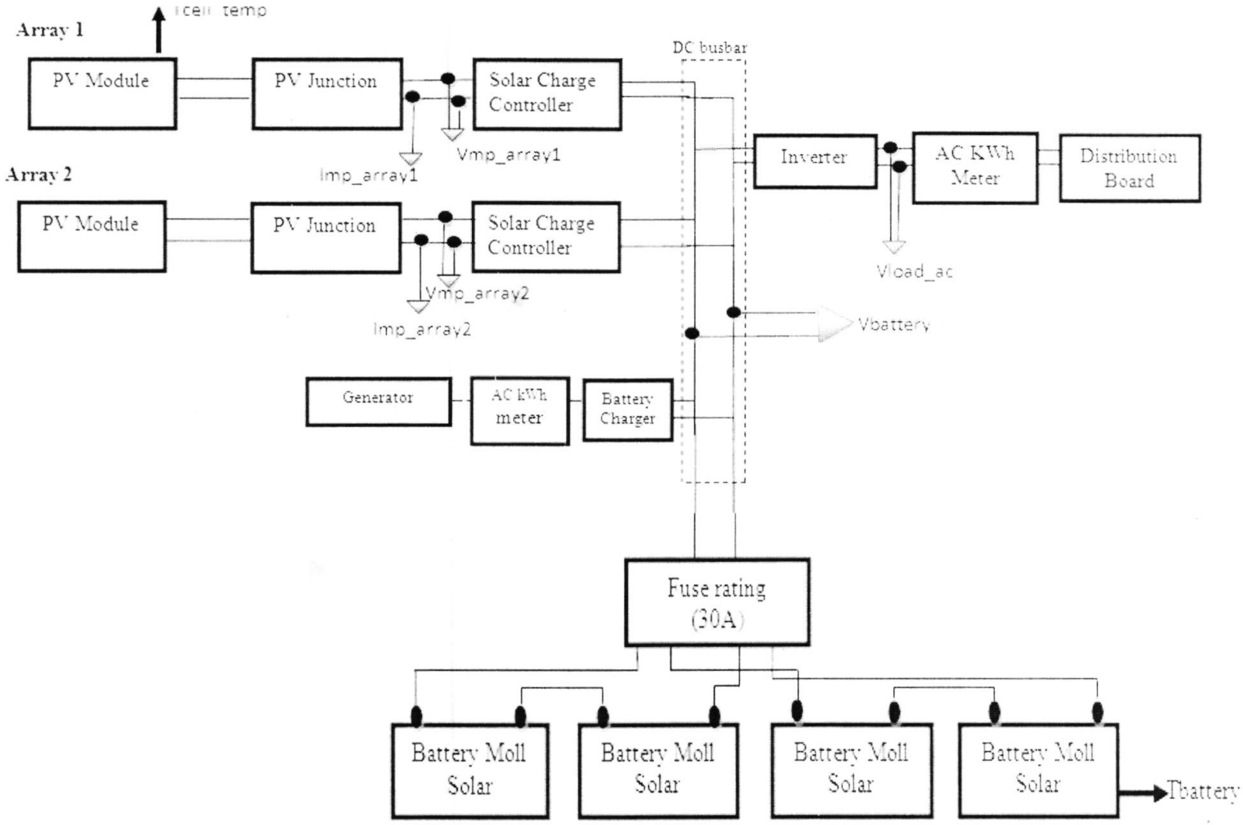

Figure 1. The parameters were measured in PV system

The measurement of the array temperature and battery temperature is detected by PT100 Thermocouple Type K. Sensors for current in two PV arrays are detected by current transducer (LEM HAS50-S). The voltage of battery and two PV arrays are detected by using voltage transducer (LV25-P) and lastly for detecting voltage at AC load by using AC voltage transmitter (CR4620-250).

Another sensor available in PVSCADA kit is to measure voltage at generator by using loop powered AC voltage transmitter (CR4620-250) and the current of generator and AC load by using loop powered AC current transmitter (CR4220-15).

From the PVSCADA kit, datalogger recorded all data that were detected by sensors and transferred, stored into computer or the logger using the DataView software. DataView software will download, display and analyze recorded data. The software provides a convenient way to configure and control power analysis tests from the computer. Results can be displayed in real time [3]. Figure 2 shows the parameters were accumulated in datalogger.

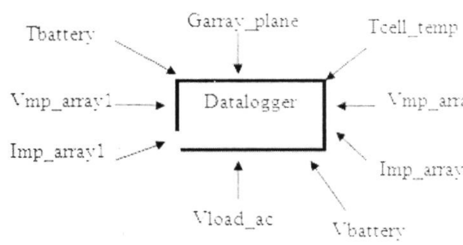

Figure 2.The parameters were recorded in datalogger

II. METHODOLOGY

The real data used for this study were collected using precision electronic devices at Photovoltaic Energy Applications Research Laboratory in Akademi Pengajian Bahasa, UiTM.

The data were taken every 2 hours in 5 times per days once a week for a period of 2 months. Every data of solar irradiance, temperature, voltage and current were taken repeatedly for at least 3 times to ensure no precision error and random error caused by the random nature of atmosphere.

During the field work, many precision electronics devices have been used in according to standard sensors used in PVSCADA kit. The description of the devices being used are as per below.

A. Hand pyranometer with display

Pyrometer is designed for field measurements of global solar irradiance. It is supplied with a digital display for direct read out of the irradiance in watts per square meter. The device is powered by a 9 volt battery. [4]

B. *Raytek MiniTemp MT4 (Non-Contact InfrarRed Thermometer)*

Raytek MiniTemp MT4 (Non-Contact InfrarRed Thermometer) is used to determine cell temperature and solar battery temperature. The Raytek MiniTemp MT4 (Non-Contact InfrarRed Thermometer) has temperature range between 18 to 400 °C (0 to 750 °F). [5]

Raytek MT4 MiniTemp is designed in pocket sized and easily to be use by just pointing, shooting and reading the temperature on the large backlit display. The MiniTemp MT4 has laser sighting to ensure aiming accuracy. [5]

C. Megger AVO300 series (Digital multimeter)

The AVO300 range of Megger digital multi-meters are tough compact instruments. Both instruments offer a range of measurement modes for AC and DC applications, resistance and current measurement. [6]

Verification of PVSCADA kit can be done by using digital multimeters by taking data measurement of DC voltage in batteries, array1, and array 2, and AC load. 4 digital multimeters are needed to be applied in the field measurement.

D. Extech 382065/382068 Datalogging AC/DC Power Clamp-on Meter.

Measurements include DC and AC True Power, Apparent Power, Power Factor, and True RMS Voltage, Current, and Watts. The jaw opening for cables is φ 1.8" (46mm). [7]

Current at array 1 and array 2 is measured using the clampmeter. The measurement are done by connecting it to wire that was attached to 20A (negative terminal) circuit breaker and solar charge controller. There are 2 solar charge controller required located at array 1 and array 2. The primary function of a solar charge controller is to prevent the battery from being overcharged.

III. RESULTS AND ANALYSIS

In order to understand the performance PVSCADA kit, 2 factors need to be considered; accuracy and sensors.

Accuracy is defined as; "The ability of a measurement to match the actual value of the quantity being measured" also can be known as percentage of error. Meanwhile full scale is the maximum measurable pressure for a particular measurement instrument. The formula to calculate accuracy of full scale is as per shown below:

:

Accuracy of full scale or percentage of error

$$= \frac{\text{RDV} - \text{DV}}{\text{DV}} \times 100\%$$

RDV= real data value

DV= datalogger value

Table I show the real data and datalogger from solar irradiance and observe that the percentage of error is between -2.98% to 5.49%. The percentage of error is highest at 402W/m^2 and the lowest percentage of error is defined at 278 W/m^2.

The percentage of error is almost good. The irradiance sensor applying in PVSCADA kit is almost accurate. It is due to solar pyronometer in measure real data changes fastest according to solar light (solar irradiance reading is high when the surrounding environment is clear and lower at cloudy environment). But using the irradiance sensor can acquire the relative distance and relative velocity between the PV array and the surrounding.

Based on the specifications of irradiance sensor the typical error under these conditions is ±

5%. It shows that the irradiance sensor is under the limit of percentage of error.

However, even if the PV arrays are in range of detection, the PV array that see from the sensor and are completely occluded by other power losses as example grid coverage, reflection loss and electrical resistance.

TABLE I: PERCENTAGE ERROR RESPECTED TO SOLAR IRRADIANCE

Garray_plane (W/m^2) (real data)	Garray_plane (W/m^2) (datalogger)	Percentage of error (%)
120	114.9551	4.39
278	286.5426	-2.98
332	339.624	-2.24
402	381.0609	5.49
500	513.991	-2.72
720	699.5908	2.92
935	889.0154	5.17

Table II shows the result of cell temperature measurement for real data and datalogger. The range of percentage of error are good which in range from -3.81% to 3.03%. It shows that the PT100 platinum resistance thermometer sensor is gives lowest percentage of error and excellent accuracy of full scale. A further advantage is that platinum sensors are available in the most diverse designs, with thread.

Totally enclosed variants to withstand over the most diverse chemicals or very small held for miniaturized applications in PV system. It is also favorable that platinum sensors flowed through only from a direct current. A main advantage of the platinum sensors is naturally the very high linearity of their resistance versus temperature, a good basis for precise measurements.

TABLE II: PERCENTAGE OF ERROR RESPECTED TO TEMPERATURE CELL

Tcell_temp (°C) (real data)	Tcell_temp (°C) (datalogger)	Percentage of error (%)
36.0	37.01023	-2.73
42.0	41.97165	0.07
50.4	49.59059	1.63
52.8	54.38873	2.92
54.2	52.94085	2.38
55.3	53.67442	3.03
63.7	66.22146	-3.81

The temperature of the battery can be a major factor in sizing the PV system. Lead acid battery capacity is reduced in cold temperatures. Lead acid battery life is shortened in high temperatures. It should be noted that the temperature of the battery itself and ambient temperature can be vastly different. While ambient temperatures can change very quickly, battery temperature change is much slower. This is due the mass of the battery. It takes time for the battery to absorb temperature and it takes time for the battery to relinquish temperature.

In many cases it can be difficult or impossible to heat or cool the battery and temperature into consideration must be taken. A battery that is required to operate continuously at 0° F. (-18° C.) will provide about 60% of its capacity. This same battery operated continuously in a 95° F. (35° C.) environment can lose half its expected life [8].

Tables III shows the percentage of error resulting from the comparison of battery temperature are good which in range of$\pm$4%.Battery temperature also detected using PT100 platinum resistance thermometer. As a PT100 platinum resistance thermometer is basically a resistor, its value can be measured with an Ohmmeter. However, the low resistance of the sensor and its low sensitivity (0.385Ω/°C) make accurate measurements difficult due to lead resistance.

A 1 Ω resistance in each lead connecting the PT100 platinum resistance thermometer to the meter will cause an error of more than 5 °C. So to avoid the problem of lead resistance errors, most PT100 platinum resistance thermometer measurements are made using a 4-wire configuration. Here, two of the wires are used to provide an excitation current and the other two connect a voltmeter over the Platinum resistance thermometer. Provided the impedance of the voltmeter is high then a few Ohms of resistance in the cables will not cause an error. Therefore by applying PT100 platinum resistance thermometer as sensor in PVSCADA kit gives the best reliable data in monitoring the performance of PV system.

TABLE III: PERCENTAGE OF ERROR RESPECTED TO BATTERY TEMPERATURE

Tbattery (°C) (real data)	Tbattery (°C) (datalogger)	Percentage of error (%)
30.0	29.0967	3.10
30.8	32.07945	-3.99
31.8	32.08098	-0.88
35.6	35.57452	0.07
36.4	35.85432	1.52
51.8	50.38989	2.80
53.7	55.78001	-3.78

The percentage of error in voltage at array 2 in table IV is range from -0.45% to 1.43% that means using voltage transducer, the performance data of PVSCADA kit is accurate. The voltage transducer application with true r.ms voltage monitoring will detect below normal or "brown out" voltage conditions and protect against possible motor at array 2 overheating. It also identifies phase loss conditions by detecting voltage reduction. PVSCADA kit with voltage transducer sensing can monitor over voltage conditions associated with regenerative voltage to help in diagnosing or avoiding PV system issues.

TABLE IV: PERCENTAGE OF ERROR RESPECTED TO MAXIMUM POWERVOLTAGE AT ARRAY 2

Vmp_array2 (Vdc) (real data)	Vmp_array2 (Vdc) (datalogger)	Percentage of error (%)
24.80	24.91288	-0.45
25.76	25.61243	0.59
26.42	26.11121	1.18
27.12	26.73827	1.43
30.58	30.22488	1.17
40.10	39.94051	0.40
41.65	25.63711	0.08

Table V shows the percentage of error in voltage at array 1, is between -1.84% *to* 1.48%. It is also presents that the voltage transducer sensor applying in PVSCADA kit gives a good accuracy of full scale.

As information, when voltage is reducing, the cell temperature is increases, thus the temperature coefficient of the resistor is a key aspect for PVSCADA kit exhibit some variance with temperature. If the resistor has a large variance with temperature, the accuracy of the PV system will also vary with temperature. Self-heating of the resistor must also be considered.

A typical design of 5V DC at full scale (20mA) requires a nominal resistance of 250 Ω (5/0.020). The power generated in this resistor at full scale is Volts times Amps or 5 X 0.020 = 0.100 Watts. Choosing a 1/8 Watt (0.125) resistor will provide reasonable safety against destruction, but will cause a significant temperature rise in the resistor. This rise in temperature can result in significant changes in the value of the resistance. For instrumentation, a resistor with a power rating of at least 10 times the expected full scale power is recommended. [8]

Therefore, the resistor should be mounted as close as possible to the PVSCADA kit. Once the signal is converted from current to voltage, voltage drops from wire resistance introduces errors in the signal. In this case, whenever possible, use similar materials for all wire connections in PV system.

Vbattery (Vdc) (real data)	Vbattery (Vdc) (datalogger)	Percentage of error (%)
25.55	25.29496	-1.00
25.85	26.47205	-2.35
26.05	26.22953	-0.68
26.16	26.69715	-2.02
26.41	26.69456	-1.07
27.02	27.0287	0.032
27.1	27.29437	-0.712

TABLE VI: PERCENTAGE OF ERROR RESPECTED TO VOLTAGE AT BATTERY

TABLE V: PERCENTAGE OF ERROR RESPECTED TO MAXIMUM POWERVOLTAGE AT ARRAY 1

Vmp_array1 (Vdc) (real data)	Vmp_array1 (Vdc) (datalogger)	Percentage of error (%)
15.45	15.22443	1.48
25.94	25.98379	-0.17
25.99	26.2138	-0.85
26.43	26.92467	-1.84
26.49	26.50242	0.05
26.54	26.28765	0.99
26.87	26.52837	1.29

Due to their multiple parallel modular units and absence of electromechanical rotating masses, fuel cell and battery power plants are more reliable than any other forms of power generation [9].Consequently, a utility that installs a number of battery power plants is able to reduce its reserve margin capacity while maintaining a constant level of the PV system reliability. Hence, to monitor the performance of voltage at battery is necessary to maintain the availability the PV system reliability.

Table VI shows the percentage of error in voltage at battery, is between $-2.02\%\ to\ 0.032\%$. The voltage at battery also detected using the voltage transducer sensor connected in PVSCADA kit. The acquire data obtained from datalogger is highly accurate and can be conclude that the voltage performance at battery is really good.

Table VII shows the voltage at AC load give more constant value in percentage of error from -0.87% to 0.07%. That means the voltage at load AC using the loop powered AC voltage transmitter in PVSCADA kit is perfectly located in PV system.

The CR4620-250, Loop-Powered AC Voltage Transmitters is designed using highly stable state of the art electronics to accept the AC voltage (230V) inputs and power a fully isolated voltage output proportional to the input signal.

TABLE VII: PERCENTAGE OF ERROR RESPECTED TO VOLTAGE AT AC LOAD

Vload_ac (Vac) (real data)	Vload_ac (Vac) (datalogger)	Percentage of error (%)
229.7	227.7186	-0.87
229.8	229.6989	0.05
230.3	230.1338	0.07
230.5	230.4031	0.04
230.7	230.8351	-0.06
230.8	229.5	-0.57
230.9	230.7643	0.06

Table VIII, shows, the accuracy of Imp at array 2 is range from 0.48% to 4.78%.It presents that the current transducer sensor is reliable in PVSCADA kit that is indispensable for monitoring PV System status, detecting process variations, and ensuring personnel safety.

Photovoltaic arrays are used primary in two ways to:

- Charge batteries that are used to power remote loads where installing a connection to the utility grid would be cost prohibitive
- Energize installations where the DC power is converted to 50 HZ AC power through an inverter.

Current transducer is good installed so that the current of the array 1 can be monitored. These transducers are available in bipolar versions so that current may be measured during charging or discharging of the batteries.

Therefore, current transducer types can be connected directly to data systems and display devices, they are ideal for monitoring PV system load that requires an analog representation over a wide range of currents. Current transducer provides high accuracy and wide turndown, and the output signal is inherently isolated from the monitored current. This isolation ensures an almost imperceptible insertion loss (voltage drop) on the monitored circuit.

TABLE VIII: PERCENTAGE OF ERROR RESPECTED TO MAXIMUM POWERCURRENT AT ARRAY 2.

Imp_array2 (Idc) (real data)	Imp_array2 (Idc) (datalogger)	Percentage of error (%)
2.6	2.61262	0.48
3.5	3.53167	0.90
4.2	4.00843	4.78
4.5	4.46524	0.78
4.6	4.52364	1.69
5.0	4.93955	1.05
6.4	6.35198	0.75

From table IX, the percentage of error in real data and datalogger are infinity. If the reading range between $-\infty < x < 0$, the value assume to be zero. It observed that data collected from datalogger are in much smaller values compare to real data. It happens because the rechargeable battery of Imp at array 2 is fully charged and causes the reading data of current transducer sensor applying at array 1 failure to collect the data accurately.

The rechargeable battery systems are used to provide primary power for PV system and back-up systems for critical equipment. DC current flows in one direction during charging and in the opposite direction during battery operation. Traditional current transformers do not work with DC current and using current shunts has been the solution. The shunt operates by producing a voltage potential across its terminals according to Ohm's law.

Current transducer, there is no insertion loss and the output voltage signal is fully isolated from both the DC current being measured and the PV system. The bipolar option also accommodates the change in direction of current flow.

TABLE IX: PERCENTAGE OF ERROR RESPECTED TO MAXIMUM POWER CURRENT AT ARRAY 1

Imp_array1 (Idc) (real data)	Imp_array1 (Idc) (datalogger)	Percentage of error (%)
-0.3	-0.29838	∞
-0.2	-0.28735	∞
1.5	-0.2859	∞
1.8	-0.2881	∞
2.3	-0.28747	∞
2.5	-0.28725	∞
2.7	-0.28728	∞

IV. CONCLUSION

The PVSCADA kit which monitors performance of PV system has been described by comparison datalogger and real data from precision devices. The value of monitoring the system has been clearly demonstrated by the diagnostic use of the data by calculating the accuracy of full scale or percentage of error.

This is due by all data measurement and comparison done, the accuracy of full scale or percentage of error of datalogger in PVSCADA kit and real data are good. Higher accuracy is obtained in most of the results of every parameter including solar irradiance, temperature, voltage and current. However during the measurement of maximum power current at array 1, the different are very high (∞).

This PVSCADA kit is feasible of measuring, acquiring, processing and storing data related with data of performance parameters on solar irradiance, temperature, voltage and current of the electrical power generated by PV system. Tests carried out using precision devices during 2 months of monitoring the PV system described indicate that the PVSCADA kit developed is very reliable. No significant differences were found comparing the values obtained from real data and the different value of datalogger with the PVCSADA kit.

V. RECOMMENDATIONS FOR FUTURE WORK

The work future recommendation is to develop more sensors of parameters including voltage at DC load, current at load DC, Change over time generator, runtime of generator and runtime of load daily in PVSCADA kit Also, the PVSCADA kit will be develop to monitor the VAR and power factor of PV system.

In the industries of electric heaters also are used to supply heat to manufactured products and, storage systems. If a heater fails, the batch or process may have to be scrapped. A real-time indication of heater status improves product quality and production efficiency. So with applying the PVSCADA will allow to monitor the heaters is on or off status, alarm the failure and automatically switch on a back-up heater.

In the other industries power plant including Hydrocarbons (oil, coal, natural gas, etc.) and nuclear also can apply the PVSCADA kit as effective monitoring operation of the electrical transmission system because the industries is critical to the health, safety, and economic viability of modern society. Electrical grid operations are becoming increasingly dependent upon information systems. Standardized open protocols are replacing more obscure vendor-specific SCADA protocols. Interconnectivity of SCADA systems to other information networks is becoming more prevalent. These trends create new vulnerabilities. Compromises in the confidentiality, availability, or integrity of these systems can potentially impact the reliability of system operations.

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