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Study of Integrated Run off River Hydro and Solar PV Power Generation Scheme in Sikkim

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ABSTRACT- Sikkim is naturally endowed with rich Hydro Power potential. The State's generation capacity is contributed solely by the hydro stations. But recent years these stations are encountering increasing number of uncertain weathers, which resulted into shortfall of precipitation during monsoon and higher abnormal rainfall during pre-monsoon times. Though some of the rivers are perennial but these uncertainty are creating challenge for them. More over the state has a large number of Run off river (RoR) hydro systems, which has a limited storage capacity. This is practically impossible to store the amount of water resource required by the hydro power plant through the use of such small pondage system. Neither this practice is permitted. The uncertain whether creates threat to the power supply, in this backdrop the present work aims to integrate the existing RoR hydro power plant with a reasonable amount of solar PV to maintain the supply reliability throughout the year. The present work involves a pre-HOMER analysis of load profile, resources at the site and post-HOMER analysis and discusses issues that are likely to affect/influence the realization of the optimal solution.

KEYWORDS- PV, Hydro, Run off river, HOMER, integrated energy

I. INTRODUCTION

Sikkim has a huge potential for hydroelectricity. Being an Himalayan state many rivers are perennial and many run off river based many hydroelectric power plants are developed in the state. The main issue with the run off river based power plant is with the storage capacity. The pondage used for such RoR system can store limited amount of water. But due to changing weather pattern the predicted level of water in the river varies at a great scale. This irregular pattern of rainfall creates challenges for such RoR hydro to maintain the supply reliability. The state largely emphasized on such system which does not disturb the ecology. On the other hand, the PV power generation is a suitable option in such region. The present work aims to introduce the Solar PV system with the already existing RoR hydro in an integrated mode and examines the Hybrid PV-RoR hydro option for ecofriendly and cost-competitive power supply with enhanced supply reliability. Analysis of such system is done with the HOMER software then a optimised model is presented considering all the factors that influence the power generation in such region.

II. LITERATURE REVIEW

Akikur et.al (2013) presents a study on solar energy in the form of a stand-alone and hybrid power generation system used to electrify off-grid locations. Bulm et.al (2013) calculates the levelized cost of electricity (LCOE) of solar photovoltaic (solar PV) and micro hydro powered village grids, and compare them to the conventional diesel solution. Nema et.al (2009) reviews the current state of the design, operation and control requirement of the stand-alone PV solar–wind hybrid energy systems with conventional backup source i.e. diesel or grid. This Paper also highlights the future developments, which have the potential to increase the economic attractiveness of such systems and their acceptance by the user. Ahn et.al (2014) proposes two practical, economical hybridization methods for small off-grid systems consisting entirely of renewable energy sources-specifically solar photovoltaic (PV), wind, and micro-hydro sources

A. *Modelling*

The study conceived on standalone mode. The present work tries to integrate the existing run off hydroelectric power plant, named as Rangit in the state of Sikkim with an adequate capacity of SPV system. The present work studies the operation with different characteristics and parameters generated by the simulation model.

To overcome the difficulties and draw back possessed by the mega hydroelectric power plant, Sikkim Government along with NHPC has developed this Rangit Dam in the year 1999 and in operation from the year 2000. This project was developed under the scheme of power to all. The scheme is operating well. The global warming and the climate change have affected the monsoon. The monsoon rainfall sometime becomes very less as compared to pre monsoon rainfall. There is difficulties in the prediction of rainfall and the power production of the ROR. One more important factor to note that the RoR has a small pondage so it is practically impossible to store the water to produce electricity according to the need throughout the year. This creates threat to the power generation. So to address this challenge an adequate capacity of PV is integrated with the existing scheme. The SPV is a passive generator and produces significant amount of energy to meet the energy requirement, particularly in the lean year where the water level at the reservoir is limited or less. And during the pre-monsoon and monsoon month the PV power production affected greatly due to the presence of cloud cover. But the precipitation during this month brings fresh water to the RoR pondage and the energy production of hydroelectric enhanced greatly and are capable to cater the daily requirement of the load.

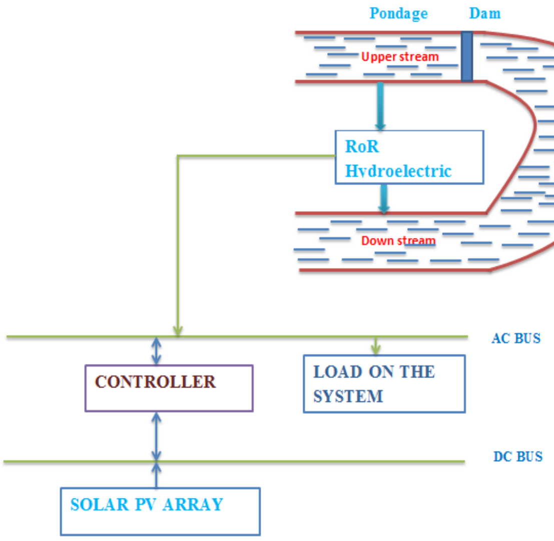

Figure 1: RoR-SPV integrated scheme

B. Load Profile

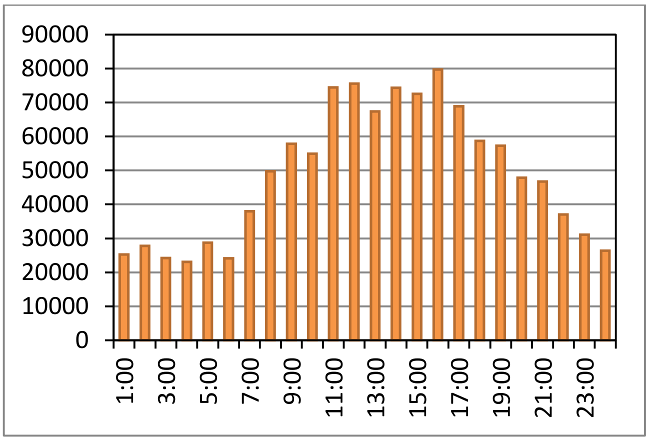

Figure 2: Daily load profile

The study observes that the daily load requirement stand at 951 MWh and the peak touches to 105 MW. The daily load curve for the 14th May is shown below. This represents the variation of the load for one typical day. And the next figure shows the average load on the system on monthly basis. The load profile is synthesized in the software by adding randomness of the day. However the seasonal variation is not considered.

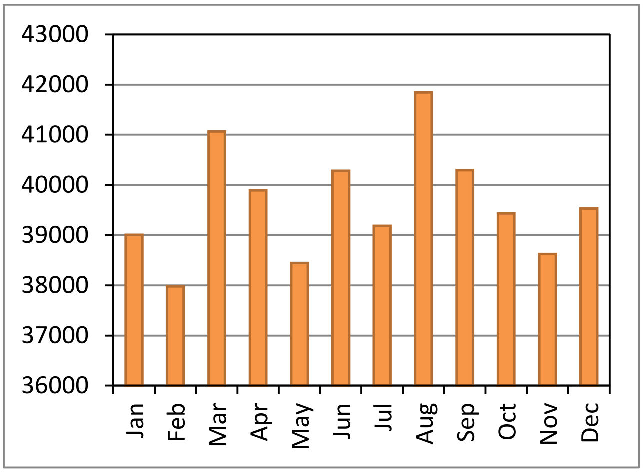

Figure 3: Monthly load profile

III. COMPONENTS USED

Name of the Component	Specification
PV	130,000 kWP
RoR Hydroelectric	60,105 kW
Inverter	7,000
Load (AC Primary)	905 MWh/day

A. Mathematical Formulation

Therefore the power output from a PV array is:

$$P = VI = N_P I_{Ph} V - N_P I_0 V \left(e^{\frac{1}{V_t}\left(\frac{V}{N_S}+\frac{I_{RS}}{N_P}\right)} - 1 \right) - \frac{N_P}{R_P} V \left(\frac{V}{N_S} + \frac{I_{RS}}{N_p} \right)$$

where Iph is the photo current (A); I0 is the diode saturation current (A); Rs is the series resistance (Ω); Rp is the shunt/parallel resistance (Ω); Vt = nKT/q is the diode thermal voltage; n is the diode ideality factor; T is the cell temperature (K); K is the Boltzmann's constant 1.381 × 1023 J/K; q is the electron charge 1.602×1019 C; Ns is the number of PV cells in series for the studied array and Np is the number of PV module in parallel.

The five key parameters I_{ph}, I_0, V_t, Rs and RP under standard test condition (STC) can be computed using analytical or numerical solution, based on the specification provided by the manufacturer. Following the method in the five parameters I_{ph}, STC, I_0, STC, V_t,STC, R_S STC and R_p,STC under standard test condition.

The nominal power of the hydro system. This would be the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine. Its unit is kW. The nominal hydro power is calculated using the following equation (7):

$$P_{hyd,nom} = \frac{\eta_{hyd} \cdot \rho_{water} \cdot g.h.Q_{design}}{1000W/kW}$$

Where Phyd,nom= nominal power output of the hydro turbine [kW], ηhyd= hydro turbine efficiency [%], ρwater=density of water [1000 kg/m3], g= acceleration due to gravity [9.81 m/s2], h= available head [m], Qdesign=the design flow rate of the hydro turbine.

B. Simulation Methodology

Hybrid optimization model for electric renewable (HOMER) software , the renewable energy based system optimization tool developed by the United States (US) national renewable energy laboratory (NREL) is used in this work for modelling and simulation purpose. It is a flexible tool that models a mix of conventional fuels and renewable energy to determine the most cost effective configuration for each system. Input information to be provided in HOMER includes: electric load (primary energy demand), renewable resources (solar radiation), hydro resources, component technical details/costs, type of dispatch strategy, etc.

IV. RESULTS AND DISCUSSION

A. Monthly Power output from PV array

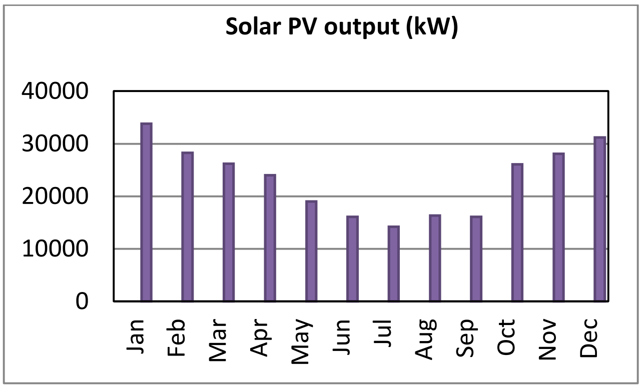

Figure 2: Power output from PV array

The above graph portrays the average output of the solar PV on monthly basis. It is observed that during the pre-monsoon and monsoon season the solar PV output reduces drastically due to the presence of cloud and the reduction in the average sunny hour. The trend continues from April to September. The solar output of 203,808,112 kWh/yr is estimated by the simulation software.

B. Monthly average water discharge

In the below fig. estimated water discharge are shown. The pre monsoon and monsoon season brings quite good amount of rainfall to the Dam. The proposed scheme is of run of river type hydro scheme, so it has a limited capacity to store and discharge the rest. So the observation shows that the discharge rate is quite high during the monsoon season and this complements the solar PV production. The average discharge of the system is 68,776.2 L/s.

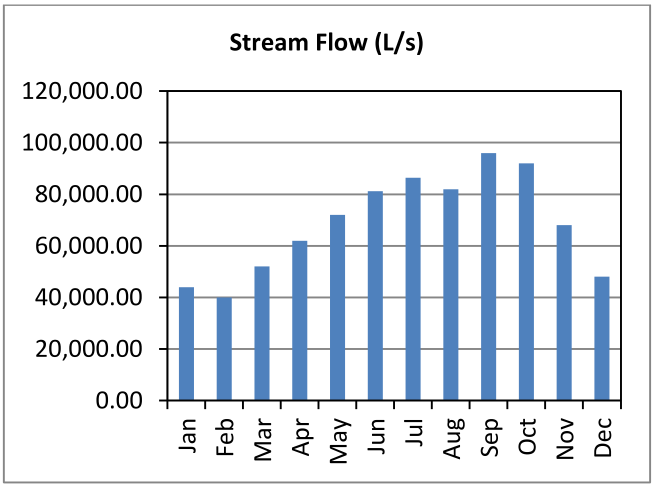

Figure 4: Monthly average water discharge

C. Battery Output

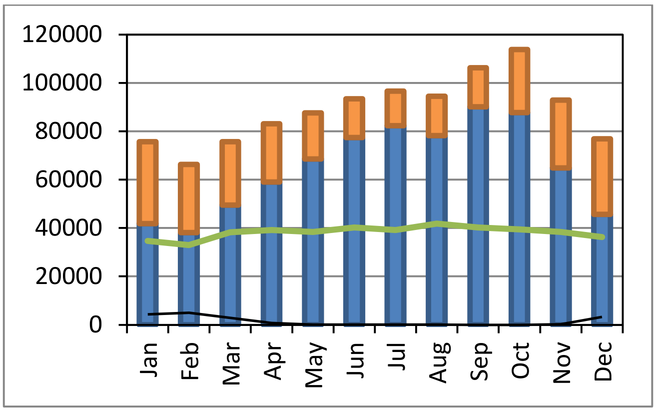

Figure 5: Daily mean energy production and load demand

The average energy production on daily basis is depicted in the below figure. The RoR Hydro serves 74% of the demand whereas the PV caters 26% of the demand. It can be observed that due to presence of cloud the PV generation affected in the pre monsoon and monsoon season, at the same period the reservoir water level improves significantly. The characteristics observed is favourable in the given context. The green line shows the average load of the scheme, the blue and orange bar represents the power production by the ROR Hydro and SPV respectively and the black line shows the unmet load.

D. Energy balance of the scheme

An example of the hourly simulation result during one typical day is illustrated in the below fig. to analyze the energy balance of the proposed scheme. The SPV is a passive energy producer and the ROR is an active energy producer. The ROR Hydro is designed in such a way that either the energy is produced or not the amount of water must be flow. Owing to these disability significant amount of energy is being wasted to overcome this one may suggest to use the battery bank, but using such a large capacity of battery bank will be a threat to the ecology of the site. The blue bar depicts the hydroelectric power generation, yellow bar depicts the SPV power, the red line shows the AC primary load, the green bar shows excess electricity and the short fall is shown by the blue line.

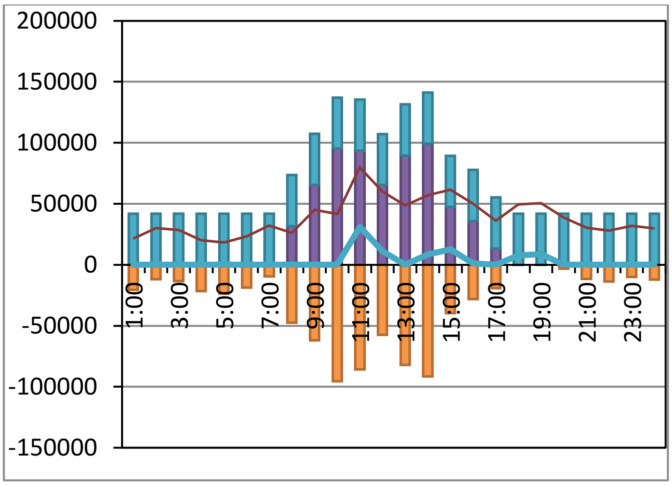

Figure 6: Energy balanced of the system

E. Converter performance

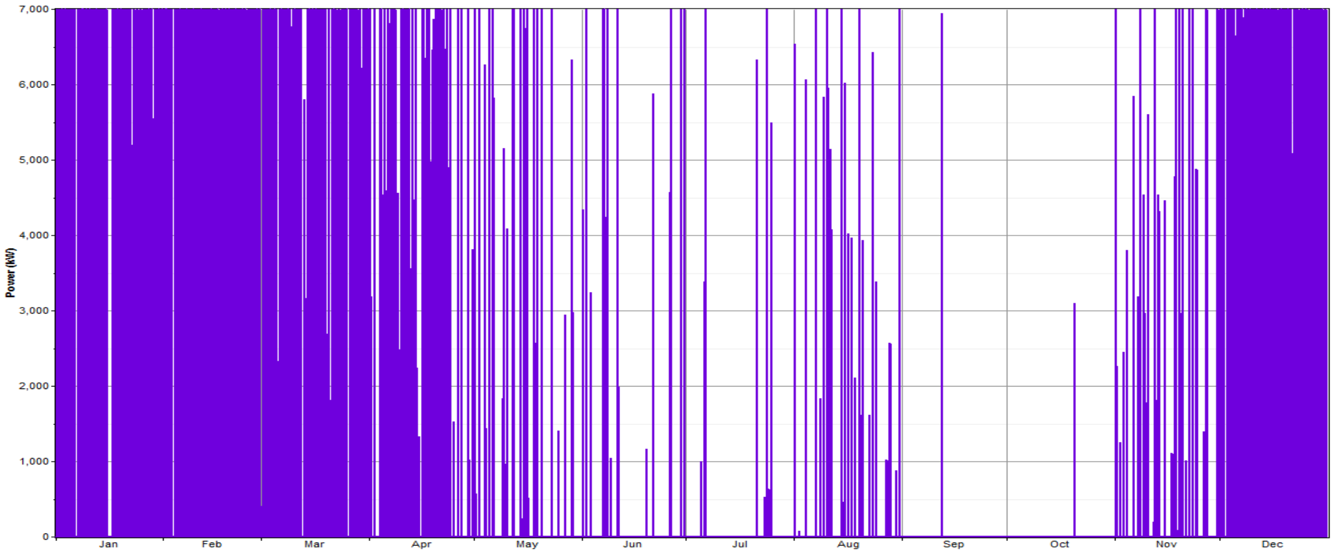

Figure 7: Inverter Performance

Inverter is the major Balance of System of the proposed scheme; the inverter operation is required only during the operation of transforming PV power to DC power. However the simulation suggests that the operation of inverter is required for around 1165 hours in a year. The below two picture depicts the operation characteristics of the inverter, it is observed that during the pre-monsoon and monsoon time maximum portion of load is carried out by the ROR hydroelectric, and the cloud cover also reduces the output of solar, and so the inverter output also significantly reduced.

F. Duration Curve

Duration curve depicts the hours of operation of a particular source or component in a year; it additionally shows the efficiency at which it is being operated. This helps the operator to find out the critical characteristics of the component and this characteristic helps to plan the maintenance of the critical components to avoid the supply loss or failure due to poor maintenance. The load is present for the entire duration, so it is there for 8760 hours, shown in red line, with varying load requirements and of AC nature. The power production unit of ROR Hydro again operates for 8760 hours and with varying capacity depending upon the reservoir level, presented in Green line. As the ROR hydroelectric plant produces AC power so it does not require the operation of inverter. The second power source, the SPV operates for around 4390 hours, shown in indigo line. The inverter operation is restricted with 1165 hours only, represented in blue line. The power shortage is observed for around 1038 around, but this is again not absolute hours. This power shortage is with varying degree. It is represented using the orange line.

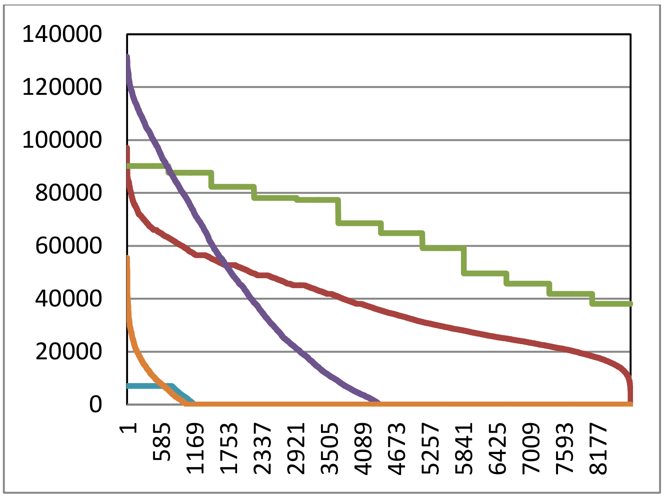

Figure 8: Duration Curve

G. Sensitivity Analysis

The sensitivity analysis provides protection against the market instability and cost uncertainty. The cost reduction and technological development of renewable energy systems in recent years has been encouraging in Indian context. Hence, it is presumed in the study that the system cost is likely to decrease in future. In order to simulate the declining cost for the long term analysis; a 20% reduction in PV and 15% slash in Inverter costs has been incorporated in the estimation. However the cost of materials used and other accessories are increased day by day for the hydroelectric power plant, as the power plant is already in operation, the hydro power plant variation cost is not calculated in the scheme. When PV and Inverter cost slashed down by their respected maximum value the cost of energy is stands at INR 9.094 and INR 9.131. When they price declines simultaneously the cost of per unit energy reduces to INR 9.082.

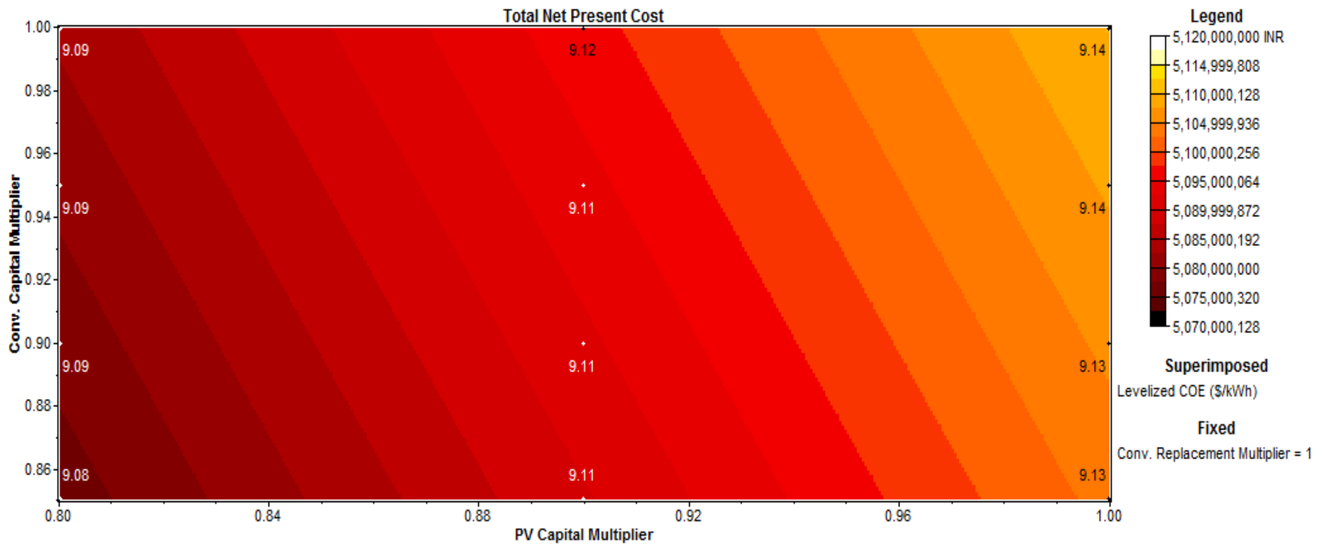

Figure 9: Surface plot of electrical energy

H. Economic Analysis

			PV (kW)	Hydro (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
			130...	60105	7000	$ 5,104,10...	3,623,680	$ 5,110,142...	9.143	1.00	0.06
			130...	60105	8000	$ 5,110,60...	3,926,784	$ 5,117,148...	9.135	1.00	0.05
			140...	60105	7000	$ 5,114,56...	3,623,680	$ 5,120,604...	9.161	1.00	0.06
			130...	60105	9000	$ 5,117,10...	4,230,400	$ 5,124,154...	9.128	1.00	0.05
			140...	60105	8000	$ 5,121,06...	3,926,784	$ 5,127,610...	9.153	1.00	0.05
			150...	60105	7000	$ 5,125,02...	3,623,680	$ 5,131,066...	9.180	1.00	0.06
			130...	60105	10...	$ 5,123,60...	4,533,504	$ 5,131,159...	9.123	1.00	0.05
			140...	60105	9000	$ 5,127,56...	4,230,400	$ 5,134,616...	9.147	1.00	0.05

Figure 10: Optimization table

The optimal result produced by the simulating software is depicted in the above figure. The table key simulation results, such as capital cost of the system, operating cost, Net present cost, levelized cost of COE, renewable fraction and capacity shortage along with the optimized size of resource equipment's. The optimal results are achieved with 130 MW of SPV, 60 MW of ROR and 7 MW inverter. The COE is found to be INR 9.143/kWh and100% renewable fraction and capacity shortage of only 6%.

V. CONCLUSION

The present work aims to integrate the RoR based hydroelectric power with the SPV system. The results of the study are inspiring. The complementary nature of the power sources makes the system more feasible in the monetary context, and viable in technical aspects. The study finds that the system can serve the entire load for a nominal charge of INR 9.143 with a capacity shortage of 6%. The scheme is in cohesion with the environmental prospects and suggested.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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