Design and Implementation of a PLC-Based Real-Time Monitoring and Control System for a Hybrid Renewable Energy System

G. Madhan, Dr. S. Muruganand

Research Scholar*, Assistant professor
Department of Electronics and Instrumentation
Bharathiar University, Coimbatore-46, India.

Abstract-The present study is about the design and implementation of renewable energy by means of solar, small hydro and stair climbing power systems based on Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) technology. The PLC technology correlates the hybrid system process parameters for the On-Grid and Off-Grid conditions. The hardware and the software implemented in this proposed system have been put forward to demonstrate the validity and feasibility of the approach. The test results obtained from this renewable energy system prove high accuracy and reliability in regulation while compared with the individual power unit. This renewable Hybrid Power Generation System (HPGS) was studied in real time and it proves to be a versatile and effective gadget for remote area and also for domestic applications.

Keywords: renewable energy; on-off grids; PLC-SCADA; solar; hydro; stair climbing;

I. INTRODUCTION

Today the demand for electricity in the world is gradually increasing. Nearly 1.2 billion people have no access to electricity in the world, as per the report by the International Energy Agency (IEA). In India about 80,000 Villages have no access to electricity, whereas in the state of Tamilnadu, nearly 400 villages have no access to electricity [1]. In order to achieve the electricity requirement government is taking steps to increase the power production from the Nuclear Power plants. The energy that is produced from Nuclear power plants results in an increase in the emission of greenhouse gases, which is harmful and hazardous to the environment [2]. Solar and wind energy are the main sources for electricity production. Even though the energy from the sun is uniform, solar irradiance changes from one place to other place throughout the year. In India, this solar irradiance is found to be quite high [3]. On the other hand the necessity for wind energy is found to be increasing at a rate of 25-35% when compared to the last decade [4]. The efficiency of solar power is 18%, whilst efficiency of wind power is 55%. These efficiencies could be improved to 50% by implementing a tracking system for solar and by implementing adaptive motor methods for wind direction respectively [5].

Rupesh et al [6] proved that the power balance throughout the operation of hybrid photovoltaic and wind squirrel cage induction generator system has been developed by the emulation method. In general rural areas own surplus natural energy resources such as wind, solar and hydro. Considering these powerful resources the author [7] described the hybrid system and implemented the system in rural areas of cele county near Tarim Desert. By the method of meta-heuristic techniques, hybrid combinations of hydro, solar, wind, fuel cell energy system performance has been evaluated in the paper [8]. IIT 9]author'sproposedthedesign of[hybrid energy system model in the remote areas using wind, photovoltaic, biomass and small hydro by the off-grid method. Author [10] focused on unit sizing of stand-alone hybrid energy system using bees algorithm with different combination of energy sources like micro hydro, fuel cell, electrolyte, hydrogen cell, wind and solar by simulation method. Author [11] explains the communication of the Ethernet/IP protocol for power transmission using a PLC. Several works for foot step energy harvesting system have been developed by using DC motor for power generation [12-13].

The paper [14] explains the development of power quality by wind, fuel cell and ultra-capacitor systems in the simulation process. Author [15] elucidated the simulation results for hybrid power generation system using wind, fuel cell, and ultra-capacitor. In paper [16] the author identified the efficiency of power generation system of small hydro power station in Greece and explained about the properties of small hydro. Author [17] proposed Permanent Magnet Synchronous (PMAC) for wind generator based on low harmonic distortion with high induced voltage and high efficiency, this system was based on Maxwell 2-D and Matlab software.

From the above survey, it is observed that the maximum amount of power is taken from solar, wind and hydro, etc. In this proposed work, in addition to solar and small hydro, a novel renewable resource (stair-climbing) is implemented and the power production of the hybrid system is analysed by PLC and monitored by SCADA. This research paper aims to provide Eco friendly, safer, less maintenance and cost free sources of energy.

II. Experimental Module of HPGS

The proposed framework includes three types of power generation system, namely solar, small hydro and stair climbing. Fig. 1 explains the structure of the On-Grid and Off-Grid system through serial communication of PLC and SCADA. The main role of this proposed system is to integrate the energy from solar, hydro, and the stair climb system. The requirement desired in this HPGS design is described in Table 2.

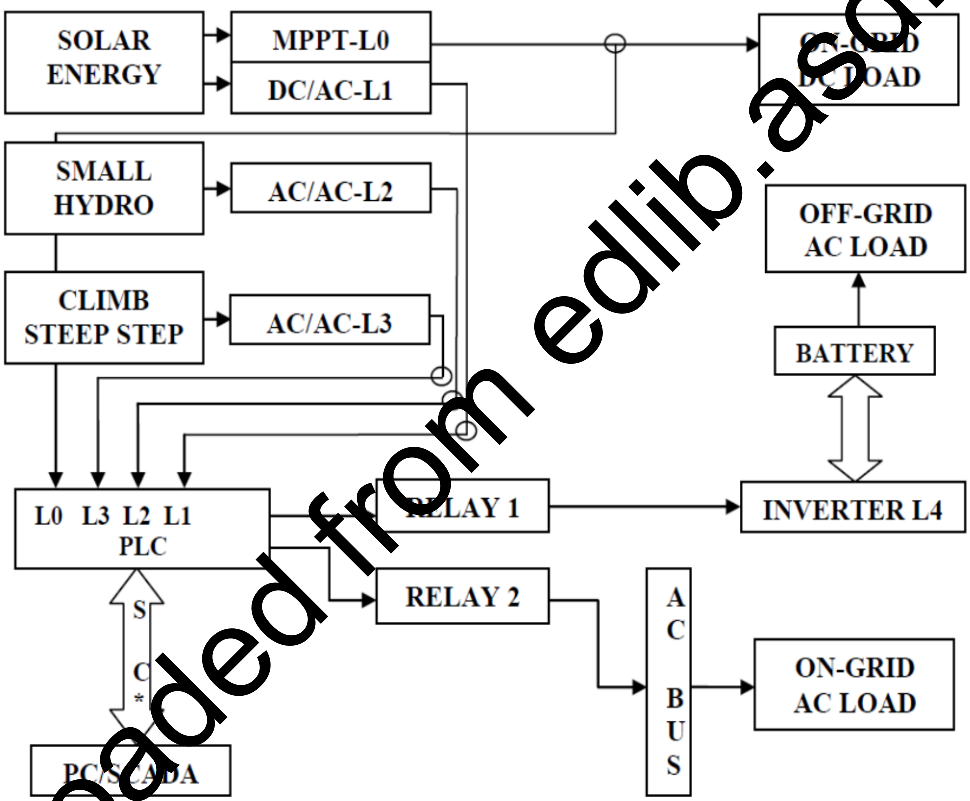


Figure1. Block diagram of HPGS

The above block diagram of the HPGS designed in the proposed framework is described briefly in the below table1 and SC*-Serial Communication.

Table 1. Block diagram description

Sources	PLC line	Instrument	Power	Grid system	Remark
Solar	L0	MPPT	DC	On	Acts as on grid
Solar	L1	DC-AC Converter	AC	On	Voltage sensor connected to a PLC
Hydro	L2	AC Converter	PMAC	On	Voltage sensor connected to a PLC
Stair climb	L3	AC Converter	PMAC	On	Voltage sensor connected to a PLC
Hybrid	L4	Inverter	AC	Off	The PLC will Compare the line L3, L2 with L1 by voltage sensor

Table 2. Construction parts of HPGS

S. NO	Name	Requirement	Qty
1	Spring	6.5”	2
2	Rack	11.5”	1
3	Gear wheel	6”	3
4	Chain sprocket	56”& 3	2
5	Bearing	1.3/4”- 16”bo	6
6	Flywheel	6.5”	1
7	Pinion	2”	1
9	AC Synchronous Motor	1000Watts	1
11	Inverter circuit	600VA	1

12	IR-Infrared Sensor	AH and AL Pins-5V	1

A.Dynamic Representation for Solar Panel

In general, the solar Photovoltaic cell produces energy when light energy is converted into Electric energy. In this proposed system, the solar photovoltaic cells are arranged in series along with parallel connections. These solar PV cells are made up of silicon cells that forms a structure of an array. The maximum operating voltage rate for each solar cell is 0.542 Volts. The snapshot of the solar module is shown in figure 2. The power required for the solar panel [18] is calculated by the following equation.

A.1. Equations

$$V_M = 0.542V$$

$$I_M = \left[190.5\ \frac{A}{M^2}\right][6 \times 10^{-4} M^2]$$

$$I_M = 0.1143A$$

Where V_M-maximum voltage and I_M-maximum current.

For the proposed research work, solar panel with capacity of 80Watts is required.

The Power required for proposed application is

$$\text{Power/cell} = V_M \times I_M$$

$$\text{Power/cell} = 0.542 \times 0.1143 = 0.062w$$

$$\text{Number of cells required} = \frac{80w}{0.062w/cell} = 1291$$

$$\text{Number of cells in series} = \frac{\text{system volts}}{\text{Voltage/cell}}$$

$$= \frac{12V}{0.542V} = 23$$

$$\text{Number of rows of 23 cells when connected parallel} = \frac{1291}{23} = \sim 56.12$$

From the above connections, Maximum Power Point Tracker (MPPT) has been used for obtaining higher efficiency along with the solar panels of 80Watts.

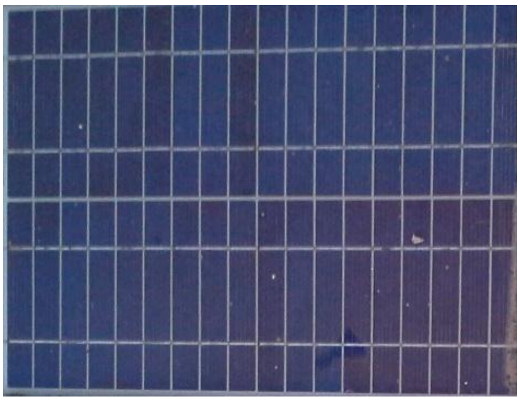


Fig.2 Solar Panel

B. Physical Construction of Small Hydro

The proposed small hydro system is constructed with the help of bearings, Pelton wheel and the gear wheel. The Pelton wheel is constructed with 3” round sheet, 12 cups, where they are combined and welded together. This Pelton wheel is connected to a shaft of 1 feet, 15mm bore. A 16mm bore bearing is fixed along the both sides of the shaft. One end of the shaft is welded with 6” gear wheel and from there the gear wheel is connected to the PMAC [Permanent Magnet AC Synchronous motor] turbine through chain sprocket. The snapshot of the small hydro power module is shown in figure 3. The working principle of the proposed small hydro system is explained below.

The Pelton wheel rotates automatically, when the water flows from the under tank to the over tank. According to the water flow rate in the hydropower system, the voltage is calibrated to 230V. This total setup is constructed in 10”×10” box. The technical specifications of the system are shown in Table 2. This experimental setup is constructed in real time and the test results are verified and it is shown in table3. The water flow rate is calculated by the below method.

B.1. Equations

$$Q = \frac{V}{T} \text{ (Litre/Sec)} \quad (1)$$

Where Q-Flow rate

V-Volume of bucket (litre) (2)

T- Average time (Sec) (3)

$$\textbf{Flow rate} = \frac{\textit{Volume of the bucket}}{\textit{Total time taken}} \quad (4)$$

$$= \frac{v}{T} \textit{ (Lit/Sec)} \quad (5)$$

Figure3. Small Hydro System

C. Physical Construction of Stair Climbing

The stair climb module is constructed with the help of spring, rack wheel, pinion, bearing, chain drive, gear wheel, flywheel, chain sprocket and shaft. The constructed stair climb system and the technical specifications are shown in Fig. 4 and table 2 respectively.

In this system the stress induced in each step when climbing makes the PMAC along with the gear wheel and the pinion wheel to rotate. For each rotation, the mechanical stress produced is converted into electrical energy based on the rotation of the motor setup. In this system the IR sensor is placed behind the pinion wheel, this sensor identifies the number of rotations for each step in this mechanism. The experimental output from this total setup is calibrated to 230Volt per step for every six rotation.

Figure4. A module of the stair climbs step system

III. Control System for Energy Management

The proposed framework of renewable hybrid energy management system (HEMS) is developed using Crouzet Programming Logic Controller (PLC) along with SCADA for the online monitoring system. This PLC program is based on the analog/digital signal and this program was predominantly implemented in numerical computational algorithms rather than logical program. The HPG system controls the analog inputs of a PMAC motor by varying the load speed and thereby this HPG system activates the output based on the algorithm. The PLC programmed for Off-grid and On-grid conditions are shown in fig5.

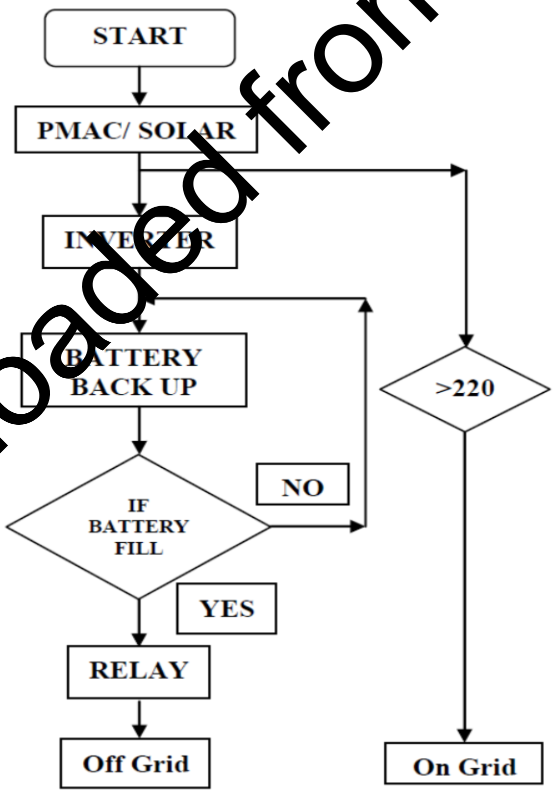


Figure.5 Flow chart for HEMS

D. Software Description

The programming language of Crouzet PLC is determined by Ladder Diagram and Function Block Diagram. The instruction code from the Crouzet PLC is converted into binary code which is stored in Erasable Programmable Read-Only Memory (EPROM) / Random Access Memory (RAM) [19]. This instruction code is debugged and it is executed by the Millenium 3 Logic controller software. For the given PLC, the scanning time for executing the program is around 0-20ms and the maximum programming capacity is around 350 Blocks [20]. The Crouzet PLC configurations are described in Table3.

Table3. PLC- CD 20 PLC Configurations

Pin Configuration	No. of pins Available	No. of Pins Used
Discrete Inputs (I)	6	2
Analog Inputs (I)	4	4
Output Relays (O)	8	6
LED Display	36*72	Digital Display
Register Memory (M)	368bits	-

The software programmed in this proposed system works on two-conditions, namely “Off-grid and On-grid”based on “low andpowerhighpower”conditions respectively. The high power of the system is calibrated to be greater than 220V and the low power is calibrated to be less than 210V” respectively.Theexperimental setup is illustrated in the Fig 10.

The configuration settings performed in this module are described below:

a. The status of the power production is monitored by the computer

b. Programmable Logic Controller, (PLC) is programmed with Ladder Diagram and communicated with PC through RS232/USB

c. The power production process of solar, small hydro and stair climbing power system is controlled in the HPG system by Auto and Manual switch designed in the circuit board.

d. High power is fed directly to the load which acts as On-Grid system.

e. Low power is fed to the load through an inverter circuit with the help of a battery which acts as an Off - Grid system.

IV. EXPERIMENTAL RESULT AND DISCUSSION

In order to validate the proposed framework, a HPGS hardware/software platform using PLC and SCADA has been set up in the laboratory and it is shown in Fig 10. The PLC controller parameters i.e (I, V, R, F) are measured in real time by the use of SCADA and NI-myDAQ and the results observed in the experimental operation of the HPGS module are described below:

(a) In the proposed solar power module, the DC voltage obtained by the use of 80Watt solar panels connected along with MPPT (L0) is used as ON-Grid. An AC signal is obtained, when the solar panel output is connected by DC to AC (L1) converter. This the AC signal L1 is compared with L2 and L3, and the output obtained in the relay (L1) acts as an off-grid to help of battery backup. The system was tested in various conditions in On-Off Grid and it is shown in Table 4 and 5. From the results achieved, it has been observed that the maximum DC & AC voltage is around 19V and 120 V respectively.

(b) In HPG system, the proposed small hydropower system was tested with various water flow rates and it has been observed that around 230V AC signal in L2 was achieved. The line L2 and L3 are compared against the designed program and the achieved AC signal is connected to the AC bus through Relay2. The On-Grid results obtained are verified and illustrated in Table 6.

(c) In the proposed stair climbing power system, it has been observed that around 230V AC signal in L3 was achieved at each step in the stair, based on the applied stress on each step. The line L2&L3 are compared in PLC and then the AC signal fetched is connected to the AC BUS through Relay3. The On-Grid observed results are illustrated in Table7.

The frequency response for the AC signal obtained from the hybrid power system combinations was tested using NI-myDAQ from the (Dept. Of Electronics and Instrumentation, Bharathiar university, India) and it has been noted that 49.917 Hz was achieved.

Finally, the power obtained from the three AC signals (L1/L2/L3) is compared by the PLC controller. The greatest of the power is connected to the AC bus through the corresponding relay 2 and the system can be utilized as On-Grid. The least power from the relay1 is connected to the inverter (L4) which could be used as Off-Grid and thus the output power acquired charges the battery and thereby produces 230v. The off-grid and on-grid setup are simultaneously monitored by the SCADA via serial communication.

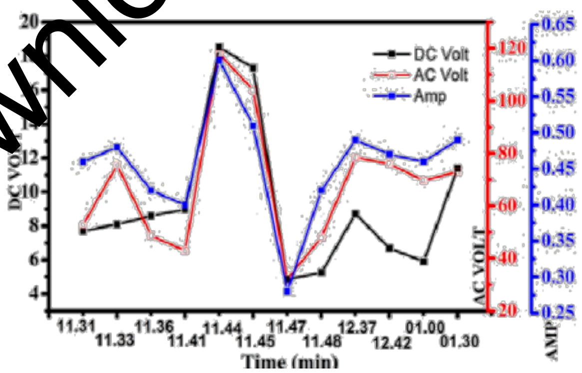
Table4. AC Power vs DC power from solar module

Time	DC Volt	AC Volt	Amp
03/01/2014 11.31PM	7.7	52.6	0.46
03/01/2014 11.33PM	8.1	75.6	0.48
03/01/2014 11.36PM	8.6	48.7	0.42
03/01/2014 11.41PM	8.96	42.9	0.4
03/01/2014 11.44PM	18.53	118	0.6
03/01/2014 11.45PM	17.3	104	0.51
03/01/2014 11.47PM	4.842	32	0.28
03/01/2014 11.48PM	5.25	48	0.42
03/01/2014 12.37PM	8.72	78.5	0.49

03/01/2014 12.42PM	6.69	76	0.47
03/01/2014 1.00PM	5.9	69.7	0.46
03/01/2014 1.30PM	11.4	73	0.49

Table5. AC Power vs. DC power from solar module

Time	DC Volt	AC Volt	Amp
02/01/2014 12.11PM	5.6	71.1	0.48
02/01/2014 12.19PM	11.9	73	0.49
02/01/2014 12.22PM	12.5	77.3	0.49
02/01/2014 12.24PM	5.9	75.2	[illegible]
02/01/2014 12.28PM	5.5	69.9	0.46
02/01/2014 12.33PM	5.4	75	0.48
02/01/2014 12.50PM	6.8	78	0.49
02/11/2014 1.00PM	6.[illegible]	80	0.50
02/11/2013 1.15PM	4.69	69.3	0.46
02/01/2014 1.30PM	5.2	70.1	0.47
02/01/2014 1.45PM	5.4	66.5	0.45
02/01/2014 2.00PM	5.53	71	0.47



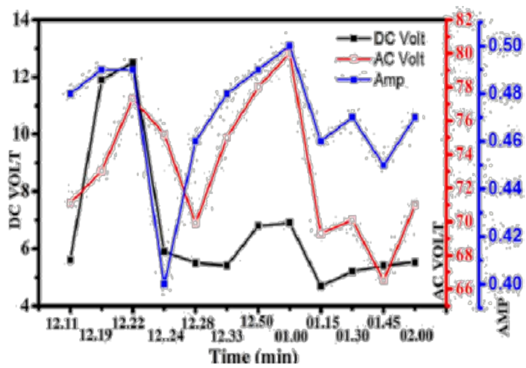


Figure6. Hybrid schematic of solar AC vs. DC power Figure7. Hybrid schematic of solar AC vs. DC power

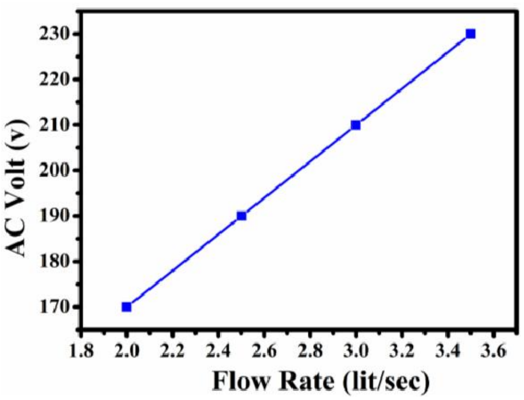


Figure8. Schematic flow rate of small hydro system

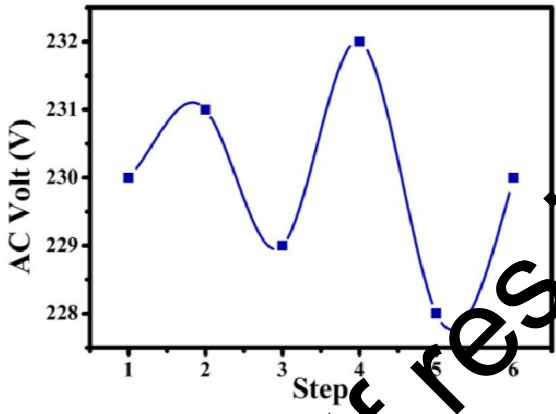


Figure9. Schematic rotation of stair climbing system

Figure 6 and 7 describes the output voltage and current from the solar panel . The system was tested in the Coimbatore region, in India. Figure 8 gives the output results from small hydro, which was found to increase periodically with increase in water flow rate. Figure 9 illustrates the output for each step of the stair climbing system.

Table6.Flow rate of small hydro system

Flow Rate (Lit/Sec)	AC Volt (V)
2	170
2.5	190
3	210
3.5	230

Fig10.Experimental setup of HPGS

Table7. Output Voltage for each step

Step	AC Volt (V)
1	230
2	231
3	229
4	232
5	228
6	230

CONCLUSION

In this paper, the results of the designed hybrid power system that includes solar, hydro and stair climbing are investigated by the PLC-based monitoring and control system. The main objective of this paper is to supply consistent power to the domestic area at an optimal cost. The experimental results show that the closed-loop hybrid control system supplies energy with more accuracy and high efficiency when compared to the energy supplied from the individual power unit. The total power generated from this proposed hybrid power module was measured around 600W. It is anticipated that in future when a highly efficient PMAC synchronous motor along with a highly efficient solar panel is implemented the power production could be increased enormously which can be used for domestic and Commercial purposes thereby not depending on the power supply from the government.

ACKNOWLEDGMENT

I am deeply indebted to the faculties of the Department of Electronics and Instrumentation, Bharathiar University for providing the research facilities in the PLC Laboratory.

REFERENCES

[1] http://mnre.gov.in/file-manager/UserFiles/compendium.pdf.

[2] Y M Irwan, I Daut, S Ibrahim and N Gomesh, The improvement of Photovoltaic, Wind Hybrid System in perlis, *procedia Engineering*, vol. 50, pp. 808-816 (Elsevier), 2012

[3] Mohd. Tariq, Khyzer Shamsi and Tabrez Akhtar, Modeling Analysis and Development of Hybrid manual and Solar PV Based Power Generation System" *American Journal of Electrical Power and Energy Systems*, Science Publishing Group Vol.2, pp. 44-49, March10-2013

[4] Tao zhou and Bruno francois, Energy management power of a hybrid active wind generator for distributed power generation and grid integration, *IEEE Transactions on Industries Electronics*, Vol.58, pp. 95-104, 2011

[5] U. Fesli, R. Bayir, M. Ozer, Design and implementation of a domestic solar, wind hybrid energy system, IEEE publication, pp. I-29 - I-33, 2009

[6] Rupesh g. wandhare, and vivek agarwal, A Control Strategy to Reduce the Effect of Intermittent Solar Radiation and Wind Velocity in the Hybrid Photovoltaic, Wind SCIG System Without Losing MPPT, 978-1-4673-0066- IEEE publication, pp. 001399- 001404, 2011

[7] Litifu, Z. A Research on Planning and Installing Scattered Power into a Local Power System International Conference on Advanced Mechatronic Systems, Tokyo, IEEE publication, pp54-59, September 2012.
[8] B. Tudu, K. K. MandaI, N. Chakraborty, Optimal Design and Performance Evaluation of A Grid Independent Hybrid Micro Hydro, Solar, WindFuel Cell Energy System Using Meta-Heuristic Techniques, 978-1-4799-3340-2/14/ IEEE publication, pp. 89-93, 2014
[9] A. Gupta*, R.P. Saini and M.P. Sharma, Design of an Optimal Hybrid Energy System Model for Remote Rural Area Power Generation, IEEE publication, pp. 1–6, April 2007
[10] B. Tudu, S. Majumder, K. K. Mandal and N. Chakraborty, Optimal Unit Sizing of Stand-alone Renewable Hybrid Energy System Using Bees Algorithm, IEEE publication, pp1-6. Dec 2011
[11] GE Yifei, YU Tiesong, ZHAO Lei, Application of ControlLogix in Remote Monitoring System of ESP, FF Hybrid Precipitator, 11th International Conference on Electrostatic Precipitation, springer, pp. 485-488,2009
[12] Foot Step Power Generation System for Rural Energy Application to run AC and DC loads *EEE Dept, Rymec*
[13] Ghosh.J, Sen.S, Saha.A and Basak.S, Electrical Power Generation using Foot Step for Urban Area Energy Applications, *IEEE Xplore, Microwave and Antenna lab*, pp.1367 – 1369, Aug 2013
[14] O.C. Onar, M. Uzunoglu, M.S. Alam, Dynamic modeling Design and simulation of a wind, fuel cell, ultra-capacitor based hybrid power generation system, *Journal of Power Sources, vol. 161 pp. 707–722, 2006*
[15] Nilesh K. Meshram, Shubhas Y. Kamdi, Sustained power generation by Dynamic Modeling of wind, fuel cell, ultra-capacitor based hybrid power generation system, *International Refereed Journal of Engineering and Science, pp1-5,2014*
[16] J.K. Kaldellis, The contribution of small hydro power stations to the electricity generation in Greece: Technical and economic considerations, Energy Policy 35, pp. 2187–2196 2007

[17] Chun-yu Hsiao, Design of high performance permanent-magnet synchronous wind generators,Energies,MDPI,pp7105-7124,2014
[18] D. yogi goswami, frank kreith, jan f. kreider, Principles of solar engineering, second edition, Taylor and Francis, 2003
[19] A J Crispin, Handbook of Programmable Logic Controllers and their Engineering Applications, Second Ed. New York: McGraw-Hill, 1997
[20] Crouzet Automation, Millenium 3 Standard logic controller specification and its applications, pp. 1-92, 2006.