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DESIGN OF A HYBRID SOLAR AND HYDRO POWERED SYSTEM FOR RURAL REGIONS- A REVIEW FROM INDIA PERSPECTIVES

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Abstract

The objective of this research paper is to design a hybrid renewable energy system to perform the dual function of supplying electricity and potable water to a rural community. The proposed system incorporates solar and hydro-electric generators which operate in a two-stage solar-hydro cycle – a solar phase during the day and a hydro phase at night. The two generators are coupled to enable the solar generator to power a pump which stores water in the reservoir of the hydro-electric subsystem. This serves a dual purpose as a storage mechanism for the excess solar energy produced during the day and a means of stepping up the hydro-electric potential which is harnessed at night, during the hydro phase of the two-step cycle. The system also incorporates a subsystem for the storage, processing and supply of potable water. This subsystem is driven both by the solar and hydro-electric generators. The research paper has four main goals. The first is to design the system and its constituent subsystems using Labview as a design tool. This Labview-Aided Design (LAD) concept is at the core of the whole project. The second goal is to produce a laboratory prototype. The third goal ia to use the laboratory prototype as a blue-print for providing outreach services to rural communities. The fourth goal is to impact the well-being of rural inhabitants as a result of the subsequent deployment of this technology in their communities. The impact is multifaceted and includes health, education, food preservation, stimulation of small-scale enterprises and the use of Information Technology.

Keywords: Hybrid Solar, Rural Region, Energy.

1]. INTRODUCTION:

Over sixty percent (60%) of Cameroonians live in the rural areas. These rural inhabitants have no access to electricity or potable water. This situation has remained unchanged for over a quarter of a century. The national electricity grid is limited to the urban centers, with no prospects for expansion to the rural areas in the short or medium term. This bleak prospect results from the fact that the existing urban network faces three major constraints – technological, economic and demographic. Technologically, most of the equipment used for the generation and transmission of electricity is obsolete. The remoteness of most rural areas makes it inefficient to extend the current national grid by thousands of kilometers of transmission lines. The transmission losses would be prohibitively high and would further degrade the existing urban network. Economically, huge investments are required to upgrade the existing network and construct new dams and hydro-electric stations which are required to significantly step up the power generation capacity of the system. Demographically, the urban population is growing at an exponential rate – a trend which is accelerated by the exodus of young people from the rural areas to the urban centers, in search of better living conditions. This further increases the imbalance between the demand and supply of electricity and puts additional strain on the urban network. The lack of electricity and potable water in the rural areas has dire consequences for these communities. These include:

1. Poor health. Existing rural health centers function far below their optimum potential since no electrically powered equipment can be used. Vaccines cannot be preserved for the vaccination of children. The absence of potable water sometimes results in outbreaks of cholera.
2. Absence of science laboratories in secondary schools. It is impossible to set up laboratories for the teaching of basic sciences such as Physics, Chemistry and Biology. Even the simplest microscope requires electricity
3. Food insecurity due to poor conservation of agricultural products. The absence of refrigeration facilities makes it difficult to preserve food products such as fruits and vegetables. Most rural families are constrained to live on the day's production. In times of excess there is waste and in times of shortages, there is no reserve to draw from

4. Absence of small-scale technological outfits. It is impossible to set up even the most rudimentary workshops since no electrically powered tools can be used.
5. Information Technology remains a distant dream. No computers can be used in the absence of electricity. IT is now taught in secondary schools nationwide but children in rural secondary schools learn about computers without ever using them.
6. Degradation of the quality of life. The cumulative effect of the problems resulting from the absence of electricity and water is a degradation of the quality of life.

While the millennium development goals set very useful baselines for the well-being of citizens, rural inhabitants will continue to live on the fringes of the millennium-world unless the twin-problem of rural electrification and potable water supply is solved. Ironically, India has an abundance of renewable energy and water resources. The challenge is to harness this huge potential to provide electricity and potable water to the rural inhabitants. This challenge is the main motivation for this project.

The system proposed in this project uses a combination of solar and hydro-electric generators to power an autonomous micro-grid, separated from the urban grid. The turbine in the hydro-electric generator is driven by water from a large reservoir. The two generators function in a two-step solar-hydro cycle. The solar-phase operates during the day while the hydro-phase is at night. During the solar-phase, the solar generator operates a pump which stores water in a reservoir. At night, during the hydro-phase, the hydro-electric generator comes into operation to compensate for the loss in solar generation capacity.

After impacting the turbine blades, the water is stored in a huge sink from where it is pumped back to the reservoir during the next solar-phase. The two-step solar-hydro cycle serves as a mechanism for storing solar energy. Excess solar energy is converted to the hydro-electric potential of water stored at a height. A second reservoir, called the potable-water reservoir, is used to store and process water for distribution to the rural community. This reservoir is not as high as that of hydro-electric generator. Its height is calculated to provide sufficient hydraulic head for water to flow by gravitation. The water in this reservoir is purified through a process of filtration and chlorination, before being distributed to the community.

Another component of the system is the reservoirs-feeder which is designed to collect and channel rain water into the two reservoirs during the rainy season. This feature is motivated by the abundant rainfall in India and the rest of the rural regions. This functionality will ease the strain on the pump as it provides an alternative way of filling the reservoirs.

There are seven (7) technological problems to be solved in the project:-

1. Design of a micro-grid to supply electricity to a village of five hundred (500) inhabitants (the average population of villages in Cameroon).
2. Design and configuration of the solar generator
3. Design and configuration of the hydro-electric generator
4. Coupling of the two generators to enable the pump of the hydro-electric generator to be powered by the solar generator
5. Design of the potable water supply system and its coupling to the generators
6. Design of a control system for the scheduling and execution of the operations in the two-phase duty cycle
7. Construction of a laboratory prototype

The innovations to implement include:-

i. Storage of solar energy in the form of a hydro-potential, as an alternative to the use of batteries
ii. Micro-grid technology
iii. Control system for the implementation of the two-phase cycle and the operation of the potable water supply subsystem
iv. Hybrid renewable energy systems which couple hydro and solar components

NI hardware and software will be used in four ways:-

1. Labview-Aided Design (LAD). Labview and some of the instruments in MYDAC will be used to design the various subsystems and integrate them into a single system
2. Simulation of system operation
3. Design of the Control System
4. Creation of a virtual-reality model of the final design

2]. DESIGN METHODOLOGY:

The execution of the project will follow the nine-step activity schedule shown in figure 1. The first six activities involve the use of Labview to design the various subsystems and integrate them into a single system. These Labview-Aided Design (LAD) activities include the design of the solar and hydro-electric generators, coupling of the two generators and the design of the micro-grid, water supply subsystem and the control system. The seventh activity involves the simulation of the integrated system. This will also be done using Labview. The eight activity involves the construction of a laboratory prototype. The last activity will involve reaching an agreement with one of the local Councils for the subsequent construction of a pilot scheme in the Council area.

Activity No.	Activity	Timeline (weeks)
1	Design of Solar generator (Labview-Aided Design)	1
2	Design of Hydro-electric Generator (Labview-Aided design)	1
3	Coupling of the two generators (Labview-Aided design)	1
4	Micro-grid design (Labview-Aided design)	1
5	Design of Water Supply system (Labview-Aided design)	1
6	Control System design (Labview-Aided design)	1
7	System simulation (Labview based)	1
8	Construction of a Laboratory Prototype	1
9	Agreement for construction of a pilot scheme in a Council area	2

Figure 1 : Nine-step Activity Schedule for Project

3]. DESIGN ARCHITECTURE:

The architecture of the system, illustrated in figure 2, is based on five components or subsystems:

- Solar Generator
- Hydraulic Coupling (Water Pumping and Storage)
- Potable Water System
- Control System

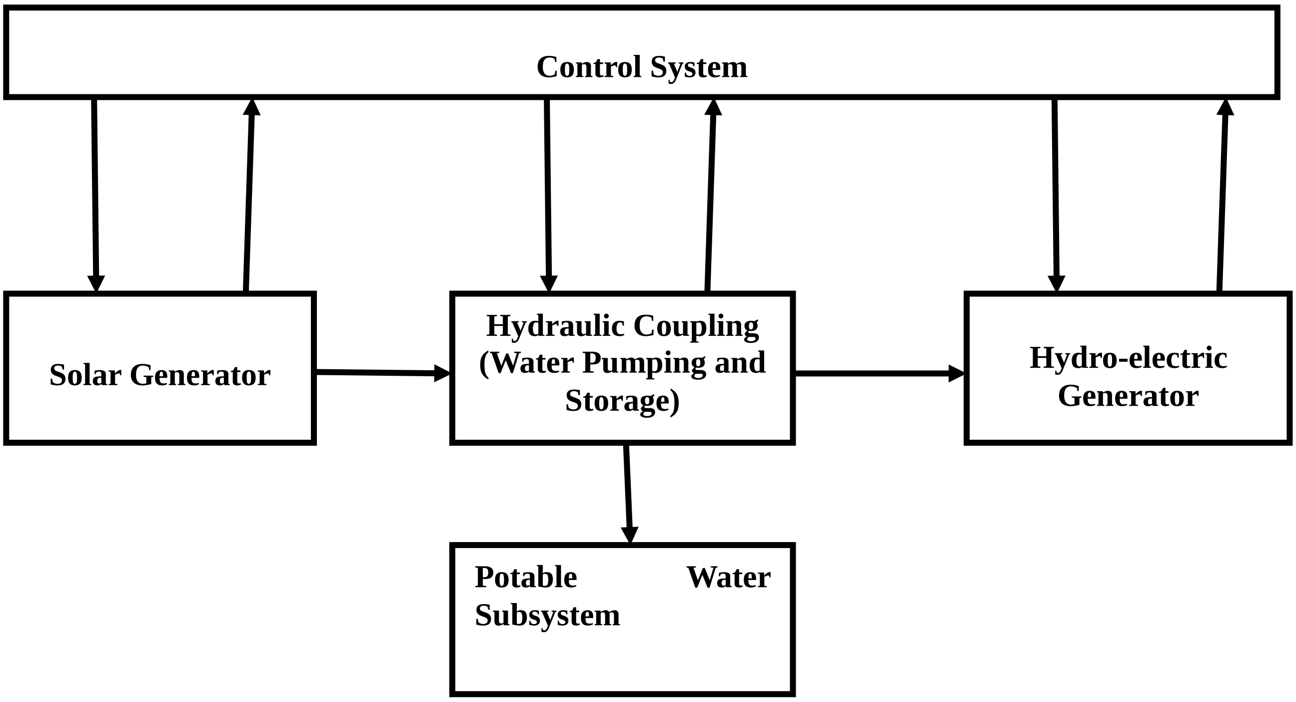


Figure 2: Architecture of the hybrid Solar and Hydro powered

- Hydro-electric Generator

The two generators are designed to supply electricity to a rural community of about five hundred inhabitants, in an alternate two-phase cycle. The solar-phase, which operates from 6 a.m to 6 p.m. (12 hours), is characterized by low power consumption and high residual capacity which requires storage. The storage function is performed by the Hydraulic Coupling Subsystem which uses a solar-powered pump to feed water to a reservoir. Solar-powered pumps have been used for various purposes, including irrigation farming [4]. In this project the technology is used as a storage mechanism for excess solar energy. This strives to overcome the main limitation of solar energy – its intermittent nature [3]. This is preferred to conventional battery storage which is mostly suited to small installations in single residences [1].

When the solar-phase ends the hydro-phase starts and runs for twelve hours, until 6 a.m. The water stored in the reservoir serves as a dam which supplies water to the hydro-electric generator. As the water impacts on the turbine blades, the motion of the turbine drives the rotor which cuts lines of flux in an in-built magnetic field to generate electricity. The hydraulic coupling subsystem thus performs a dual-function of solar energy storage and the supply of the hydraulic head which drives the turbine. The energy from the generators is fed to an autonomous micro-grid which is not part of the Cameroon national grid. The system is, thus, a typical example of recent trends in Decentralized and Distributed Energy Systems [5]. [7], [12], [13]. The potable water system consists of a separate reservoir which is fed by the solar-powered pump, as part of the solar-cycle. The reservoir contains a filtration chamber and is periodically iodized. The Control System schedules, monitors and co-ordinates the activities of the other subsystems. This requires a two-way flow of information – control signals from the control system to the other subsystems and feedback signals from the other subsystems to the control system. Labview was used for the dimensioning and parameterization of the various subsystems, based on the following design data:-

Duty Cycles

The average rural residence has three bedrooms and one living room and uses electricity mainly for lighting. The peak power consumption, P_{res}, occurs between 7 p.m. and 10 p.m. Between 10 p.m. and 6 a.m, the power consumption drops to about 1% of its peak value.

Power Output of the Hydro-electric Generator

The hydro-electric generator, thus, functions in two regimes with two power outputs:

$$Phe_{\max} = 500P_{res}$$
$$Phe_{\min} = 0.01Phe_{\max}$$

Power Output of the Solar Generator

This is calculated as a weighted average of the two power outputs of the hydro-electric generator:

$$P_{solar} = \frac{3Phe_{\max} + 9Phe_{\min}}{12}$$

P_{solar} is adjusted by 20% to compensate for the additional energy used in pumping water to the potable water reservoir.

4]. FUNCTIONAL DESCRIPTION:

The Labview-Aided Design (LAD) of the various subsystems is described in this section.

4.1 Labview Model of the Solar Generator

The model of a single solar cell was designed in Labview and used to calculate the power generated by one cell. This parameter was used to dimension the solar panels in terms of the total number of solar cells required, based on the relationship:

$$N_{cells} = \frac{1.2P_{solar}}{P_{cell}} \qquad (1)$$

Where,

N_{cells} = Number of Solar Cells

P_{solar} = Power output of the solar generator

P_{cell} = Power generated by one cell

The factor of 1.2 allows for the 20% compensation for the additional solar power used in pumping water to the potable water reservoir. This water is not used for hydro-electric generation. The model of a single cell is based on the equivalent circuit shown in figure 3.

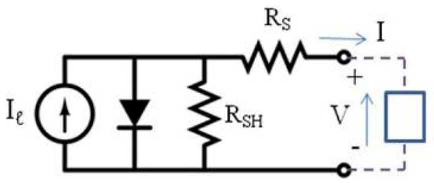


Figure 3: Equivalent Circuit of a Solar Cell

The circuit consists of a current source I_l in parallel with a diode and two resistances – a series resistance R_s and a parallel resistance R_{SH}. The variation of the current I, as a function of V, is shown in figure 4. R_{SH} drains some of the cell current while R_S dissipates energy. Consequently, for an ideal cell, R_{SH} tends to infinity and R_S tends to zero. Under these idealized conditions:

$I = I_{SC}$ and $V = V_{OC}$, where I_{SC} and V_{OC} are short-circuit current and open-circuit voltage respectively. The corresponding idealized power is P_T.

For a none-ideal cell, the actual current $I_{MP} < I_{SC}$ and the actual voltage $V_{MP} < V_{OC}$. The corresponding power is P_{MAX}. The cell efficiency,

$$\eta = \frac{P_{MAX}}{P_T} = \frac{I_{MP}V_{MP}}{I_{SC}V_{OC}}$$

The model parameters calculated from Labview include P_{max}, I_{MP}, V_{MP}, I_{SC}, V_{OC}, R_S, and R_{SH}. From these, we obtain:

$$P_{cell} = P_{MAX}$$

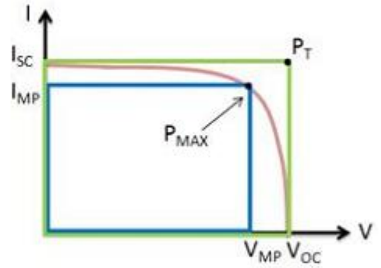


Figure 4: Cell Current as a function of Voltage

The conversion of the voltage output of the solar cells into an alternating voltage was also modeled in Labview, using the Single Phase Voltage Source Inverter (VSI) shown in figure 5. The VSI uses carrier-based Pulse Width Modulation (PWM).

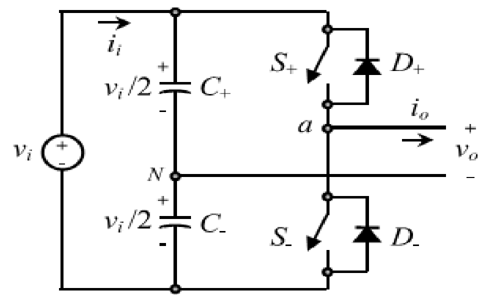


Figure 5: A Single Phase Voltage Source Inverter (VSI)

The circuit which consists of two capacitors, two diodes and two switches converts the input d.c. voltage V_i into the output a.c. voltage V_o.

4.2 Labview Model of the Hydro-electric Generator

A linearized model of the hydraulic turbine, shown in figure 6, was implemented in Labview.

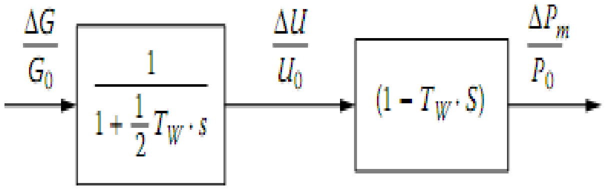


Figure 6: Linearized Model of a Hydraulic Turbine

4.3 Labview Model of the Hydraulic Coupling and Potable Water Subsystems

A tank was modeled as an integrator, using the relationship:

$$h = h_o + \frac{1}{a}\int q(t)dt \qquad (2)$$

Where,

h = Level in reservoir

h_o = Initial Level

q(t)= Volumetric Flow Rate

a= Cross-sectional area

This model was modified and applied to the potable water system in the form:

$$h = h_o + \frac{1}{a}\int q(t)dt \; - \frac{1}{a}\int q_1(t)dt$$

The additional variable $q_1(t)$ is the volumetric flow rate of water consumption.

4.4 Model of the Control System

The Control System is modeled as the ***Grafcet*** (Sequential Function Chart) shown in figure 7.

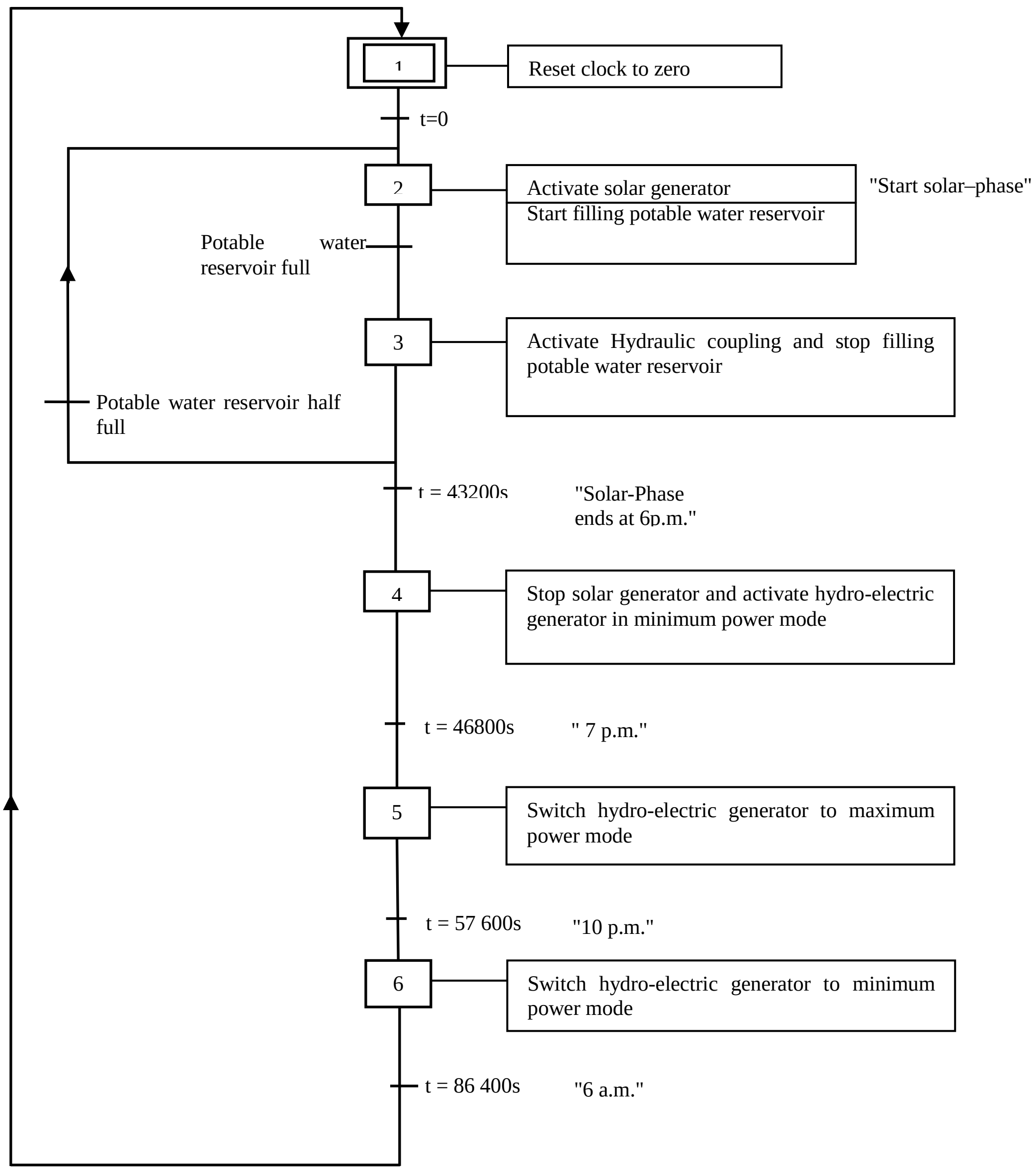


Figure 7 : Grafcet of the Dual Solar and Hydro Powered System

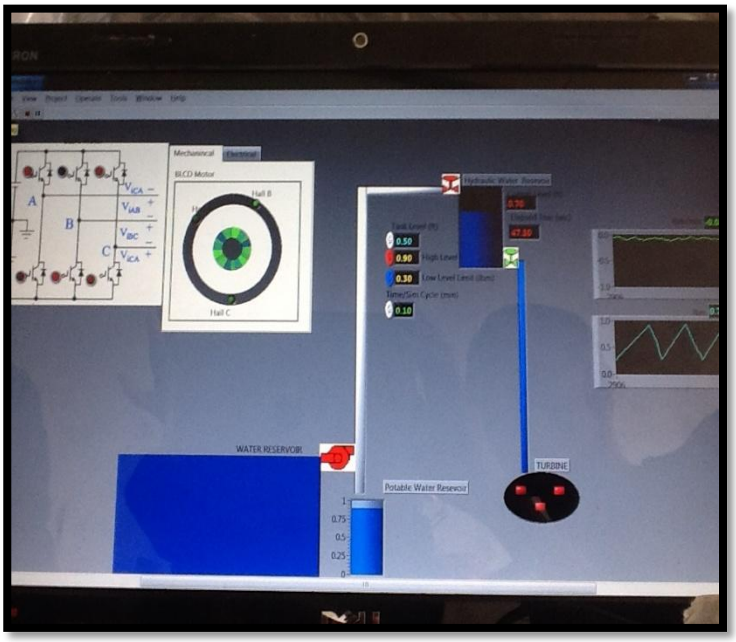
4.5 System Validation and Implementation

A Laboratory Prototype was built to test the functionality of the system. This consists of a ten-meter high metallic tower, built behind the laboratory, a reservoir placed on top of the tower, a motor-pump unit, a locally fabricated turbine, an alternator, a solar panel and converter, accessories and MYDAC. The solar-powered motor-pump unit feeds water to the reservoir and the water is released from the height of 10 meters, to impact the turbine. The turbine drives the rotor which interacts with a magnetic field to generate electricity. MYDAC displays the main variables of the Prototype.

5]. RESULTS AND DISCUSSION:

Two sets of results are presented in this section:

1. Labview models and simulation results
2. Laboratory Prototype

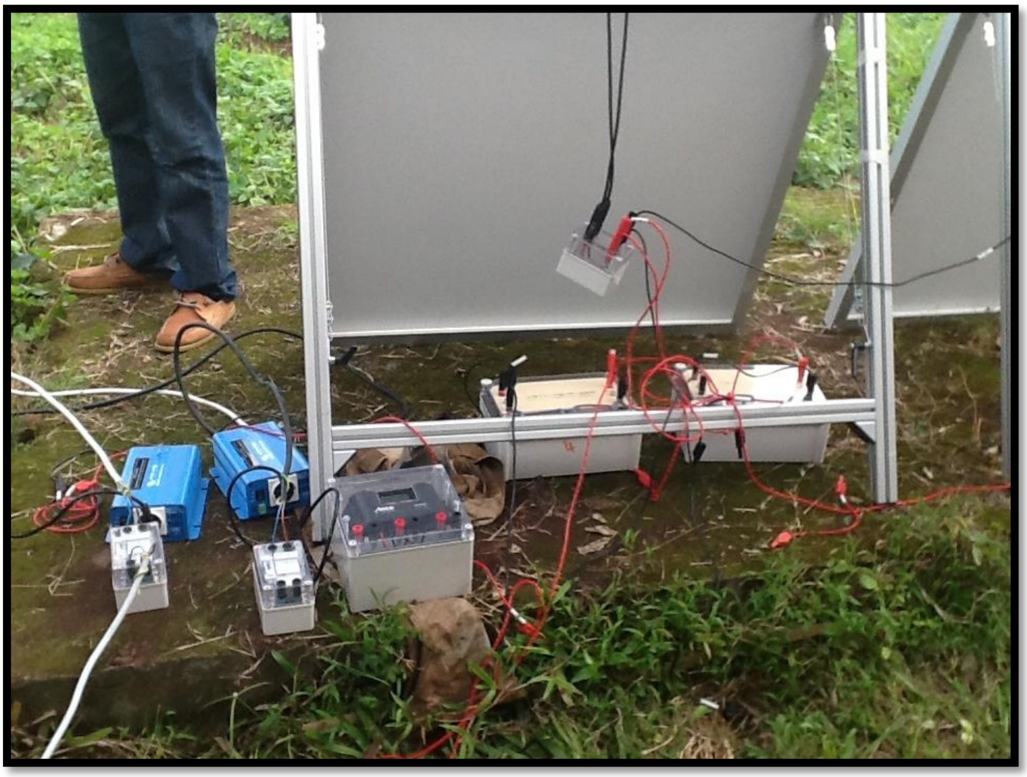


Hydraulic Sub-system

Turbine and Motor Graphs

Solar Cell Current

Solar Panels used to power the Prototype



Connection of the Solar Panel to the motor-pump unit

Motor-pump Unit

Platform carrying the Reservoir

The Design Methodology, outlined in section 2 of this paper, was based on a nine-step Activity Schedule (figure 1). Most of these activities were executed using the Labview-Aided Design (LAD) approach which has proved to be an efficient way of designing and integrating the subsystems.

6]. CONCLUSION:

This project demonstrates the feasibility of a hybrid Solar and Hydro-powered System for the supply of electricity and potable water to rural communities in India.

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