

Photovoltaic Wind-Turbine Battery Hybrid System Monitoring using LabVIEW Virtual Environment

MOHAMED ZAHARAN^{1,2} AND ALI M. YOUSEF^{1,3}

¹Jazan University, Faculty of Engineering, Electrical Eng. Dept, KSA

²Electronics Research Institute, PV Dept., NRC Building, 33 El-Tahrir St., Dokki, 12311-Giza, Egypt

³Electrical Engineering Department, Faculty of Engineering – Assuit University

Mbazahran_2007@yahoo.com, drali_yousef@yahoo.com

Abstract: - The purpose of the work is to investigate a monitoring of autonomous photovoltaic battery wind turbine hybrid system (PVBWHS). The PV array, wind turbine and the storage batteries sizes will be estimated based the site of application; Jazan province, KSA. The sizing result of the proposed PVBWHS will estimate the components ratings as well as the ratings of inverter and hybrid system controller.

In this paper an intelligent graphical user interface (GUI) going to be built in sub-menus for system characterization. The PVBWHS modeling, simulation, and performance monitoring will be also introduced. Models are made to simulate the different power sources; PV system, Wind turbine, a storage battery, the electrical loads, and required meteorological conditions. A LabVIEW model will be developed whereby the hybrid system components are simulated as virtual instruments [VI] interacted with functional blocks. The developed monitoring system measures continuously the available power generated from the solar array and wind turbine, and the functional VI compare this with the actual load demand on real time estimates the storage battery operation mode.

Keywords: PV array, wind turbine, sizing, modeling, monitoring system, hybrid system, Meteorological Data Base “MDB”, sensors and actuators, LabVIEW, Virtual Instrumentation.

1. Introduction

Saudi Arabia is a large country with an area of 2.3 million km². It is a relatively rich and rapidly developing country and so demand for electricity is growing on average at around 5% annually. Over the next 25 years, it is estimated that US\$117 billion will be invested in the country's power sector. The state power grid system has supplied electricity to approximately 80% of the population living in the state capitals and industrial centers. It is highly uneconomical to extend the electrical power grid system into the sparsely populated regions of the Kingdom.

Hence there are many small remote communities that need an independent source of electrical energy. These locations represent a significant potential for renewable energy applications. The importance of using renewable energy in Saudi Arabia will not only be confined to meeting the demands of remote sites, but can also contribute to the national grid, helping to meet the peak-load demand during the summer months.

Even though Saudi Arabia is a leading oil producer, it is keenly interested in taking an active part in the development of new technologies for exploiting and utilizing renewable sources of energy. The most natural renewable energy sources which are freely available are wind and solar. The power in the earth's wind and in the solar radiation, which reaches

the earth, is sufficient to make significant as well as strategic contributions to the Kingdom energy supply.

Due to the fluctuating power supplies of the renewable energy sources and the natural varying of the load demands, the hybrid systems that composes a multiple renewable energy sources is preferred compared to standalone's. The proposed hybrid system is comprised of PV, storage battery and wind turbine generator. The combined utilization of these renewable energy sources are therefore becoming increasingly attractive and are being widely used as alternative of oil-produced energy. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. These hybrid energy systems are becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably monitoring and control its operation performance.

The most frequently used hybrid system is the hybrid which consists of Photovoltaic (PV) modules and wind turbines. Because the supply pattern of different renewable energy sources intermittent but

with different patterns of intermittency, it is often possible to achieve a better overall supply pattern by integrating two or more sources [4-7, 11, 18, 21-23].

Optimum match design is very important for PV/wind hybrid system, which can guarantee battery bank working at the optimum conditions as possible as can be, therefore the battery bank's lifetime can be prolonged to the maximum and energy production cost decreased to the minimum.

The main advantages of a hybrid system can be summarized as:

- The possibility to combine two or more renewable energy sources, based on the natural local potential of the users.
- Environmental friendly especially in terms of CO₂ emissions reduction.
- Low cost – wind energy, and also solar energy can be competitive with oil, nuclear, coal and gas energy.
- Diversity and security of supply.
- Rapid deployment - modular and quick to install.
- Fuel is abundant, free and inexhaustible.
- Costs are predictable and not influenced by fuel price fluctuations although fluctuations in the price of batteries will be an influence where these are incorporated.

This paper is organized in ten sections. It starts with introduction followed by block diagram of HS, then the MDB of solar and wind are deduced and compared with pre-measured one's. The GUI of the developed SW package is implemented showing the main control front panel, then system sizing as well as modeling of system components performances. After that the LabVIEW panel for system emulation and monitoring system are presented. At the end, the discussion of system operation and conclusions are given.

2. Block Diagram of a Hybrid System

There are many possible configurations of hybrid power systems. One way to classify systems architectures is to distinguish between AC and DC bus systems. Figure 1 illustrates the block diagram of this configuration.

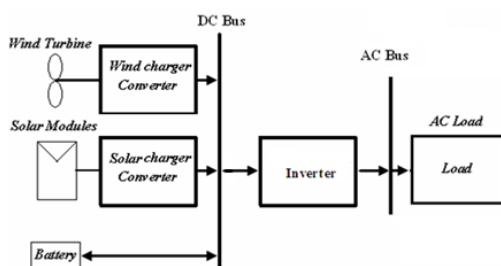


Figure 1, Block Diagram of Photovoltaic Wind Turbine and Storage Battery Hybrid System

DC bus systems are those where the renewable energy components and sometimes even the backup diesel generator feed their power to a DC bus, to which is connected an inverter that supplies the loads. This is for small hybrid systems, as shown in Figure 2. Large power hybrid systems use an AC bus architecture where wind turbines are connected to the AC distribution bus and can serve the loads directly. The configuration used to be evaluated in this thesis has a DC bus which combines the DC output of the PV module, the DC output of the wind turbine, and the battery bank.

The AC bus of this configuration combines the output of the bidirectional inverter, the output of the back-up diesel generator and the load. This parallel configuration requires no switching of the AC load supply while maintaining flexibility of energy source, but the bidirectional power inverter shall be chosen to deal with this mode of operation.

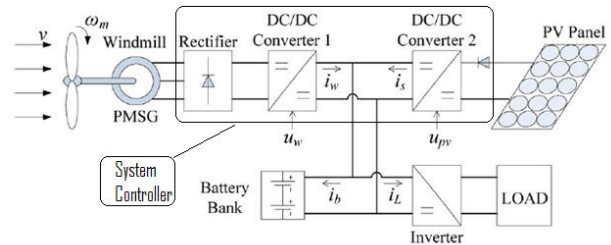


Figure 2, Wiring Diagram of PVWBH System [14]

3. Meteorological Data Base Modeling (MDB)

The site of application weather conditions affects directly the performance of system. Solar radiation affects the generated current value as a major parameter while its affects on solar array voltage is minor. The temperature has a vice versa affects on solar array current and voltage with respect to solar radiation. The wind speed and wind direction affects strongly the output power from wind turbine both as major parameters [3, 26].

3.1. Solar Radiation Modeling

A solar radiation sub-program is built on the LabVIEW GUI and Math-script to calculate the daily average global solar radiation on horizontal and tilted surfaces of solar array.

The extraterrestrial radiation based on the mean Sun-Earth distance, zenith, azimuth, hour angle, solar and local standard time, equation of time and sunrise and sunset hours; all these parameters needed calculating the horizontal and tilted solar radiation are modeled and values are dynamically calculated and

presented in this paper as shown in Figure 3 [5]. In the following two figures; Figure 4 and Figure 5, the details of solar radiation calculation parameters at noon are illustrated.

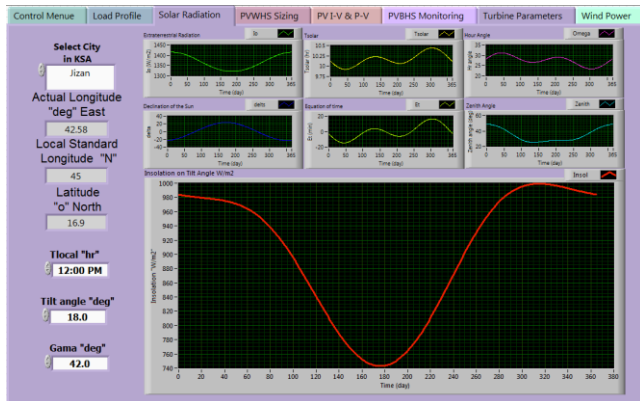


Figure 3, GUI of Solar Radiation at extraterrestrial and on tilt angle of the site of application

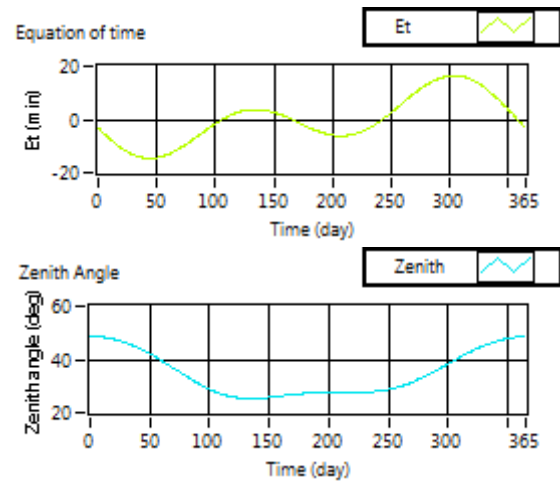


Figure 4, Parameters of Solar Radiation Estimation

In the GUI model of solar radiation it could be noted that, data base of multiple sites of applications in Kingdom Saudi Arabia is added. The control panel has the capability to estimate the different parameters of solar radiation at any local time, any tilt and azimuth angles. The following figure represents a solar radiation at Jazan Province (JP) at noon.

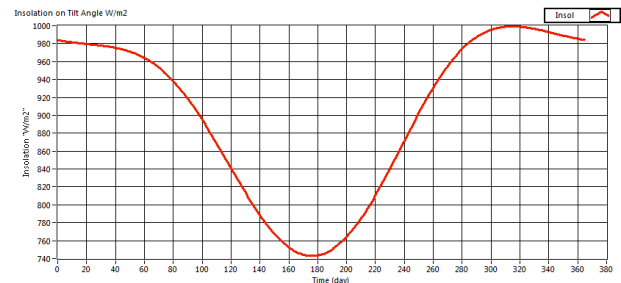
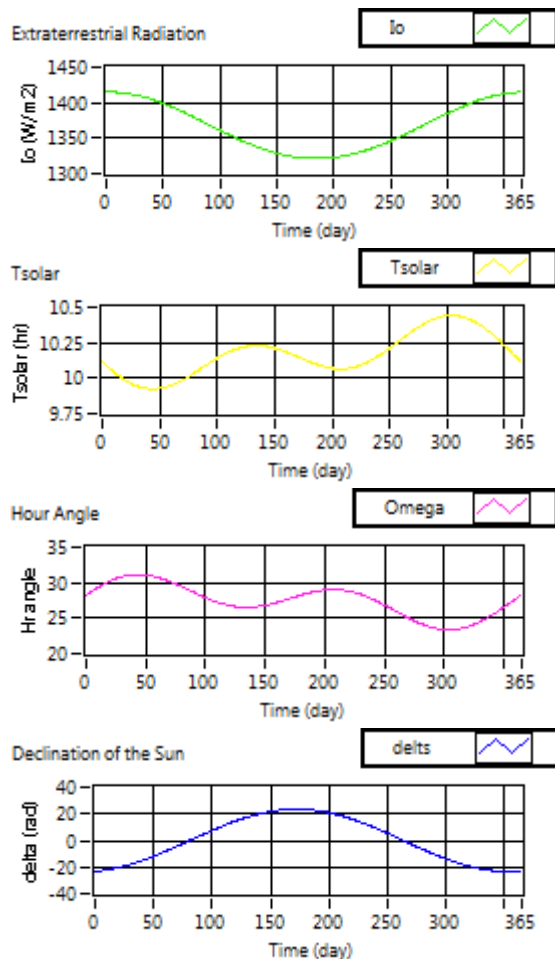


Figure 5, Average daily Solar Radiation at JP at noon.

The following three figures confirm the results taken from the developed software models.

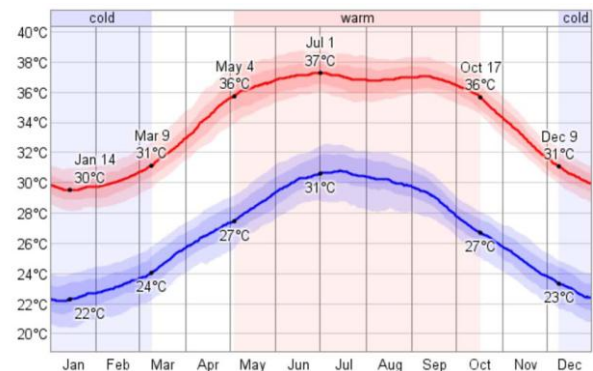


Figure 6, Daily High and Low Temperature

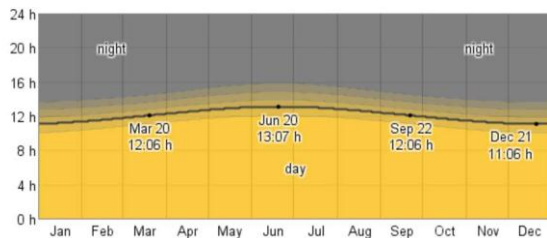


Figure 7, Daily Hours of Daylight and Twilight

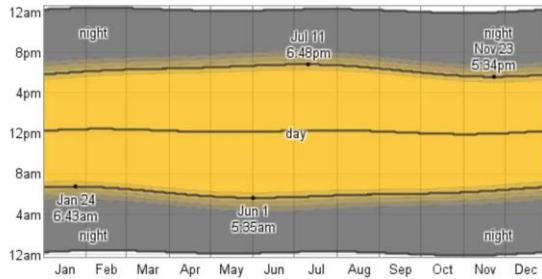


Figure 8, Daily Sunrise & Sunset with Twilight

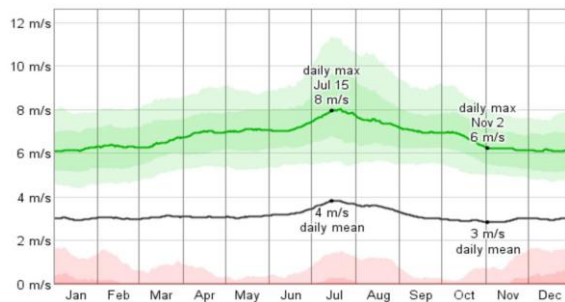


Figure 9, Wind Speed of JP

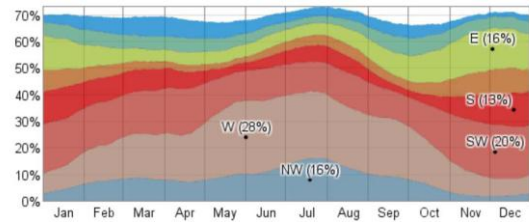


Figure 10, Fraction of Time Spent with Various Wind Directions of JP

4. Wing Energy Meteorological data

The site of application values of wind speed and wind direction are taken from an approved ATLAS of JP. The average minimum and maximum wind speed lies between 3 and 8 m/s, this means that the wind turbine will be in operation and generate sensible values of output power during all the day. The following two figures show the wind speed and wind direction of JP.

5. GUI of PVBWHS Main Control Page

The main front panel page in the developed GUI is introduced in Figure 12. The page contains all the launching buttons of the other GUI pages. It also contains in the middle the toggle switch between “Emulation” or “Hardware”, and the wind speed control bar. In the right side it contains the solar radiation control knob, the read data buffers from data acquisition boards. In the left side, the rotor speed of wind turbine and the wind direction control are allocated. In the bottom of page, the serial interface parameters; lime com port number, baud rate, read buffer, etc are present [2, 8-9, 13-15, 20, 28-29].

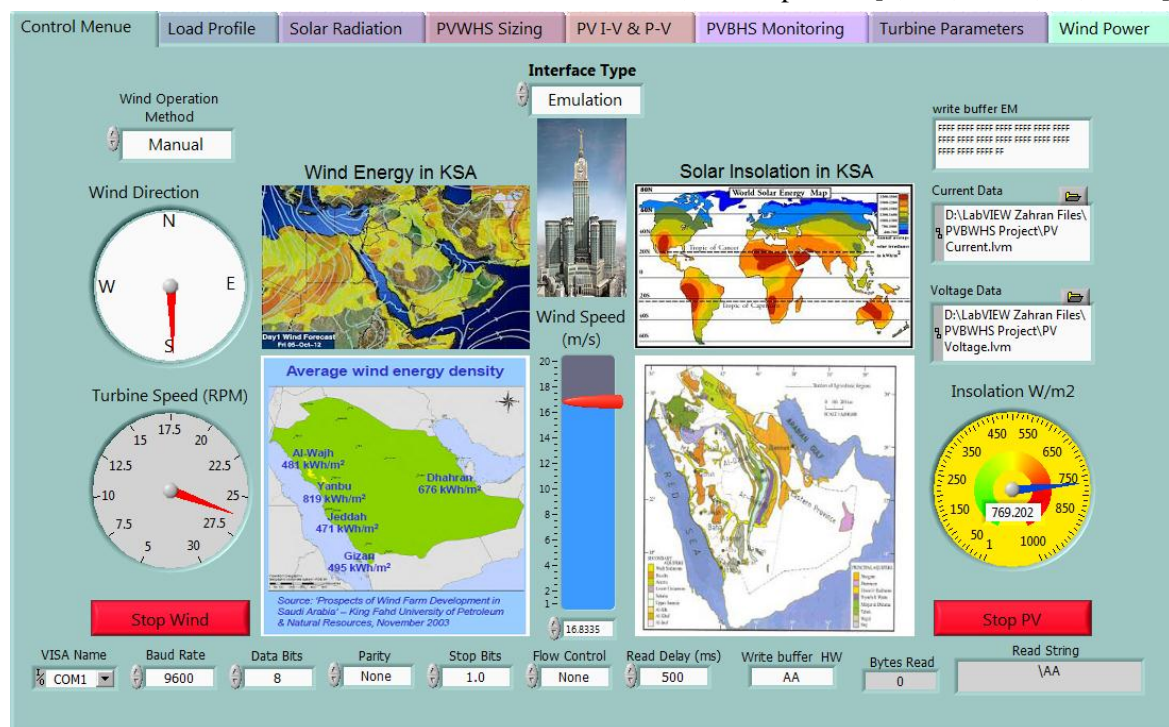


Figure 11, the main Control Page Front panel

6. PVBWHS Components Sizing

The specific output power from the solar array (SA) depends on the type of solar array (SA), MDB parameters, site parameters type, and inclination of SA. The orientation of the solar arrays strongly affects the generated output power [1, 10, 12, 16-17, 24-25]. The energy transfer from the solar array to batteries and loads is shown in Figure 12.

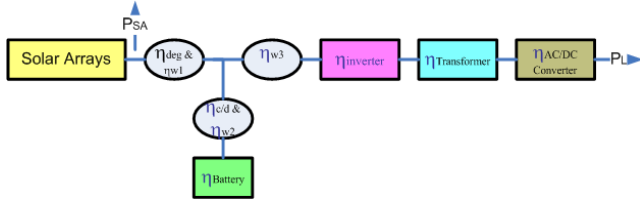


Figure 12, Energy Transfer Diagram of PV Battery System

The PVBWHS load profile, load types is shown in Figure 13.

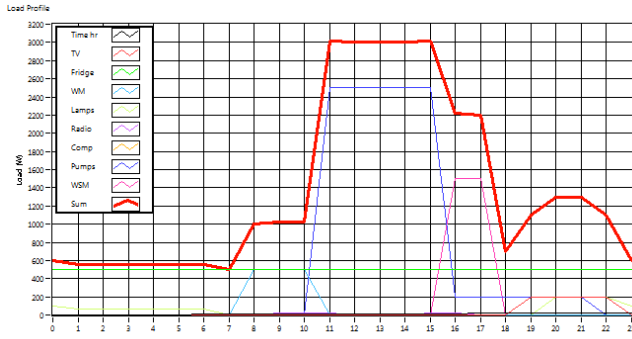


Figure 13, Load Profile

From the energy balance point of view, the amount of average power that must be produced by the solar arrays, P_{sa} could be expressed as:

$$P_{sa} = \{ (P_e * T_e / X_e) + (P_d * T_d / X_d) \} / T_d \quad \text{Eq. 1}$$

Where:

P_e, P_d is the power requirements during eclipse and daylight (power budget),
 X_e, X_d is the efficiency of the paths from the arrays to the batteries and the loads, and
 T_e, T_d is the times in eclipse and daylight.

The specific output power from solar arrays at the terminals could be expressed as follows:

$$P_{SA} (W / m^2) = P_n * FF * K_{ill} * K_{th} * K_{mppd} * \eta_{sys} * K_d \quad \text{Eq. 2}$$

Where:

P_n is the output power at begins of life;

$P_n = AM1.5 (W/m^2) * \eta_{SA} (\sim 0.14)$,

FF is the filling factor of SA module; ~ 0.85 ,

K_{ill} is the solar array surface illumination coefficient,

K_{th} is the thermal coefficient of solar array,

K_{mppd} is the matching factor between SA MPP,

η_{sys} is the energy transmission efficiency; ~ 0.87 ,

K_d is the Si solar array degradation parameter; ~ 0.9

By estimating the specific output power from solar arrays and substitution to Eq. 3, we get the results of P_{sa} , the required area of solar arrays can be estimated.

$$Area = P_{sa} / P_{SA} \quad \text{Eq. 3}$$

A sizing sub-program is built in the GUI of LabVIEW, the system parameters are given and the sizing results have been got. The sizing menu is shown in Figure 15 .

7. PVBWHS Components Modeling

7.1. Modeling of the Solar Array

The sized solar array is modeled. The I_V and P_V curves are shown in Figure 14. The values of open circuit voltage and short circuit current are shown on graph while current, voltage and out power at maximum power point is illustrated. It should be noted that the solar array characteristics and dynamically changed either with solar radiation or temperature changes.

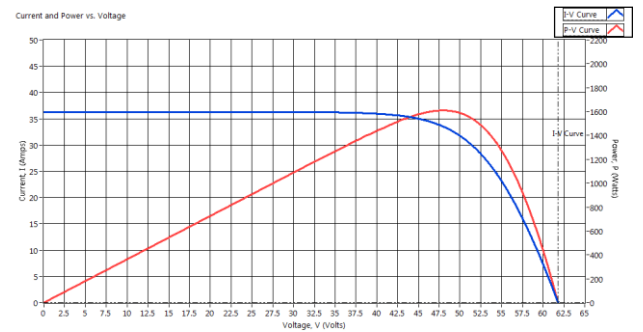


Figure 14, V-I and V-P Curves of the solar array at Jazan
Average Solar Radiation, 745 W/m2

Control Menu	Load Profile	Solar Radiation	PVWHS Sizing	PV I-V & P-V	PVBHS Monitoring	Turbine Parameters	Wind Power
--------------	--------------	-----------------	--------------	--------------	------------------	--------------------	------------

Legend:

DLL - Average load at day light, Normal = 2091W
DLT - Day Light Time, Normal = 11 hours
NEL - Average load at night, Normal = 774W
NLT - Night Load Time, Normal = 13 hours
DETe - Direct Energy Transfer Efficiency, Normal = 0.9
NETe - Night Energy Transfer Efficiency, Normal = 0.76
PSM - Nominal Solar Module Power = 180W
NBC - Nominal Battery Capacity, Normal 100Ah
DoD - Maximum Battery Depth of Discharge, Normal for LAB = .75
JASR - Jazan Average yearly Solar Radiation, nominal 745W/m2
COS - Cut-out Speed 35 m/s
CIS - Cut-in Speed 3 m/s
RD - Wind Turbine Rotor Diameter "3.2m"
RWP - rated Wind Power.

Load parameter	PV Battery	Wind Turbine	SA Wind Battery Sizing Results
DLL	PSM "Watt"	CIS "m/s"	2160
2091	180	3	PV Rated Power "W"
DLT "hr"	NBC "Ah"	COS "m/s"	12
11	100	20	Number of Solar Modules each
NEL "Watt"	Jazan Av. SR	RWS "m/s"	409
774	745	9	CR Ah at 48V
NLT "hr"	BOS	Rotor Diam. "meter"	16
13	Efficiencies	Jazan Av. RWS "m/s"	Number of Storage Batteries 100Ah
	DETe "%"	7	2000
	0.9		Rated Wind Turbine Power
	NETe "%"		
	0.76		
	DoD "%"		
	0.75		

23800 kWh PV Array	22600 kWh Wind Turbine	40300 kWh Load	6080 kWh Loasses	86.9 System Efficiency %
--------------------	------------------------	----------------	------------------	--------------------------

Figure 15, PVBWHS Sizing parameters and results Menu

7.2. Dynamic Modeling of the Wind Turbine

The wind turbine is characterized by no dimensional curves of the power coefficient (C_p) as a function of both the tip speed ratio (λ) and the blade pitch angle (β). In order to fully utilize the available wind energy, the value of (λ) should be maintained at its optimum value. Therefore, the power coefficient corresponding to that value will become maximum also.

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine [27].

The tip speed ratio (λ) can be defined as the ratio of the angular rotor speed of the wind turbine to the linear wind speed at the tip of the blades. It can be expressed as follows:

$$\lambda = \omega_t R / V_\omega \quad \text{Eq. 4}$$

Where

- R is the wind turbine rotor radius,
- V_ω is the wind speed and ω_t is the mechanical angular rotor speed of the wind turbine.

A generic equation is used to model $C_p(\lambda, \beta)$. This equation, based on the modeling turbine characteristics of [27], is:

$$C_p(\lambda, \beta) = C_1 * (C_2 / \lambda_i - C_3 * \beta - C_4) * e^{(-C_5 / \lambda_i)} + C_6 * \lambda \quad \text{Eq. 5}$$

Where the coefficients $c1$ to $c6$ are:

- $c1 = 0.5176$, $c2 = 116$, $c3 = 0.4$,
- $c4 = 5$, $c5 = 21$ and $c6 = 0.0068$.

In addition to Eq. 1, the relation between λ and β can be found in the following relation [27]:

$$1 / \lambda_i = \frac{1}{\lambda + 0.08 * \beta} - \frac{0.035}{\beta^3 + 1} \quad \text{Eq. 6}$$

The $C_{p-\lambda}$ characteristics, for different values of the pitch angle β , are illustrated below. The maximum value of C_p ($C_{pmax} = 0.48$) is achieved for $\beta = 0$ degree and for $\lambda = 8.1$. This particular value of λ is defined as the nominal value (λ_{nom}).

The instantaneous values of C_p as a function of rotor speed and angle of attack is shown in Figure 17.

Wind turbine is designed to have low cut-in and cut-out speed (2-3m/s: 7-9m/s) to suit Jazan wind condition.

The power output equation [14] of wind turbine can be described in Eq. 8:

$$P_t = \frac{1}{2} \rho \pi C_p V^3 (\lambda, \beta) R^2 \quad \text{Eq. 7}$$

Where: P_T = wind power (W)

ρ = air density (kg/m3)

V = wind speed (m/s)

R = radius of turbine blades (m)
 C_p = wind power coefficient.

Power Coefficient (C_p) as a function of Blade Pitch Angle and Tip Speed Ratio

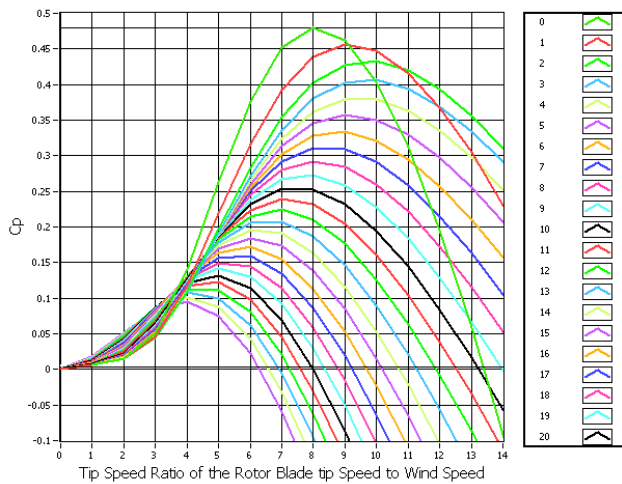


Figure 16, Wind turbine $C_{p-\lambda}$ characteristics

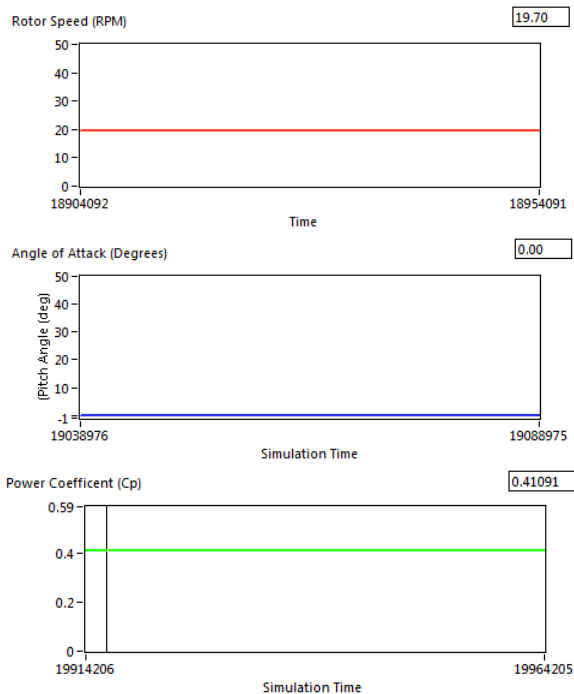


Figure 17, Wind Turbine efficiency Parameters C_p

The relation between the wind turbine output power and the wind speeds is shown in Figure 18. The cut-in speed is 3m/s, rated speed is 9m/s while cut-out speed is 20m/s.

In case when wind speed is greater than rated speed, it should be noted that the power in wind is greater than output power from wind turbine, as shown in Figure 19.

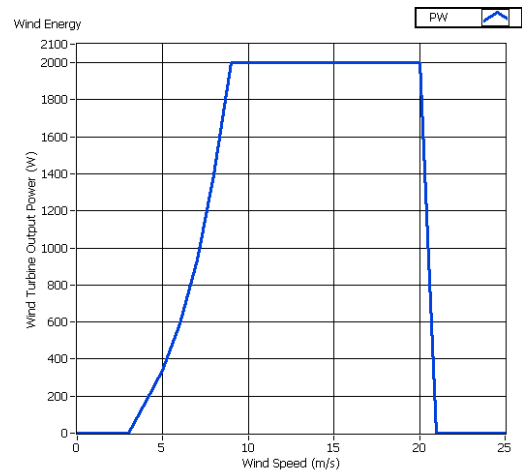


Figure 18, Wind turbine Power - Wind speed curve

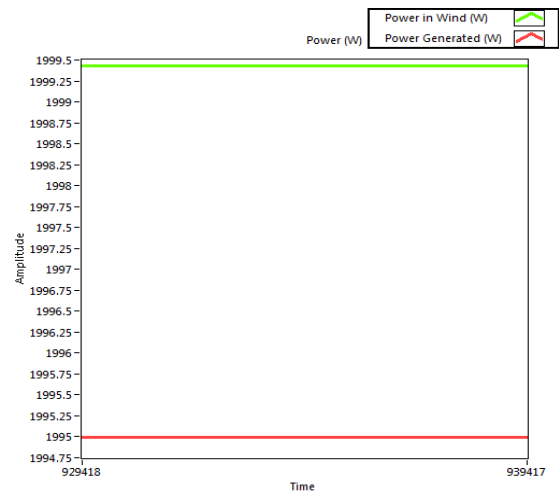


Figure 19, Power in Wind and Generated Power

8. LabVIEW based System Hardware Emulation and Monitoring

In this section, the block diagram and the different from panel control and monitoring pages will be presented.

8.1. Implemented Block Diagram

The implemented LabVIEW block diagram is developed in two cases; the first case is hardware interfacing with physical components and data acquisition module through serial interfacing, as shown in Figure 20. The second case depends on modeling and emulation of the PVBWHS components variables, as shown in Figure 21.

9. GUI of PVBWHS Monitoring Page

The photovoltaic battery wind turbine hybrid system monitoring page is shown in Figure 22. The wiring

diagram of hybrid system, number of solar array strings, control switches, and load branches controls are illustrated. The current values of PV, wind, Battery and summation load currents are also presented. The instantaneous values of system variables are dynamically changes according to input variables like; solar radiation, wind speeds and temperature. The summation output power of hybrid

system as well as status of battery operation charging or discharging is illustrated on the hybrid system monitoring GUI too. The imaged stated in the main front panel presents the daily average and distributed renewable energy resources in the Kingdom Saudi Arabia in general and for JP especially.

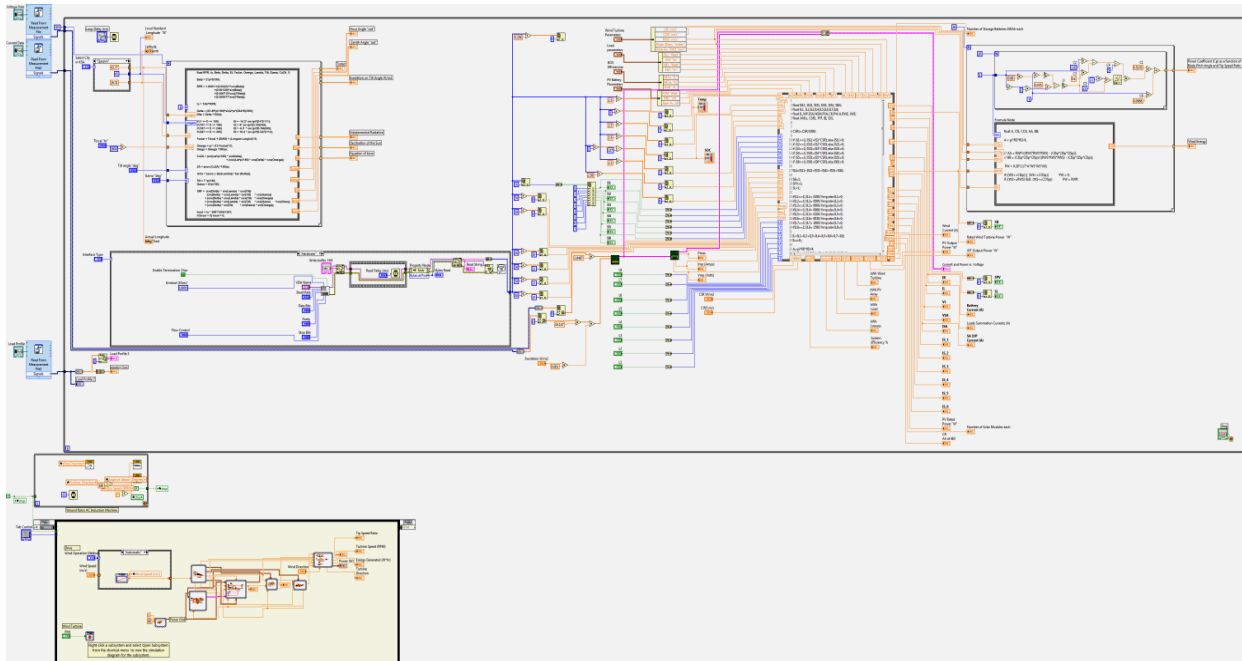


Figure 20, LabVIEW Based Hardware of PVWHS Monitoring

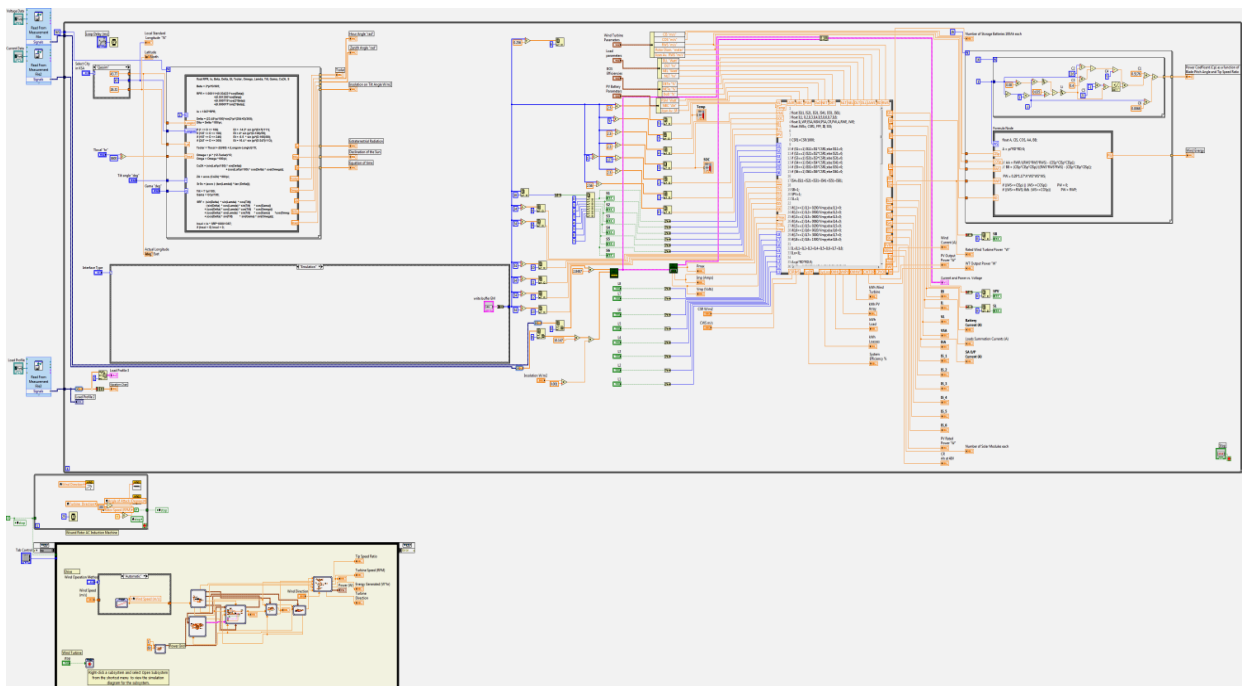


Figure 21, LabVIEW Based Emulation of PVWHS Monitoring

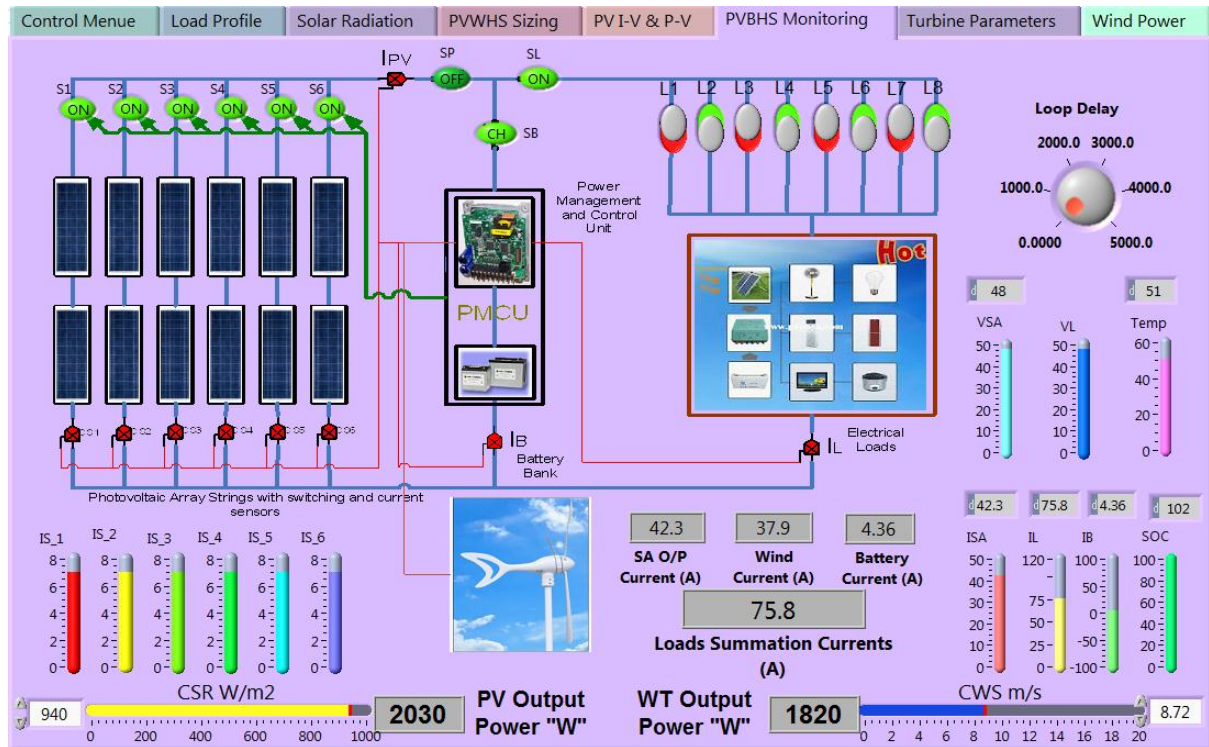


Figure 22, PVBWHS system performance study showing all the necessary variables

10. Conclusions:

The system was created in LabVIEW environment, as it provides a programming language with possibilities of easy control of external hardware and of being used in many hardware and software platforms with a variety of operating systems. The created system was implemented on a PC and Windows Operating System.

In the developed program, eight interacted menus have been implemented; main control menu, load profile menu, solar radiation menu, sizing menu, PV characteristics menu, hybrid system monitoring menu, wind turbine parameters menu and wind and wind turbine power menu. The different menus are working in active mode by means any change in design or MDB parameters will directly affect the system sizing or system output energy performance. The system design parameters in this paper is introduced for a specific site of application; Jazan Province KSA where the hybrid system is installed, but the developed program could be applied at any site and any load profile worldwide.

The developed monitoring system has the capability to work in emulation mode or hardware interfacing mode. In emulation mode, the signals and actuators are emulated by potentiometers and electronic switches while in hardware interfacing mode, a microcontroller with analog multiplexer working as data acquisition is interfaced with PC with LabVIEW monitoring and management program. In

this paper the PV array, wind turbine and the storage batteries sizes are estimated based the site of application; Jazan province, KSA. The sizing result of the proposed PVBWHS is generator with 2.16kW, wind turbine generator with 2kW, Battery Bank with ~400Ah, and 5kW ratings of inverter and hybrid system controller. The developed program has the capability to design the hybrid system in any other site in Saudi Arabia or worldwide.

11. Acknowledgment

The author would like to express their thanks for the Deanship of Scientific Research in Jazan University for their support and financial agreement for this project.

12. Future Work

In future the developed SW package will be enhanced to incorporate all models and online calculations of system signals. Also, the data base will be updated to worldwide not dedicated for specific locations.

13. References:

- [1]. Adel Mellita,1, Soteris A. Kalogirou, "Artificial intelligence techniques for sizing photovoltaic systems: A review", Renewable and Sustainable Energy Reviews 13 (2009) 406–419
- [2]. Richard Welch, and Ganesh K. Venayagamoorthy, "A Fuzzy-PSO Based Controller for a Grid Independent Photovoltaic System", Proceedings of

- the 2007 IEEE Swarm Intelligence Symposium (SIS 2007)
- [3]. Colin Rickert, "A Neural Network Algorithm with Weight Decay for 2-6 Hour Ahead Wind Speed Forecasting", <http://www.colinrickert.com/ANN-Forecast.pdf>
 - [4]. Annette Evans, Vladimir Strezov *, Tim J. Evans, "Assessment of sustainability indicators for renewable energy technologies", *Renewable and Sustainable Energy Reviews* 13 (2009) 1082–1088
 - [5]. S. A. M. Said, I. M. El-Amin and A.M. Al-Shehri, "Renewable Energy Potentials in Saudi Arabia", webfea-lb.fea.aub.edu.lb/fea/research/erg/RCW
 - [6]. Yasser Al-Saleh, Paul Upham and Khaleel Malik, "Renewable Energy Scenarios for the Kingdom of Saudi Arabia", Tyndall Centre for Climate Change Research Working Paper 125
 - [7]. Mohamed B.A. Zahran, "Photovoltaic Hybrid Systems Reliability and Availability", *Journal of Power Electronics*, Vol. 3, No.3, July 2003
 - [8]. S. Antvorskov, "Introduction to integration of renewable energy in demand controlled hybrid ventilation systems for residential buildings", *Building and Environment* 43 (2008) 1350–1353
 - [9]. Silkyung Kim and Changbong Kim et. Al, "Load Sharing Operation of A 14kw Photovoltaic/Wind Hybrid Power System", *Photovoltaic Specialists Conference, 1997.*, Conference Record of the Twenty-Sixth IEEE
 - [10]. Banu Y. Ekren a,*, Orhan Ekren b, "Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions", *Applied Energy* (2009)
 - [11]. M.Zahran, et. al, "PV Battery Wind-Turbine Public-Grid Hybrid Power Supply for Telecom. – Equipment, System Management & Control", Makowiec Installation-POLAND. "35th International Energy Conversion Engineering Conference", Las Vegas, USA, JULY 23-28, 2000.
 - [12]. M.Zahran, A.Hanafy, S.El-Hennawi, M.Kamel, O.Mahgoub and F.Fett, "Optimal sizing for Photovoltaic Diesel Generator Hybrid Power System", *Eurosun96 Conference*, 16-19 Aug., 1996, Freiburg, Germany, and *Engineering Research Journal*, Helwan Univ., Vol. 54, Nov., 1997.
 - [13]. M. S. I. Abdel-Qader, "Simulation of a Hybrid Power System Consisting of Wind Turbine, PV, Storage Battery", *M. Sc. Thesis, An-Najah National University*, Nablus, Palestine, 2008
 - [14]. Wei Qi, Jinfeng Liu, Xianzhong Chen, and Panagiotis D. Christofides, "Supervisory Predictive Control of Standalone Wind/Solar Energy Generation Systems", *IEEE Transactions On Control Systems Technology*, 1063-6536/\$26.00 © 2010 IEEE
 - [15]. Boquan Zhang, Yimin Yangb, Lu Ganb, "Dynamic Control of Wind/Photovoltaic Hybrid Power Systems Based on an Advanced Particle Swarm Optimization", 978-1-4244-1706-3/08/\$25.00 ©2008 IEEE.
 - [16]. S.C.Gupta, Dr.Y.Kumar and Dr.Gayatri Agnihotri, "Optimal Sizing Of Solar-Wind Hybrid System", *IET-UKInternational Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007)*, Chennai, Tamil Nadu, India. Dec. 20-22, 2007. pp. 282-287.
 - [17]. Giuseppe La Terra, Gagliano Salvina, Tina Giuseppe Marco, "Optimal Sizing Procedure for Hybrid Solar Wind Power Systems by Fuzzy Logic", *IEEE MELECON 2006*, May 16-19, Benalmadena (Malaga), Spain
 - [18]. Wang Jinggang Gao Xiaoxia and Du Hongbiao, "The Economic Analysis of Wind Solar Hybrid Power Generation System in Villa", 2009 *International Conference on Energy and Environment Technology*, 978-0-7695-3819-8/09 \$26.00 © 2009 IEEE
 - [19]. Fatih O. Hocaog lu, Omer N. Gerek, Mehmet Kurban, "A novel hybrid (wind–photovoltaic) system sizing procedure", *Solar Energy* 83 (2009) 2019–2028
 - [20]. Yang Hongxing a,*, Zhou Wei a, Lou Chengzhi, "Optimal design and techno-economic analysis of a hybrid solar–wind power generation system", *Applied Energy* 86 (2009) 163–169
 - [21]. N. Phuangpornpitak, S. Kumar, "PV hybrid systems for rural electrification in Thailand", *Renewable and Sustainable Energy Reviews* 11 (2007) 1530–1543
 - [22]. Pragma Nema,*, R.K. Nemab, Saroj Rangnekar, "A current and future state of art development of hybrid energy system using wind and PV-solar: A review", *Renewable and Sustainable Energy Reviews* 13 (2009) 2096–2103
 - [23]. Luis Arribas a,*, Luis Cano a, Ignacio Cruz a, Montserrat Mata b, Ermen Llobet, "PV–wind hybrid system performance: A new approach and a case study", *Renewable Energy* 35 (2010) 128–137
 - [24]. Banu Y. Ekren, Orhan Ekren, "Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions", *Applied Energy* 86 (2009) 1387–1394
 - [25]. M.H. Zamani and G.H. Riahy, "Introducing a new method for optimal sizing of a hybrid (wind/ PV/battery) system considering instantaneous wind speed variations", *Energy for Sustainable Development*, Volume XII No. 2, June 2008
 - [26]. Average Weather For Gizan, Saudi Arabia – Weather Spark, "<http://weatherspark.com/averages/32762/Gizan-Jizan-Saudi-Arabia>
 - [27]. Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems," John Wiley & Sons Ltd, 1998, ISBN 0-471-97143-X
 - [28]. Yousry Atia, Mohamed Zahran and Abdullah Al-Hossain, "Solar Cell Emulator and Solar Cell Characteristics Measurements in Dark and Illuminated Conditions", *WSEAS TRANSACTIONS*

on SYSTEMS and CONTROL, Issue 4, Volume 6, April 2011.

- [29]. MOHAMED ZAHRAN , YOUSRY ATIA , ABDULLAH AL-HUSSAIN & IHAB EL-SAYED, “LabVIEW Based Monitoring System Applied for PV Power Station”, Proceedings of the 12th WSEAS International Conference on AUTOMATIC CONTROL, MODELLING & SIMULATION, Catania, Italy, May 29-31, 2010.