GRD Journals | GRD Journal for Engineering | National Conference on Recent Trends in Electrical Engineering (NCRTEE'18) | March 2018
e-ISSN: 2455-5703

Integrated Solar and in-Pipe Hydro Energy from Overhead Tank for off-Grid Applications

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Abstract

This research article proposes a novel Economical and Eco-Friendly (EEF) hybrid model of Solar Photovoltaic (SPV) energy integrated with In-Pipe Hydro Energy (HER) recovered from the High Head Water (HHW) flows in the pipelines for Stand-Alone Applications (SOA) in High-Rise Buildings (HRB) such as Residential Apartments. Although the SPV energy is considered as one of the most viable Renewable Energy Resources (RES) in the world, its limitation with off-grid applications is its intermittent nature of power generation. Even the integration of SPV with Battery Storage Backup (BSB) also has limitations such as capacity and peak load constrains, besides the requirement of high initial capital investments. These aspects motivated the authors to carry out the present research study for integrating the SPV with HER, which is the untapped energy of the HHW flows from overhead tanks to the point of consumption. The research study shows that integration of SPV with HER can deliver uninterrupted, reliable and environmental-friendly electric power supply for SOA at an optimal unit cost. A working model of the proposed system has been designed, installed in a typical multistoried apartment building and tested.

Keyword- Economical and Eco-Friendly (EEF), Solar Photovoltaic (SPV), Hydro Energy (HER), Stand-Alone Applications (SOA), Renewable Energy Resource (RES)

I. INTRODUCTION

The world is ceased with four major priorities as per the U.N. These are 'Energy security', 'Drinking water', 'Climate change' and 'poverty'. India is a highly populated country in the world, and hence its energy need is also more and growing with time. The Renewable Energy Resource (RES) such as Hydro Power, Solar Photo Voltaic (SPV) Power, and Wind Power etc. have several inherent defects. They intermittent and fluctuating power generation and unable provide reliable power continuously to meet the constant load demands due to significant fluctuations of solar radiation or wind speeds throughout the year. This makes RES to be coupled with Battery Storage Backup (BSB) to satisfy the power demands. Since BSB is expensive and the size has to be reduced to a minimum value so as to make the RES cost effective. Combining or Integrating multiple RES system can be a viable solution to overcome the usage of large capacity BSB in Stand-Alone Applications (SOA) or Off-Grid (OFG) applications like islands, remote villages, project sites where the On-Grid (ONG) supply is not feasible. Integration or hybridization of multiple RES, ie Hybrid Renewable Energy System (HRES) will provide reliable and uninterrupted power supply with optimum size of BSB [1]. The SPV the most abundant RES is available free of cost. Similarly a large potential energy source lies in the piping systems of high-rise buildings, both in tap water supply and drainages systems of commercial and residential sky scrapers. They require large amounts of pressure to supply water to the higher floors, and the excess pressure in the lower section is usually wasted via Pressure Relief Valves (PRV) and could be harvested for powering buildings appliances. The HRES can be used for both OFG as well as ONG applications. In this research work, a unique design is proposed to integrate the SPV and HER harnessed from the High Head Water (HHW) flows in the pipelines of a G+3 apartment building of 15 meters height is considered. A 12V-10W Polycrystalline Silicon (p-Si) SPV panel is installed in the terrace of the building. The Over Head Tank (OHT) water flows in the pipe lines of the building is sufficient enough to run a 12V-10W DC Micro Hydro Turbine (MHT. The feasibility of integrating the electrical energy derived from the experimental setup of SPV and MHT connected through Hybrid Charge Controller (HCC) to a BSB is found. The power generated is supplied to a set of Light Emitting Diode (LED) used for general lighting.

II. LITERATURE REVIEW

Sharaf and El-sayed (2009) demonstrated the application of Wind- Solar-PV hybrid system in a micro grid. Their system consists of a common DC and common AC collection bus interface. The power obtained from SPV is connected to common DC bus. Bakos (2002) performed the feasibility study of wind-pumped hydro storage system assisted by diesel generator in case of power shortage. The system is designed as a wind farm which supplies to the load first. Excess energy if available is used for pumping water from lower tank to the higher reservoir so that the excess energy is stored as hydro potential energy. When wind farm is incapable of covering the whole load, the hydro system is called into operation and energy is supplied from both wind and hydro. Bekele and

Tedesse (2012) suggested a PV-hydro-wind hybrid system which can supply uninterrupted electricity for a village in Ethiopia. HOMER was used to optimize six small hydropower potentials together with wind PV systems. Bhagwan Reddy (2008) carried a study on SOA, Wind-Hydro Hybrid, Solar-Wind Hybrid, Solar-Hydro Hybrid, Solar-Wind-Diesel Hybrid and Solar-Wind-Diesel-Hydro Hybrid systems. Mark Jacobson & Mark Delucchi (2011) studied PV-wind-battery hybrid and PV-wind-diesel-battery hybrid with the aim of rural electrification in Malaysia. Fthenakis et al. (2009) analyzed the technical, geographical, and economic feasibility for solar energy to supply the energy needs of U.S. Jacobson (2009) evaluated several long-term energy systems according to environmental and other criteria, and found WWS systems to be superior to nuclear, fossil-fuel, and bio-fuel systems.

III. MATERIALS AND METHODS

The RES such as Wind, Water (Hydro), SPV, Concentrated Solar Power (CSP), Wave, Geothermal, Tidal are Green, Clean and Risk free (GCR) energy sources. The contribution of various types of energy resources has been depicted as Fig.1.

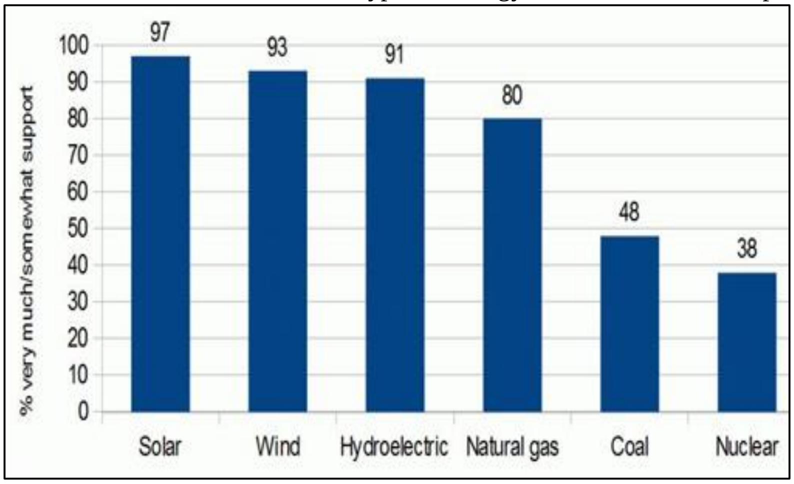

Fig. 1: Contribution of various types of Energy Resources

A. Renewable Energy Source – Wind

Wind turbines convert wind energy into electricity. New modern gearless small turbines are used in homes or buildings. Wind farms on land and offshore with individual turbines ranging in size up to 10MW are commonly used. High-altitude wind energy capture is also possible [2].

B. Renewable Energy Source – Wave

Winds passing over water create surface waves. The faster the wind speed, the greater the distance the wind travels, the greater the wave height, and the greater the wave energy produced. Wave power devices capture energy from ocean surface waves to produce electricity.

C. Renewable Energy Source – Geothermal

Steam and hot water from below the Earth's surface have been used historically to provide heat for buildings. In Geo-thermal power plants, two bore holes are drilled, one for steam alone or liquid water plus steam to flow up, and the second for condensed water to return after it passes through the plant. In some plants, steam drives a turbine; in others, hot water heats another fluid that evaporates and drives the turbine.

D. Renewable Energy Source – Water

Water generates Hydroelectricity when it drops gravitationally, driving a turbine and thereby, a generator. Hydroelectricity presents several advantages over most other sources of electrical power, including a high level of reliability, high efficiency (about 90% efficiency, water to wire), very low operating and maintenance costs [3].

E. Renewable Energy Source – Tidal

A tidal turbine is similar to a wind turbine in that it consists of a rotor that rotates due to its interaction with water during the ebb and flow of a tide. Tidal turbines are generally mounted on the sea floor. Tidal turbines can provide a predictable energy source.

F. Renewable Energy Source – Solar

Solar Photo-Voltaic (SPV) are arrays of cells containing a material, such as silicon, that converts solar radiation into electricity. Today, SPVs are used in a wide range of applications, from residential roof top power generation to medium scale utility level power generation [4].

G. Integrating the RES Systems

The HRES refers to multiple RES used together to supply the energy requirement. The HRES can not only prevent the environmental degradation but also improve the system performance in terms of:

- Fuel Flexibility
- Efficiency
- Reliability
- Emissions
- Economics

The salient features of the present research study to power OFG applications from the integrated SPV and MHT Energy System has been shown as block diagram in Fig. 2.

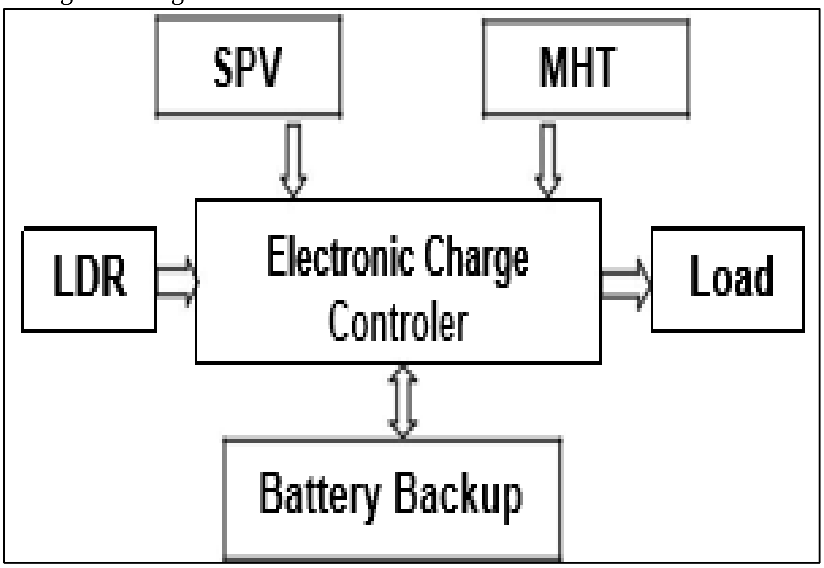

Fig. 2: Integrated Renewable Energy Sources System

IV. EXPERIMENTAL SETUP OF HRES SYSTEM

The experimental setup consists of 12V-32 SPV cells and a 135 mm diameter MHT coupled to 12V DC generator, LEDs and resistors employed to validate the results. For simple lighting operations, 12 V DC power is considered. The HRES consists of autonomous SPV-MHT for SOA requirements. The operation of integrated SPV and HER is subjected to fluctuating solar insolation and varying flow of water as well as to varying load demand. Hence, a Charge Controller Unit (CCU) is essential to control the output from each RES, when the power is supplied to the load and when to be stored in BSB. The CCU system should employ the available energies from the SPV and HYE in each sub-period to be used first and the excess energy to be stored in BSB to meet the load demand during no power generation [5].

A. Solar Photo-Voltaic Power

The SPV Power is that energy which is got by the radiation of the sun. A Polycrystalline Solar Panel of 2 W, 12 V used for the present research has been shown in Fig. 3.

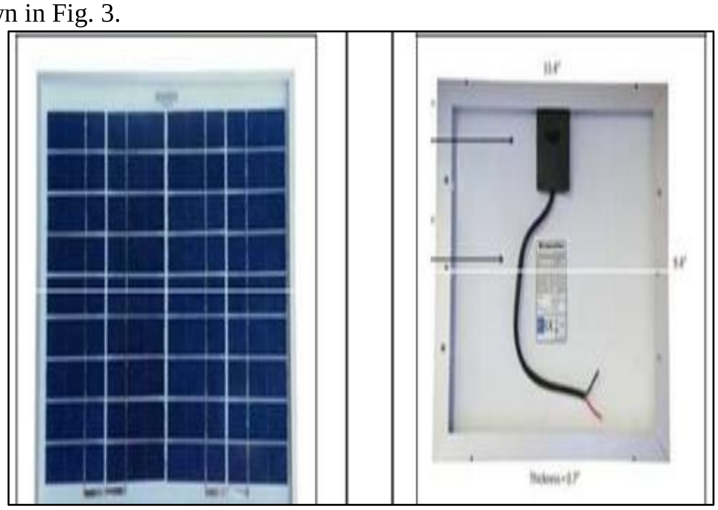

Fig. 3: Polycrystalline Solar Panel-10 W, 12 V

The only constraint with SPV system is that it cannot produce energy during night time and in bad weather conditions. But it has greater efficiency than any other energy resources. It only needs initial investment. It has long life span and has low or nil emission [6].

B. SPV Potential Assessment

The solar cell is the basic building block of the PV power system which produces about 1 W of power. To obtain high power, many such cells are placed on a panel (module), the solar array or panel is a group of a several modules electrically connected in series or parallel combination to generate the required current and voltage. The Current Vs. Voltage (I-V) and the Voltage Vs. Power (P-V) curves are shown as Fig. 4.

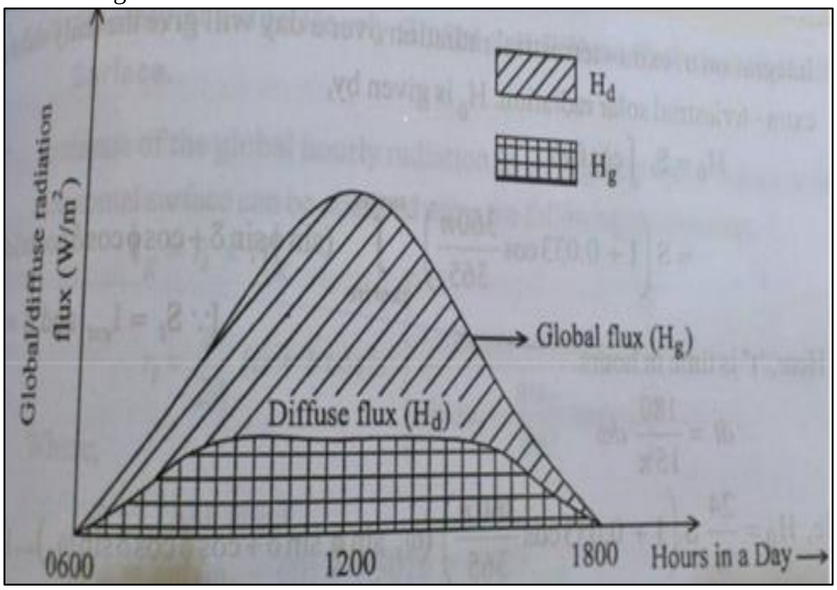

Fig. 4: Variation in radiation flux over a day

Power output of a PV array is based on solar irradiance and ambient temperature. To determine the size of PV modules, the required energy consumption must be estimated [7]. Therefore, the power is calculated as,

$$Ps = Ins\ (t) * As * \eta(\rho v)$$

Where,

Ins (t) = insolation at time t (kw/ m^2)

As = area of single PV panel (m^2)

η(ρv) = overall efficiency of the PV panels.

Overall efficiency of the PV panel is given by,

$$\eta(\rho v) = H * Ps$$

Where,

H = Annual average solar radiation on tilted panels.

P_s = Performance ratio, coefficient for losses.

The average values of data recorded from the experimental set up of SPV from morning 4'O-clock to evening 5'O-clock are presented as Table 1 and the line graph as Fig. 5.

Time (24 hours)	*Output Voltage (V)*	*Output Current (mA)*	*Output Power(W)*
4	0	0	0.00
5	0	0	0.00
6	4.85	202.64	0.98
7	5.46	209.46	1.14
8	7.92	215.31	1.71
9	9.01	230.88	2.08
10	9.55	240.92	2.30
11	11.38	246.61	2.81
12	12.18	248.99	3.03
13	11.91	242.85	2.89
14	10.65	240.77	2.56
15	9.77	235.33	2.30
16	8.26	236.76	1.96
17	6.51	206.27	1.34

Table 1: Hourly variation in SPV output power

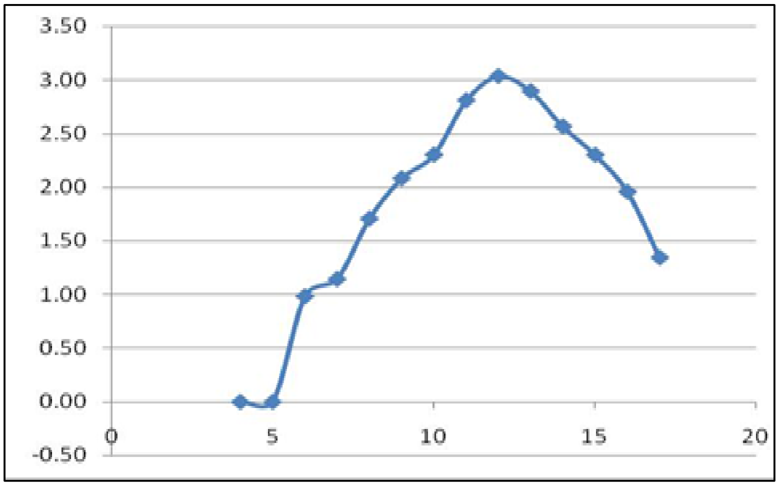

Fig. 5: Power Vs Time for SPV

C. Micro Hydro Turbine Power

A Micro Hydro Turbine of 10 W, 12 V DC Generator is shown as the Fig. 6. The water from the overhead tank enters the inlet of the casing and a nozzle is used to increase the velocity. The high velocity water hits the buckets and flows through the exit pipe connected to the tap. The kinetic energy of the water flowing in the pipe rotates the DC generator coupled with the MHT generating electricity [8].

Fig. 6: The Micro Hydro Turbine with 10 W, 12 V DC Generator

The line diagram of the experimental setup of MHT and the pipe connections are shown in Fig. 7. In the figure Point 1 refers to the free water surface of the overhead tank. Point 2 is the entry of water the MHT. Point 3 is the exits of water from the MHT and entering in to the water tap.

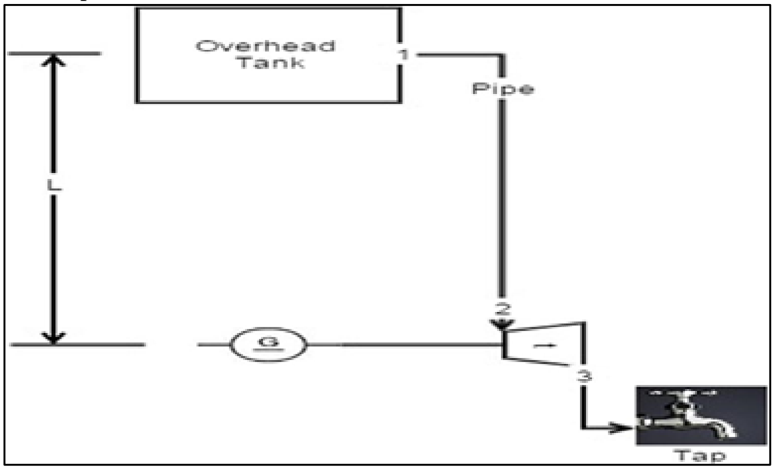

Fig. 7: Pipe Connection and Location of MHT

The shaft of the turbine is coupled to a generator and output of the generator is connected to a Hybrid Charge Controller [9].

D. Hydro Turbine Potential Assessment

Thanks to the development of small hydro turbines, compact and specified water turbines for urban use have been developed which help to harness water power of on-site energy generation for domestic, industrial and agricultural use. In general, ordinary turbines and waterwheels use the energy that can be evaluated as the sum of the three forms of energy given by Bernoulli's theorem [10]. This expression remains constant for a given cross section and position in a channel:

$$\frac{V^2}{2g} + z + \frac{p}{\rho g h} = \frac{Po}{\rho g Q}$$

Where,
v = Velocity of water flow (m/s)
g = Acceleration due to gravity constant (9.8 m/s^2)
z = Water head (m)
P = Pressure of the water (N/m^2)
ρ = Density of the water (kg/m^3)
Po= Power (N m/s) (1 HP = 75 kg m/ s =746 W)
Q= Rate of discharge of the watercourse (m^3 /s)

For ordinary modern turbines, the effective power at their input may be obtained from equation neglecting the terms 'v' and 'p' for the potential energy in the watercourse as:

$$Pt = \eta t * p * g * Q * Hm$$

Where,
ηt = Turbine simplified efficiency (for standard turbines it is taken as 80%)
The available flow of a watercourse (m3/s) is expressed by:

$$Q = A * v$$

Where,
A = Area of cross section of pipe (m^2)
v = Velocity of water flow (m/s).

The average values of data recorded from the experimental set up of MHT from morning 4'O-clock to evening 5'O-clock are presented as Table 2. The analysis of the data has been depicted as line graph as Fig. 8.

Time (24 hours)	*Output Volatge(V)*	*Output Current(mA)*	*Output Power(W)*
4	9.63	790.67	7.61
5	10.99	800.64	8.80
6	12.6	831.88	10.48
7	11.89	830.22	9.87
8	10.31	798.64	8.23
9	9.11	780.72	7.11
10	7.16	769.49	5.51
11	6.24	754.12	4.71
12	5.33	748.99	3.99
13	5.18	747.68	3.87
14	4.24	716.54	3.04
15	7.46	775.69	5.79
16	10.44	238.76	2.49
17	11.97	206.27	2.47

Table 2: Hourly variation in hydro turbine output power

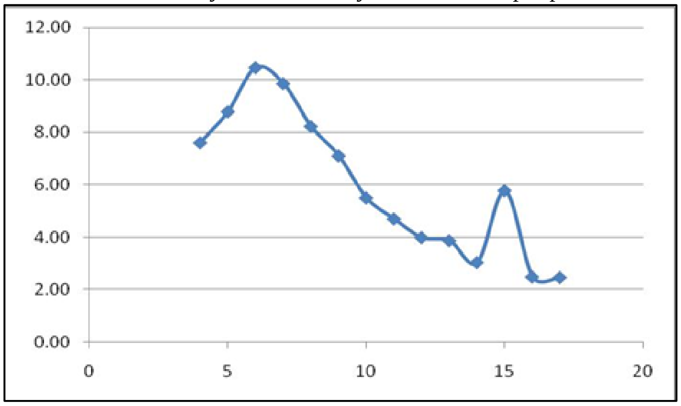

Fig. 8: Power Vs Time for MHT

E. Storage Battery Backup

BSB is to store the power when the power production exceeds the demand. The BSB are used basically for three purposes, energy stabilization, ride through capability and dispatch ability. Since both SPV and HER are intermediate sources of power, it is highly desirable to incorporate BSB into such hybrid power systems.

F. Hybrid Charge Controller

The SPV and HER are hybridized using a Hybrid Charge Controller (HCC), and the power output from the HCC is fed into the BSB to charge the batteries is shown as Fig. 9.

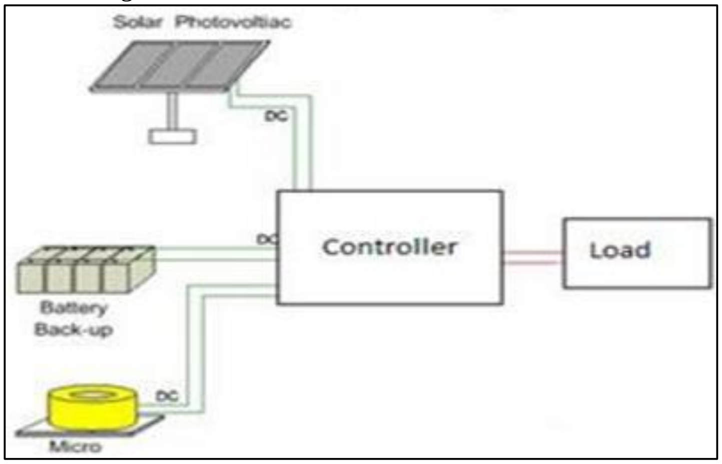

Fig. 9: Application of Hybrid Charge Controller

V. MATHEMATICAL MODELING OF HRES

The mathematical modeling helped to predict the characteristics of HRES for evaluating the performance and design the system components. The experimental results recorded from residential complex street lightings are presented. The system consists of SPV, MHT and BSB [11].

A. Modeling of Solar Photo Voltaic Energy

Using the solar radiation incident on the tilted surface, the hourly energy output (EPVG) of the PV generator can be calculated according to the following equation:

$$EPVG = G(t) * A * P * \eta(PVG)$$

The temperature effects (on PV cells) are ignored.

B. Modeling of Micro Hydro Turbine Energy

The MHT will supply power to the base load. The capacity factor of the resources is taken as unity [12]. The electrical power generated by MHT generator is given by,

$$PMHP\ (t) = \eta Hydro * \rho * g * Q * H$$

And the total energy in kWh is given by

$$EMHP\ (t) = PMHP\ (t) \times t$$

C. Evaluating of Total Energy

The total power is sum of power from SPV panel and power generated by the MHT. Mathematically it can be represented as,

$$PT = Ps * Ns + Ph * Nh$$

Where,

P_T is the Total Power Generated.

P_s is the Power Generated by Solar PV Panel.

P_h is the Power Generated by Micro Hydro Turbine.

N_s is the number of Solar PV Panels.

N_h is the number of Micro Hydro Turbines.

The total power obtained from the Hybrid experimental set up is presented as Table 3. The analysis of integrated Power with respect to Time is depicted as line graph as Fig. 10.

Time (24 hours)	*Output from SPV(W)*	*Output from MHT (W)*	*Total Output (W)*
4	*0.00*	*7.61*	*7.61*

5	*0.00*	*8.80*	*8.8*
6	*0.98*	*10.48*	*11.46*
7	*1.14*	*9.87*	*11.01*
8	*1.71*	*8.23*	*9.94*
9	*2.08*	*7.11*	*9.19*
10	*2.30*	*5.51*	*7.81*
11	*2.81*	*4.71*	*7.52*
12	*3.03*	*3.99*	*7.02*
13	*2.89*	*3.87*	*6.76*
14	*2.56*	*3.04*	*5.6*
15	*2.30*	*5.79*	*8.09*
16	*1.96*	*2.49*	*4.45*
17	*1.34*	*2.47*	*3.81*

Table 3: Hourly variation of Output Power SPV, MHT and Total Power

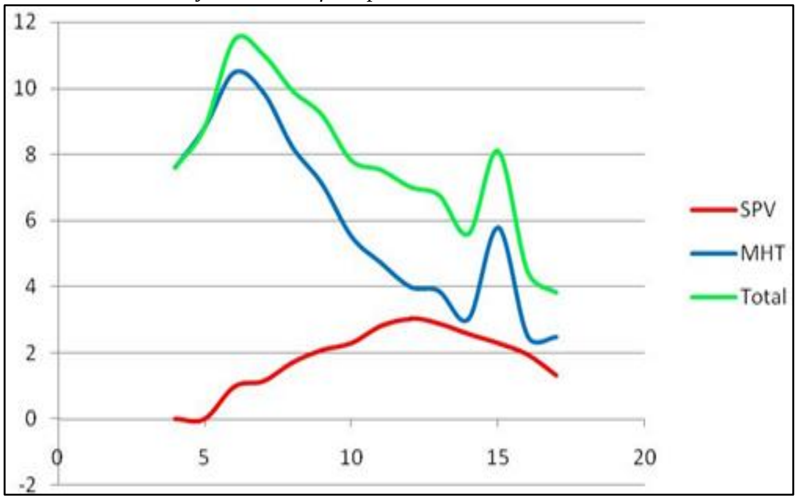

Fig. 10: Analysis of SPV, MHT and Total Power Vs Time of HRES

The analysis of integrated Power, Voltage and Current with respect to Time is depicted as line graph as Fig. 11.

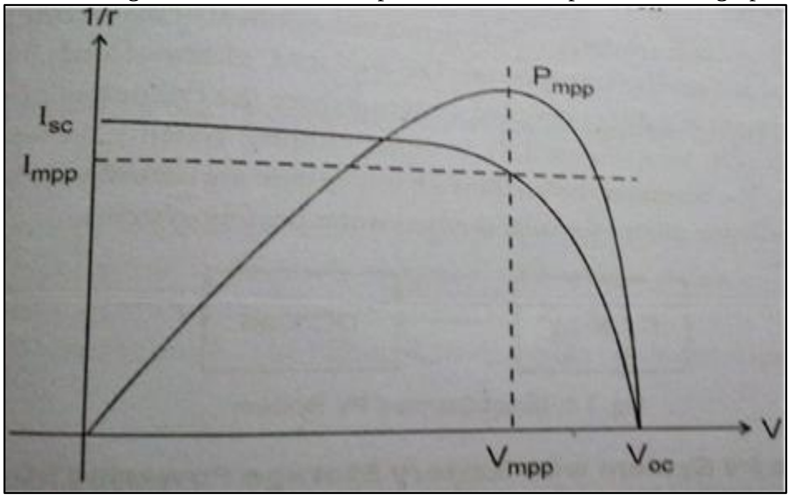

Fig. 11: Power V-I characteristics

D. Cost Analysis

The total cost of the solar-hydro hybrid energy system depends upon the total no. of solar panels used and the total no. of hydro turbines used [13]. Therefore, the total cost is given as follows,

Total cost = (No. of SPV panels * Cost of single SPV panel)
+ (No. of MHT * Cost of single MHT)
+ (No. of BSB * Cost of single BSB)

$C_T = (C_{SP} * Ns) + (C_h * N_h) + (C_B * N_B)$

Where,

C_T is the total cost in Rupees.

C_{SP} is the cost of single solar panel in Rupees.
C_h is the cost of single hydro turbine in Rupees.
C_B is the cost of single battery in Rupee.
N_s is the number of solar panels used.
N_h is the number of hydro turbine used.
N_B is the number of batteries used in BSB.
SPV – MHT hybrid energy systems needs only initial investment. It will compete well in terms of generation with the conventional energy sources, when accounted for a lifetime of reduced or avoided utility costs [14].

VI. RESULT AND DISCUSSIONS

The integrated SPV and In-Pipe MHT is mature enough to allow large scale use in urban centers. Though, the Returns on Investment (ROI) of these HRES is considerably low, it helps to prevent the environmental degradation and best useful for rural electrification. The use and hybridization of available energy resources will promote environmental sustainability by reducing the demand for fossil fuels and wood, and by contributing to productive healthy lifestyles [15].

A. Advantages of HRES

- Very high reliability and efficiency.
- Economical in operation (only one time investment). Low maintenance cost (there is nothing to replace). No pollution, hence clean and pure energy.
- Un-interrupted power supply with longer life.
- The system suitable for both OFG and ONG applications.

B. Limitations of HRES

- High initial investment.
- Complicated arrangement and noise due to MHT. Long Pay Back Period due to low ROI.

C. Application of HRES

- Best suitable for High Rise Office Complexes.
- Remote rural electrification and street lighting.
- Residential Apartment general lighting.

D. Ecological Impact

There is no waste or toxic chemicals produced during the course of power generation either by SPV or by HER. So, the energy produced by HRES is clean energy.

VII. CONCLUSION

Throughout the literature review, the authors have not found any published papers of Integrated SPV and In-Pipe MHT from Overhead Tank for Off-Grid application to provide electricity, for OGA making this study the first of its kind. This system best used for OFG applications like remote Villages, Islands, Project Sites, General and Street Lighting applications for HRB, Public Utility Buildings, Multistory Residential Complexes, Educational Institutions etc. Analysis shows that In-Pipe MHT systems can offer many advantages both in terms of quantity of energy produced and supply continuity without the problems of architectural integration and dependence on weather conditions. In this approach, a part of energy consumed in the building is produced in the building itself which has wide applicability in cities where there are many high-rise buildings.

A. Limitations of the Present Research

The present research project presented by the authors is carried out by integrating a SPV and a MHT tested in a single residential apartment only.

B. Scope for Future Research

To promote these promising renewable energy systems, it is proposed to expand, co-ordinate and disseminate results of hybrid SPV and In-Pipe MHT technology development to improve operational performance and reduce costs. The authors propose to develop On-Grid integration of large amounts of various RES, in order to achieve a clean and resilient electricity system that supports efficient, flexible, reliable and affordable operation.

ACKNOWLEDGMENT

The authors would like to gratefully acknowledge to their mentor Dr. P. Etraj of Southern Railways for his valuable guidance and support to design and develop the experimental setup for the present research work.

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