Australian Journal of Basic and Applied Sciences, 10(11) Special 2016, Pages: 307-314

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Fabrication and Analysis of the Characteristics of the Grid-Connected Photovoltaic System based on LabVIEW

Napat Watjanatepin

Solar Energy Research and technology Transfer Center, Faculty of Engineering and Architecture Rajamangala University of Technology Suvarnabhumi, 11000, THAILAND

Address For Correspondence:
Napat Watjanatepin, Solar Energy Research and technology Transfer Center, Faculty of Engineering and Architecture Rajamangala University of Technology Suvarnabhumi, 11000, THAILAND

ARTICLE INFO

Article history:
Received 3 March 2016
Accepted 2 May 2016
published 26 May 2016

Keywords:
Photovoltaic grid-connected system, Analysis characteristic, LabVIEW, monitor program, Data acquisition, efficiency of GC inverter.

ABSTRACT

The aim of this work is to fabricate the LabVIEW PC-based monitor system and to use it for the analysis of the characteristic of Grid-connected Photovoltaic (GCPV) energy system on a demonstrative scale. The characteristics of the software are that it is able to measure and display real-time data and is able to interface with the DAQ hardware. The GCPV can be used for demonstrations and experiments in the laboratory. The results can show analyzed characteristics of the GCPV energy system, such as; the relationship between DC power DC current and DC voltage of the PV panel as well as the relationship of DC power and AC power on the connecting mode and disconnecting mode of GC inverter. The calculating results of the efficiency of the GC inverter can also be shown. Moreover, this system could be applied to monitor the GC PV system of up to 1.8kWp without the addition of hardware and software. There is also a possibility to be used for the training program for technician or engineers in the solar PV industry, and for the PV system research study.

INTRODUCTION

In 2012, the ministry of Energy of Thailand presents the Alternative energy Development Plan (AEDP; 2012-2020), there is a focus on the renewable energy resources. Thailand's goal is to meet 25% of energy consumption from renewable resources by 2021. The target is about 13.5 GW of power capacity from renewable energy. The target for solar energy is about 3 GW in 2012. In 2013, the Energy Regulatory Commission (CRE) announced the new Feed-in tariff program to promote the solar rooftop and solar farm and solar community projects. The new Feed-in tariff will be paid throughout 25 years and the new target increased to 3.8 GW. The results found that the solar "very small power plant" (VSPP) and Solar "small power plant" (SPP) project in Thailand is equal to 285 projects by the end of 2014. The total capacity is about 1.353 GW or 35.690% of the goal. Thailand has to continue with the solar project especially the grid-connected (GC) Photovoltaic (PV) on the rooftop and in the government building and the government land to meet the target before 2021. These policies then pushed the solar industry and finance company to grow up very quickly which led to a high number of the SMLs in solar PV sectors in Thailand. However, the solar PV companies need to adjust themselves in the term of skills and knowledge of professional team, and use the new technology for PV panel, the inverter, the installation techniques and the maintenance procedure. (Energy Policy and Planning Office, 2015)

The GC-PV energy system and peripheral devices has a very fast growth rate in the Thai markets. Therefore, the study of characteristic of the GC PV System is very important because the people in this sector

To Cite This Article: Napat Watjanatepin., Fabrication and Analysis of the Characteristics of the Grid-Connected Photovoltaic System based on LabVIEW. ***Aust. J. Basic & Appl. Sci.,*** *10(11): 307-314, 2016*

Australian Journal of Basic and Applied Sciences, 10(11) Special 2016, Pages: 307-314

need to improve their skills and knowledge to become more professional. The study then needs to employ the use of good sensors and good monitoring systems. The monitoring system must be able to measure all parameter and has high accuracy, open source data based. It must also be able to display any measurements and convert to information. Moreover, it must be easy to connect to measurement wires and be easily accessible to the use of the PC based or Web based monitoring. (Agrawal and Mittal,2014) The wired monitoring system provides the reliable solution and is appropriate with the laboratory application. This study will be focusing on the study the characteristic of the GCPV system.

The objective of this work is to fabricate the LabVIEW monitor system and analyse the characteristic of GCPV energy system on the demonstrative scale. This project is applied in the laboratory of faculty of engineering and architecture of Rajamangala University of Technology Suvarnabhumi, Thailand. This development achieved in getting the GCPV energy system demonstration set with LabVIEW based monitor. This result in an beneficial setup that can transfer the knowledge and skills to the engineering students and for training the technician who are working in solar PV sector.

Table1 The characteristics of previous monitoring systems for PV energy system

Year	Author	Data transmission mechanism	PV system type	Control and interface devices	Sampling time	Monitoring method	Software
2005	Papadakis, Koutroulis, and Kalaitzakis	Wireless : RF	Hyb: PV and wind	PCI DAQ card	1 m	Web	VB, SQL server 2000
2006	Forero, Hernàndez, and Gordillo	Wired : RS232	SA	FP DAQ board	<30 s	PC	LabVIEW
2006	Soler-Bientz, Ricalde-Cab, and Solis-Rodriguez	Wired : RS232	SA	FP	1 m	PC	LabVIEW
2007	Gagliarducci, Lampasi, and Podestà	Wireless : GSM	SA	FP DAQ	1 m	PC	LabVIEW
2009	Boonmee, Plangklang, and Watjanatepin	Wired	GC (5 kW_P)	DAQ card	-	PC	LabVIEW
2009	Benghanem	Wireless : RX5002	SA	PIC 16F877	-	PC	MATLAB
2010	Ayompe, Duffy, McCormack. And Conlon	Wired : RS485	GC (1.72 kW_P)	DAQ unit	5 m	PC	Not mentioned
2011	Anwari, Dom. And Rashid	Wired : RS232	GC (700W_P)	PIC 16F877a	1 s	PC	MATLAB,LabVIEW
2011	Ranhotigamage and Mukhopadhyay	Wireless : Zigbee	SA	µC	1 s/ less	PC	Not mentioned
2012	Wittkopf, Valliaappan, Liu, Ang and Chenge	Wired	GC (142.5 kW_P)	Not mentioned	5 m	PC	Matlab
2012	Carullo and Vallan	Wired	GC	NI DAQ card	1m	PC	LabVIEW
2012	Park, Shen. Kim, and Rho	Wire/wireless: Ethernet	SA (50kW)	HMI, PLC	-	PC	Autobase
2012	López, Mantiñan, and Molina	Wireless : Zigbee	GC (1.28 kW_P)	DSP	-	PC	LabVIEW,C
2013	Chouder, Silvestre, Taghezouit, Karatepe	Wired : GPIB	GC (9.6 kW_P)	DAQ - GPIB	-	PC	LabVIEW
2014	Montero, Santiago, Rodriguez, Calvo	Wired : RS485	GC (217.6 kW_P) (17.8 kW_P)	Web Box (SMA)	5 m	PC	virtual C# MySQL
2015	Milosavljević, Pavlović, Piršl	Wired : -- Wireless : Bluethoot	GC (2 kW_P)	Web Box (SMA)	10 m	PC	Not mentioned
2015	Shariff, Rahim, Ping	Wireless : Zigbee	GC (1.25 kW_P)	PIC 18F553	1 - 5 m	Web based	Java
2015	Sundaram, Chandra Babu	Wired : RS485	GC (5MW_P)	Not mentioned	5 m	PC Server	SCADA
2015	Ahmed, Kassas, Ahmed.S.E	wired : USB	SA (150 W_P)	DAQ - NI	5 m	PC	LabVIEW

SA= Stand-alone system, CG=grid-connected system, PC= personal computer, µC= micro controller, FP=field point DAQ, DAQ=data acquisition, VB=virtual basic programming

Literature Review:

The studies of previous research about the monitor system, which are related to the monitoring of the GC–PV energy system, have been reviewed and summarized in the Table 1

There are studies about five major characteristic of PV energy systems, such as: Data transmission mechanism, Control and interfacing devices, sampling time, monitoring method and software.

a) Data transmission mechanism:

The data transmission for the PV energy system involves the wire and wireless systems. For the wired system, they are usually connected by RS232, RS485 Ethernet and USB cables. (Forero et al., 2006) (Soler-Bientz et al., 2006) (Ayompe et al., 2010) (Anwari et al., 2011) (Park et al., 2012) (Montero et al., 2014) (Sundaram et al., 2015) (Ahmed et al., 2015) Usually, the GC – PV system uses the RS232 and RS485 cable to achieve data transfer mechanism. For wireless system, this is done by the radio frequency (Papadakis et al., 2005), GSM (Gagliarducci et al., 2007), Zigbee (Ranhotigamage et al., 2011) (López et al., 2012) (Shariff et al., 2015) and Bluetooth technology. (Milosavljević et al., 2015) In all cases, this mainly depends on the distance between the location of the sensors and the host of monitoring system. For instance, the SA – PV in the remote area will use GSM or RF, but RF is more commonly used because it is cheaper than GSM. Therefore, one factor affecting the choice of the date transfer mechanism is the cost in regards to the data transfer rate.(Shariff et al., 2015)

b) Control and interface devices:

The function of controller and interface devices is to handle all data from the sensors to the end users. The most popular devices is data acquisition such as PCI–DAQ(Papadakis et al., 2005), FP–DAQ (Ayompe et al., 2010) (Soler-Bientz et al., 2006) (Gagliarducci et al., 2007), DAQ card (Boonmee et al., 2009) , DAQ unit (Ayompe et al., 2010), NI – DAQ card (Carullo and Vallan , 2012) (Ahmed et al., 2015), Some of PV monitoring systems used microcontroller such as µc, PICICF877 (Benghanem, 2009) (Anwari et al., 2011) and PICI8F553(Shariff et al., 2015). Another system used web BOX which is an interface device of SMA for grid-connected inverters system. (Montero et al., 2014) (Milosavljević et al., 2015)

C) Sampling time:

From the past ten years, the sampling interval is around 1 to 5 minutes. (Papadakis et al., 2005) (Soler-Bientz et al., 2006) (Gagliarducci et al., 2007) (Ayompe et al., 2010)(Carullo and Vallan, 2012) (Montero et al.,

2014) (Milosavljević et al., 2015) (Ahmed et al., 2015) This is all depending on the parameters that users need to measure. However, the IECG1724 standard states some suggested sampling time which should be selected by the type of parameter recorded.

d) Monitoring method:

There are two major types of monitoring methods. They are PC–based (Forero et al., 2006)(Soler-Bientz et al., 2006) (Gagliarducci et al., 2007) (Benghanem, 2009)(Anwari et al., 2011) (Ranhotigamage et al., 2011) (Wittkopf et al., 2012) (Carullo and Vallan , 2012) (Park et al., 2012) (López et al., 2012) (Chouder et al., 2014) (Montero et al., 2014) and web–based (Papadakis et al., 2005) (Shariff et al., 2015) (Sundaram et al., 2015) monitoring system. Most of them used the PC-based monitor system.

e) Software:

The most popular choice software for monitoring system is LabVIEW, because it is popular to be applied for the control, measurement and monitoring of the real time data for the PV energy system. [20] Some system used the Java applet (Sundaram et al., 2015), Microsoft visual basic, virtual C# for the web–based monitoring system for remote monitoring users (Papadakis et al., 2005) (Montero et al., 2014) (Shariff et al., 2015), However, LabVIEW software is very good match to use with the DAQ compact - DAQ interfacing hard ware.

From the previous literature study, the author could design the monitoring system via LabVIEW environment, the interfacing device choose DAQ from National Instruments, with wired USB cable. The sampling interval is able to adjust between 1 s to 300 s. It is a PC-based monitoring method.

MATERIALS AND METHOD

Hardware fabrication:

The concept to design the hardware involves the use of products that can match with the LabVIEW environments. The GC photovoltaic energy system that the author designed are as follow:

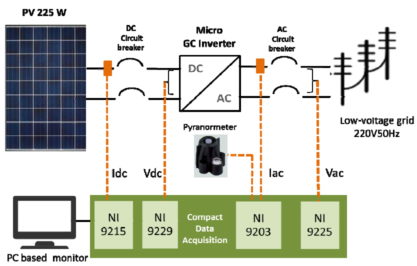

Fig. 1: The GC photovoltaic energy system with interfacing module diagram.

(1)System input voltage is 24 V_{DC} (2) System output (low-voltage grid) is about 230V_{AC}50Hz. (3) A multi-crystalline type of solar panels is 225W_p, V_{mp}=29.2V, I_{mp}=7.71A. (4) The grid-connected inverter is in the major device in this system. The inverter specification is 180-275 Watt(input power) MPPT voltage range is 22-45V, Maximum input voltage is 55V, maximum in put current 12 A, maximum output power 250W at 1.2A, output voltage 230V(range 189V-253V), frequency 50 Hz, peak efficiency 95.7%, power factor >0.95, standard IEC 62116. (5) The pyranometer 6450 solar radiation sensor was applied to this system. The hardware diagram of GCPV system as shown in figure 1, and the 250W GC inverter and the other equipment's such as current sensor, low-voltage

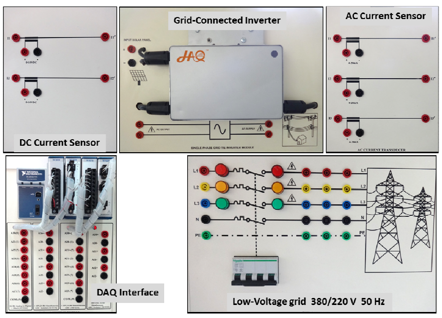

Fig. 2: The micro GC inverter (250W), DAQ interface, current sensor, and the grid disconnecting switch.grid, disconnecting switch and DAQ interface are as shown in figure 2. The hardware for experimental set up is as shown in figure 3

Australian Journal of Basic and Applied Sciences, 10(11) Special 2016, Pages: 307-314

Table. 2: The system hardware of the GC PV energy system with the data acquisition.

The system hardware				
GC PV energy system		DAQ devices		Details
PV	Multi-crystalline 225Wp			
	Vmp= 29.2V	NI 9229	input AI1	4-Channel, ±60 V/±10 V, 24-Bit , Analog Input Modules
	Imp = 7.71A	NI 9215	input AI1	4-Channel, ±10 V, 16-Bit ,Analog Input Module
I-DC sensor	DK 20 C10 U convert 0-15 A to 0-10 VDC			LEM
Inverter	180-175Vdc/230Vac	NI 9225	input AI0	300 Vrms, Analog Input, 50 kS/s, 3 Ch Module
	250W Grid-connected	NI 9203	input AI0	8-Channel, ±20 mA, 16-Bit Analog Input Module
I-AC sensor	AK 5 B420L convert 0-5 A to 0-20 mA			LEM
Pyranometer	Input 0-1500 W/m2 output 4-20 mA			Davis Instruments
		NI 9203	input AI1	National Instruments
Chassis NI DAQ		CDAQ 9174		NI cDAQ™-9174 NI CompactDAQ Four-Slot USB Chassis

There are other hardware that is required in this research such as DC current sensor, AC current sensor and chassis NI DAQ including the data acquisitions module. The author selected the DAQ module, in which the 4 channel analog input module (NI 9229) is applied for interfacing with DC voltage and NI 9215 was applied for DC current sensor. The AC voltage interface module (NI 9225) is used for measuring the grid voltage and the AC current interface module (NI 9203) is used to measure the AC current from current sensor and solar irradiance from pyranometer. All are shown in table 2.

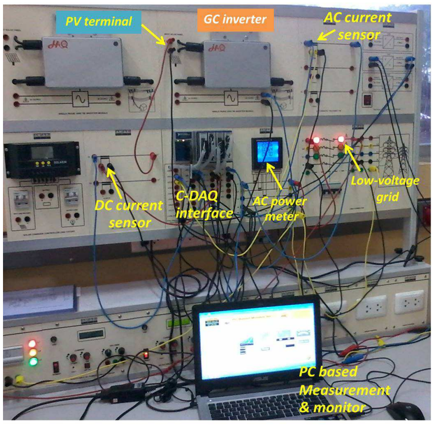

Fig. 3: The experimental setup in the laboratory.

The software development:

The monitoring software was developed by LabVIEW in order to calculate and store data to the MySQL database, communicate with sensors, DAQ module and PC-based system via USB interface. The sampling time that was setup to acquire the data can be adjusted at the default setting to be 30 s(depend on user request) in the data logger mode. However, this software could be used for the in class experiment by the set of time interval to 1-5 s. The user can reading on the screen and makes a graph also.

The program consist of nine major subprograms with the following functions which are; (1) Acquire to interface compact DAQ (2) Acquire solar irradiation from a pyranometer. (3) Acquire and calculate data from DC power. (4) Acquire and calculate data from AC power. (5) Scale data from sensor. (6) Save data to the database.(7) Setting parameter. (8) Make a report. (9) Display monitoring data. As shown in figure 4.

Fig. 4: Diagram of the LabVIEW based monitor program for GCPV system.

The author could show some of the major VI block that was developed from LabVIEW. For example, the VI-block (2) Acquire solar irradiation from a pyranometer is as shown in figure 5. That will show you about, How to get and display the measurement data from pyranometer?

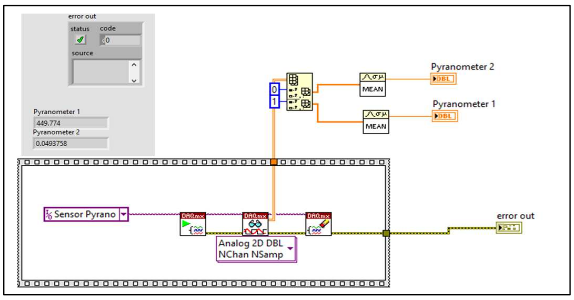

Fig. 5: VI block and measurement test of solar irradiation, sub-program (2).

The VI-block (3) Acquire and calculate data from DC power sub-program is as shown in figure 6. Lastly, the VI-block (4) Acquire and calculate data from AC power as shown in figure 7. The VI-block (3) and (4) could show the acquire technique to get the data from V-I sensors and the way to calculate and display them on the screen.

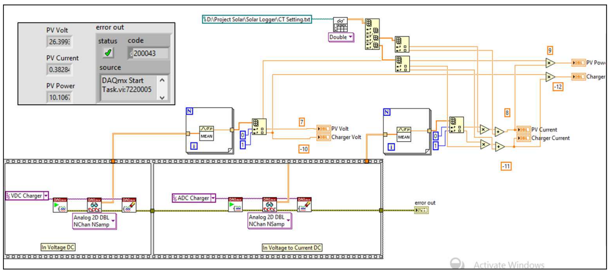

Fig. 6: VI block and measurement test of PV power, sub-program (3).

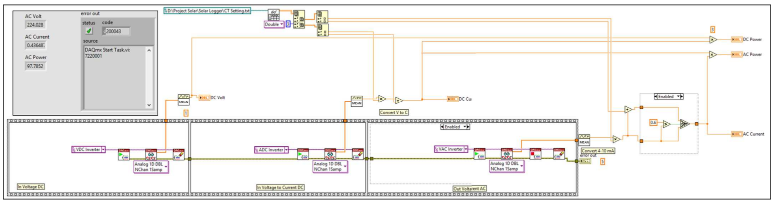

Fig. 7: VI block and measurement test of AC (Grid) power, sub-program (4).

RESULTS AND DISCUSSION

1.Developing the LabVIEW monitoring system:

The software that was developed is as shown in figure 8. This software can measure the solar irradiance, DC voltage, DC current from solar panels as well as calculate the power and display to the laptop monitor. This software can measure and display the real time data measurements of grid-voltage, AC current, power and energy that the PV sends to the utility grid. This means that the hardware that the author chose for this system works very well. It supports the software that the author developed to measure and display as well. This experimental testing was done on 15 October 2015 , the author set up the sampling time to acquire data is on the 30 s interval.

2.Characteristic of GCPV energy system:

The results of study will show you the relationship between DC power, DC current and DC voltage of the PV panel as well as the relationship of DC power and AC power on the connecting mode and disconnecting mode of GC inverter. The calculating results of the efficiency of the GC inverter. Moreover, this study could help the author to understand the operating of GC inverter in the real environment.

Figure 9 shows the measurement results of the solar irradiance on the experimental day. This is the cloudy day. The graph show that the irradiance in not to strong at noon.

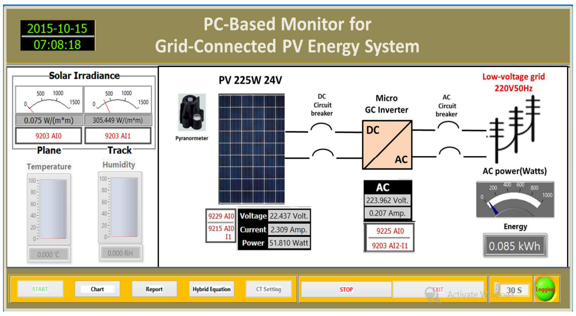

Fig. 8: Front page of the GC PV energy system monitor program.

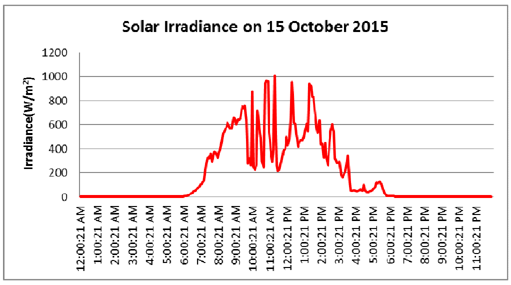

Fig. 9: Measurement results of the solar irradiance.(15 October 2015).

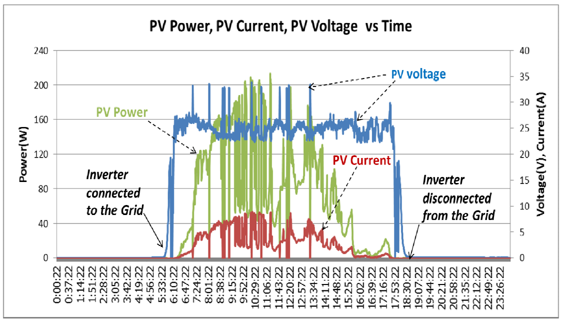

Fig. 10: Measurement results of the voltage current and power from photovoltaic panel. (15 October 2015).

The data from the DC part of GC PV energy system is as shown in figure 10. The invertor will connect to the grid around 6:10:22 a.m. and disconnect from the grid around 18:30:22 p.m.

During the grid-connecting time, the blue line was presented the DC voltage from PV. This shows about 25V-27V in the connecting mode and is around 33V in the disconnecting mode. This case the micro GC-inverter will operate in MPPT mode. Figure 10, the green line displayed the PV power and the red line showed the PV current.

Their shapes are similar to the solar irradiance (figure 9). This means that the DC power and DC current are depending on the Sun irradiance. The maximum DC power is about 210 W, and the maximum current is around 8.5 A at the same time.

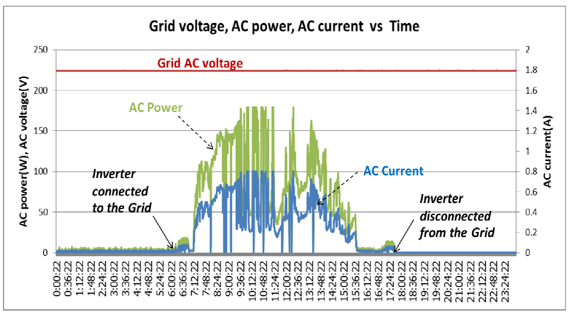

Fig. 11: Measurement results of the voltage current and power from the low-voltage grid. (15 October 2015).

According figure 11, the grid voltage is still constant around 225V (red line) all the time in the case that the GC inverter could be connected or disconnected to the grid. But the power will be fed to the grid when the GC inverter is operating during the day time. The green line will show that the maximum AC power is about 180W, and the maximum AC current is about 0.8 A(blue line).

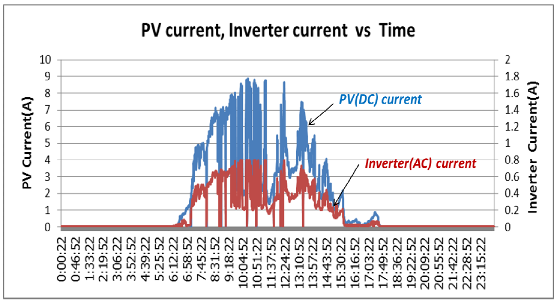

Fig. 12: Comparison the DC and AC current of the GC energy system. (15 October 2015).

The study of relationship between the input current and the output current is as shown in figure 12. They have the same shapes but the amplitude is different.

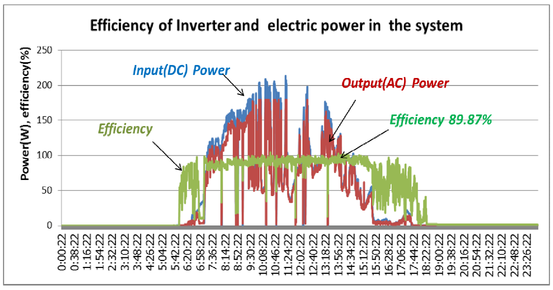

Fig. 13: The graphical calculation of efficiency of the GC energy system. (15 October 2015).

The efficiency of the inverter can be calculated by the input power and output power via the equation (1). The green graph (figure 13) will show the efficiency of GC inverter is around 89.87 % if the inverter connects to the grid and solar irradiance is still higher than 400 W/m^2. But the efficiency will be lower than this if the invertor is non-permanently connected to the grid, which is at early morning and in the evening. Because the solar irradiance will be low, it is not enough to let the invertor operate in MPPT mode.

In the same way the scratch plot between input power and the output power of GC Inverter, as show in figure 14. That user can calculate the efficiency of the GC inverter from the graph. For example the efficiency calculation on the point A, B and C is equal to 87.9, 94.1 and 91.7%.

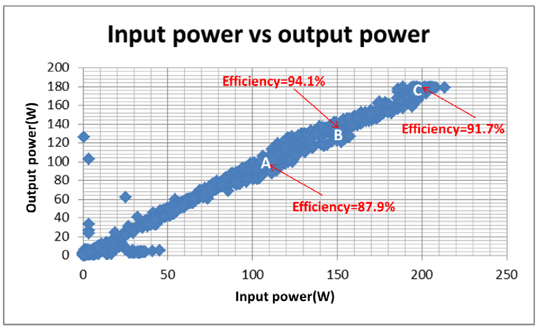

Fig. 14: The scratch plot of input power and the output power of the GC energy system.

Conclusion:

The analysis of the characteristics of the grid-connected photovoltaic system needs the reliable monitoring system. LabVIEW with PC-based monitoring system is the perfect solution. This work is very suitable to study the behavior of the GCPV system, and help us to understand the operation of every equipment's in the GCPV system easily. This system has a high accuracy of measurement, and software that can generate any information.

There is a guideline to design the protection system and the way to choose the right equipment for the GCPV system and also to develop the data acquisition system for the other applications. This system is suitable for training and teaching in order to teach the engineering students and others. Nowadays, Thailand has a renewable energy policy that promotes the solar rooftop and solar building top program across country. This work can support the policy in terms of technician development. Moreover, this system should be applied to monitor the grid-connected PV system up to 1.8kWp ($60V_{DC}/15A_{DC}$) without the need of addition hardware and software.

Future work, the author has an idea to develop the feature of the monitoring software so that it is able to evaluate the performance of GCPV energy system.

REFFERENCES

Aissa Chouder, Santiago Silvestre, Bilal Taghezouit, Engin Karatepe, 2013. Monitoring, modeling and simulation of PV systems using LabVIEW, Solar Energy, 91: 337-349

Anwari, M., M.M. Dom, M.I.M. Rashid, 2011. Small scale PV monitoring system software design. Energy Procedia, 12: 586-592.

Ayompe, L.M., A. Duffy, S.J. McCormack, M. Conlon, 2011. Measured performance of a 1.72kW rooftop grid connected photovoltaic system in Ireland. Energy Conversion and Management, 52(2): 816-825.

Benghanem, M., 2009b. Low cost management for photovoltaic systems in isolated site with new IV characterization model proposed. Energy Conversion and Management, 50(3): 748 – 755.

Boonmee, C., B. Plangklang, N. Watjanatepin, 2009. System performance of a three – phase PV – grid – connected system installed in Thailand: Data monitored analysis. Renewable Energy, 34(2): 384 – 389.

Carullo, A., A. Vallan, 2012. Outdoor experimental laboratory for long- term estimation of photovoltaic – plant performance. IEEE Transactions on Instrumentation and Measurement, 61(5): 1307 – 1314.

Chokri Belhadj Ahmed, Mahmoud Kassas, Syed Essamuddin Ahmed, 2015. LabVIEW Based PV Panel Online Characteristics and Parameters Estimation, Procedia Computer Science, 52: 876-882, ISSN 1877-0509.

Dragana, D., Milosavljević, Tomislav M. Pavlović, Danica S. Piršl, 2015. Performance analysis of A grid-connected solar PV plant in Niš, republic of Serbia, Renewable and Sustainable Energy Reviews, 44: 423-435, ISSN 1364-0321.

Trillo-Montero, D., I. Santiago, J.J. Luna-Rodriguez, R. Real-Calvo, 2014. Development of a software application to evaluate the performance and energy losses of grid-connected photovoltaic systems, Energy Conversion and Management, 81: 144-159, ISSN 0196-8904,

Energy Policy and M.O. Planning Office, 2015. Energy Statistics. Retrieved From http://www.eppo.go.th/info/Situation/quarterly/2015_Q1.pdf

Farihah Shariff, Nasrudin Abd Rahim, Wooi Ping Hew, 2015. Zigbee-based data acquisition system for online monitoring of grid-connected photovoltaic system, Expert Systems with Applications, 42-3(15): 1730-1742, ISSN 0957-4174.

Forero, N., J. Hernández, G. Gordillo, 2006. Development of a monitoring system for a PV solar plant. Energy Conversion and Management, 47(15 – 16): 2329 – 2336.

Gagliarucci, M., D.A. Lampasi, L. Podestà, 2007. GSM – based monitoring and control of photovoltaic power generation. Measurement, 40(3): 314 – 321.

Meena Agrawal and Arvind Mittal, 2014. DATA-ACQUISITION & REMOTE MONITORING FOR RENEWABLE ENERGY SYSTEMS. International Journal of Electrical, Electronics and Data Communication, ISSN:2320-2084-2-9.

López, M.E.A., F.J.G. Mantiñan, M.G. Molina, 2012. Implementation of wireless remote monitoring and control of solar photovoitaic (PV) system. In: Transmission and distribution: Latin America conference and exposition (TED – LA). 2012 sixth IEEE/PES (pp: 1 – 6).

Papadakis, K., E. Koutroulis, K. Kalaitzakis, 2005. A server database system for remote monitoring and operational evaluation of renewable energy sources plants. Renewable Energy, 30(11): 1649 – 1669.

Park, J., J. Shen, S. Kim, D. Rho, 2012. Implementation of monitoring and control systems for 50KW PV systems using the wire – wireless. *Network*, 5(1): 45 -54.

Ranhotigamage, C., S.C. Mukhopadhyay, 2011. Field trials and performance monitoring of distributed solar panels using a low – cost wireless sensors network for domestic applications. IEEE Sensors Journal, 11(10): 2583 – 2590.

Sivasankari Sundaram, Jakka Sarat Chandra Babu, 2015. Performance Evaluation and Validation of 5 MWp Grid Connected Solar Photovoltaic Plant in South India, Energy Conversion and Management, 100: Pages 429-439, ISSN 0196-8904.

Soler – Bientz, R., L.O. Ricalde – Cab, L.E. Solis – Rodriguez, 2006. Developing a mobile stand alone photovoltaic generator. Energy Conversion and Management, 47(18 – 19): 2948 – 2960.

Wittkopf, S., S. Valliappan, L. Liu, K.S. Ang. S.C.J. Cheng, 2012. Analytical performance monitoring of a 142.5kWp grid – connected rooftop BIPV system in Singapore. Renewable Energy, 47: 9–20.