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Largest Isolated Wind-Solar Hybrid System in Nepal and Its Socio-Economic Impact

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Abstract – *Among the many renewable energy resources available in Nepal, wind and solar energy are auspicious sources of clean energy for rural villages. Solar photovoltaic (PV) and wind have been incorporated in tandem to deliver better energy services as a hybrid power system. A case study of the largest off-grid wind-solar hybrid system in HariharpurGadi village, Sindhuli District, Nepal and its socio-economic impact is presented in this paper. Wind turbine generator (WTG) consists of two units of 10 kW and a solar PV comprised of 50 modules of 300 W_p. To meet the villager's daily power demand of 87 kWh, the solar-wind hybrid power system generates 110 kWh of energy/day. In addition, the impact of electrification on household lighting usage, income, satisfaction, social structure, environmental satisfaction, and education is explored in this paper. In addition, the differences between the quality of life before and after the electrification of the village are also compared. The study depicts that rural electrification using wind and PV solar hybrid power system has played a vital role in enhancing individual daily activities.*

***Key Words*: Wind Turbine Generator, Depth of Discharge DOD, Irradiance, Wind-Solar, Hybrid System.**

1. INTRODUCTION

Due to the swift demanding of the fossil fuel, the energy crisis might occur all over the world in the future. To overcome this problem, renewable energy plays a significant role in producing the electricity [1-3]. Many countries in the world have substantially invested in the renewable energy sectors to mitigate the emission of the greenhouse gases which are detrimental to our environment and health [4-5]. Renewable energy has many merits over the fossil fuels in terms of the energy security, environment, humans' health, climate changes, etc. The socio-economic situation of the rural lives can be greatly benefited from the installation of the renewable power plants in the remote area. There might be undeniable that the electricity generation from the renewable energy sources contributes to the power system with the large proportion of energy in the future. The global demand for electricity is increasing at 2.1 percent per year to 2040, twice the rate of demand for primary energy [6-7]. Besides, in the context of Nepal, the electricity demands in rises by about 7-9 percent per year [8-9]. In rural areas, two common methods, namely grid extension and the use of the diesel generators, are employed to provide electricity to the consumers. These methods are more expensive than the hybrid systems of the various renewable sources such as wind, solar, and wind-solar hybrid power systems [10]. Due to the intermittent nature of the solar and wind, they are not able to provide continuous power supply throughout the entire day. Thus, literatures suggest that the use of power buffers such as rechargeable batteries or super-capacitor to store the power and delivers it to the consumer when needed [11-12].

This manuscript investigates the socio-economic impacts of the largest isolated solar-wind hybrid system in Nepal. In this hybrid system, two wind turbine generators (WTGs) with the rated capacity of each WTG of 10 kW and a solar PV comprised of 50 modules of 300 W_p are employed in order to generate the energy of 110 kWh every day. The comparison between the pre and post lifestyle after the installation of the hybrid wind and solar PV in the village are also performed. The study demonstrates that the villagers' daily activities and the involvement of the economic activities significantly have been improved.

This paper is organized as follows. In section 2, the background of wind and power availability in context of Nepal is discussed. In section 3, the modeling of the solar PV and wind hybrid system is discussed. In section 4, the largest hybrid wind solar power plant site is examined. The detail of the various components that are employed in the system is represented in section 5. Section 6 describes the socio-economic effects of the installed hybrid power plant. The manuscript is finally concluded in section 7.

2. BACKGROUND

Hydropower is a major source of energy in Nepal. Although Nepal has an abundance of hydropower resources, the construction and commissioning of larger hydropower plants requires a significant amount of capital and time. Because of the low population density of rural areas, grid-connection costs are higher. However, while a diesel generator may be the most reliable and cost-effective option, it is not the best choice due to numerous environmental concerns and a shorter useful life. Other available renewable resources, such as wind farms, would help meet electricity demand in a shorter amount of time.

Studies have showed that four types of solar energy technology have great potential in Nepal: solar lanterns, solar water heaters, grid-connected PV and solar home systems. With about 300 days of sunny days per annum, Nepal grabs 3.6 to 6.2 kWh of solar radiation per day per square meter, making it suitable for solar power system [14].

Being a mountainous country, Nepal has a lot of scope for wind power plant. The data base is insufficient for a fair assessment of wind power. With a power density of 238 kW/m^2, the highest speed of wind is 46.76 m/s. The mean annual energy potential is 3.387 MWh/m^2. The country's wind power capacity is 6074 square kilometers, with a wind's power density of more than 300 watts per square meter. At 5 MW per sq km, more than 3,000 MW of electrical energy could be produced. Nepal's wind power potential is estimated to be around 448 MW commercially feasible.

2.1 Hybrid System

Wind energy has a lot of potential in Nepal, where the average wind speed ranges from 0.5 to 4 meters per second. In Nepal's rural areas, wind energy may be a better energy replacement. Dhading, Makwanpur, Mustang, Morang Pyuthan, Mugu and others are among the wind power plants that have been constructed in Nepal to date. According to AEPC's data from 2003, the area of wind power potential is approximately 6073.3 square kilometers, with a wind power density of exceeding 350 watts per square meter. Only 10% of the total area of 6073.3 sq km was examined, and it was discovered that beyond 3,500 MW of electricity could be produced utilizing the total capacity of 5 MW/km^2. The country's wind capacity is projected to be about 448 MW commercially viable. Based on this examination, Nepal could produce 3500 MW of electricity from wind energy by considering 10% of the land within a 10-kilometer radius of the current national grid and having a wind power density of more than 300 Watt per square metre [8][14].

Similarly, 78 percent of the total land in Nepal has a high potential for solar insolation, according to the wind energy conversion framework. Solar radiation is (3.6-6.2) kWh per metre per day on average, and the sun shines for approximately 300 days/year. Hybrid systems can support both off-grid and grid connected applications. Also, within a single day or season, the sun and the wind have opposing periods, and their strength varies.

The speed of wind is low in the summer and the intensity of the sun is high, but the situation is opposite in the case of winters. There is also an opposite trend of wind and solar energy on the same day, in various topographies of the country, or at different times of the year, which boosts the system's efficiency. It also lessens capacity of the battery banks, reducing the hybrid solar-wind system's cost.

3. WIND-SOLAR PV HYBRID SYSTEM MODELING

The modeling of a solar and a wind hybrid power system has been briefly illustrated in this section.

3.1 Wind Turbine Modelling

The aerodynamic power of a wind turbine is converted into mechanical power, which is expressed as

$$P_{mech} = 0.5 \rho A v^3 C_p(\lambda, \beta) \tag{1}$$

Where *ρ represents air* density, A represents rotor swept area by the blades, and v stand for speed of the wind. C_P is a function of tip speed ratio, λ is pitch-angle, and β is pitch-angle.

$$C_P = 0.645\{0.00912\lambda + \frac{-5 - 0.4(2.5+\beta) + 116\Lambda}{e^{21\Lambda}}\} \tag{2}$$

Where

$$\Lambda = \frac{1}{\lambda + 0.08(2.5+\beta)} - \frac{0.035}{1+(2.5+\beta)^3} \tag{3}$$

According to (2) the maximum C_P and optimal C_P, are 0.5 and 9.95, respectively. Modelling of a two-mass shaft considering the mechanical dynamics is given by

$$J\frac{d\omega_r}{dt} = T_m - K_r\omega_r - T_e \tag{4}$$

Where the momentum of inertia, generator rotating speed, rotor damping coefficient, mechanical torque, and electromagnetic torque are represented by J, ω_r, K_r, T_m, and T_e respectively.

3.2 Solar PV Model

Fig. 1 depicts the practical PV model with ideal PV cell. The solar PV cell converts solar energy into electrical one using photovoltaic effect. The solar irradiance determines the output of solar PV system. For a solar panel fixed on an inclined surface, the total hourly irradiance is given by:

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (5)$$

Where I_T, I_b, I_d are the total solar irradiance, beam part of solar irradiance and diffused part of the solar irradiance respectively on an incident surface (kWh/m^2); R_b, R_d and R_r represents the tilt factors for the beam irradiance, diffused irradiance; and the reflected part of the solar irradiance.

The hourly solar PV power output is measured in terms of area as follows

$$P = I_T A_{PV} \eta_{PV} \quad (6)$$

Where A_{PV} and η_{PV} are the area and solar PV system's conversion efficiency respectively.

The conversion efficiency of a solar PV system is described as

$$\eta_{PV} = \eta_M \eta_{PC} [1 - \beta(T_C - T_R)] \quad (7)$$

In above equation η_M represents module efficiency, η_{PC} represents efficiency of power conditioning, 'T_C' represents monthly mean cell temperature, 'T_R' represents reference temperature, at last 'β' is the array efficiency temperature coefficient.

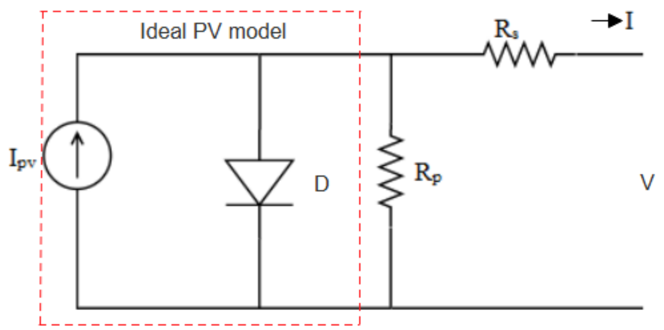

Fig -1: Practical PV model with Ideal PV cell

The current provided by a solar PV cell in its ideal equivalent circuit is given by:

$$I_{PV} = I_{PH} - I(e^{QV_{PV}/kT} - 1) \quad (8)$$

Where, I_{PV} and I are the PV current and reverse saturation current of the diode, respectively (A). The Boltzmann Constant is k, and the cell temperature is T. Q, k and T stand for electron charge, Boltzmann Constant, and the cell temperature.

3.3 Model of the battery

In this system, VRLA tubular gel battery is used. It is special type of lead acid battery with electrolyte in gel form. It facilitates deep cycle usage and are virtually maintenance free. It has long cycling capacity and lifespan which aid lesser number of replacements in a long run.

4. DESCRIPTION OF THE SITE LOCATION

In Chisapani, HariharpurGadi village, Sindhuli District, Nepal, the paper explores a case study of a solar and wind hybrid power plant with the total installed capacity of 20 kW wind turbines and 15 kW$_p$ solar PV panels with incorporating battery energy storage system. The site is located N 27021' 8.34'' and E 850 27' 44.28'', at 355-meter elevation. Fig. 2 shows the topographical image of the site. Fig. 3. Shows the installed

Fig -2: Topographical image of the site

Fig -3: Hybrid Wind solar power plant installed at the HariharpurGadi area

The hybrid Solar-wind power system was built in December 12, 2017 with the goal of electrifying 83 households and was funded by the Asian Development Bank (ADB). The perceived ease of use (PEU) demand is currently 6 kW. The hybrid system generates 110 kWh of energy/day, which is enough to meet the villager's daily energy demand of 87 kWh (15 percent demands from PEU). The Solar-wind hybrid power system generates 110 kWh of energy in a day, which is enough to meet the villager's daily electrical energy demand of 87 kWh (15 percent demands from PEU). The hybrid system's maximum daily energy demand, after losses, is 99 kWh per day. The least energy from a wind turbine is 14.07 MWh per year (50 percent of the total demand), and the least energy from a solar PV plant is 14.07 MWh per year (50 percent of total demand). Chisapani village's total energy demand in a year is 28.14MWh.

5. FEATURES OF THE COMPONENT

The length of total transmission and distribution are approximately 2920 meters. The length of three phase lines is increased to 1120 meters, while single phase lines are increased to 1800 meters. Aluminum conductor Steel Reinforced (ACSR) is the proposed conductor in this case the wires used are of the rabbit and dog varieties. With 1400 meters of phase wire and 1400 meters of neutral wire, the dog cable is 2800 meters long. The rabbit type cable is 5180 meters long, with a phase wire of 3710 meters and a neutral wire of 1470 meters. Given a 10% voltage drop, the lengths of rabbit and dog cable were estimated to be 5698m and 3080m, respectively. Similarly, the support wire has a diameter of 6 mm^2 and a length of 1660 meters. Three phase lines have a voltage of 400V, and single-phase lines have a voltage of 230V. MS Tubular Poles with 9m lengths were used in 26 cases, and MS Poles with 8m lengths were used in 43 cases. With a total of 124 and 66 insulators, the medium and large Shackle type insulators were used. The stay set comprises 17 stay plates with dimensions of 300mm*300mm*6mm. Thimble/stay cable, stranded/turnbuckle, and stay rod with a diameter of 16mm and a length of 1.8m are among the stay set's accessories. Copper plate with dimensions of 600mm*600mm*3mm and 6 numbers is used in the plate earthing system. It comprises two extra plates at the power house for machinery body and neutral earthing. A total of 14 lightning arrestors, each rated at 0.5kV and 1.5kA, are in use. The household Miniature Circuit Breaker (MCB) has a total of 83 and a rating of 230V, 1A, SP. The 1A SP 230V household miniature circuit breaker (MCB) has a number of 83 and a rating of 1A SP 230V. The energy meter is single phase 2 wire, 230V, 5A static type, and there are 83 of them. Figure 6 shows a schematic representation of the various components of the wind-solar hybrid model.

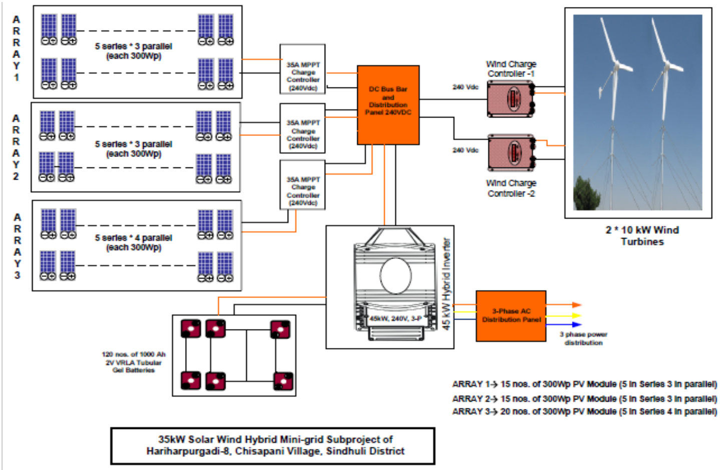

Fig -4: Solar-wind hybrid design Schematic block diagram

Source: AEPC, Nepal

Table 1 describes the main device components used in a hybrid model.

Table -1: Hybrid system components details

Components	Quantity	Unit	Total
Turbine (Wind)	2	10 kW	20 kW
Solar Module	50	300 W_p	15 kW_p
Batteries (VRLA Tub Gel)	120	2 V & 100 Ah	240 V& 1000 Ah
Inverter	1	45 kVA	45kVA

Table -2: Solar Power System data

Depth of Discharge of Battery	70 %
Days of Autonomous	2 days
Peak Sunshine hours	5 hrs.
Coulombic efficiency	90%
Efficiency of inverter	94%
De-rating factor	5%
Horizontal Irradiance	5.18 kWh per square metre per day
Tilted (27^0) irradiance	5.75 kW per square metre per day
Average temperature	14.6^0 C
Other losses	7%
Daily average energy production	60 kWh

Table- 3: Wind power System data

Average Wind Speed at 10m height	3.21m/s
Spot measurement	6-8m/s
Average daily wind production	49 kWh

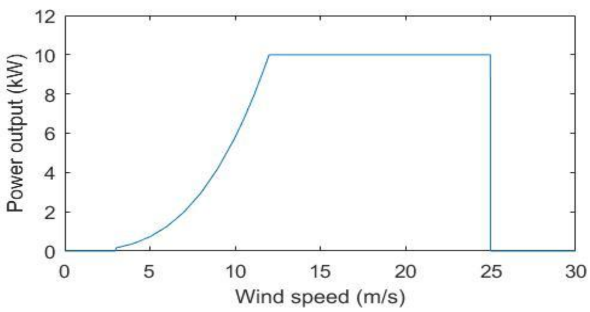

Fig -5: Power curve for 10kW wind turbine

Fig. 5. Depicts the block diagram of the system installed at HariharpurGadi site. The hybrid solar wind plant consists of three solar arrays, in which solar panels each of capacity of 300Wp are used. The array 1 and 2 consists of 15 solar panels arranged in 5*3 layout whereas the array 3 consists of 20 solar panels arranged in 5*4 layout. Also, two wind turbines of capacity 10kW are connected in the plant. Fig. 6. Depicts the power curve of a 10-kW wind turbine, where 3 m/s is cut-in speed, 12 m/s is rated speed and 25m/s is cut-off speed. Through charge controllers, both the wind turbines and the solar PV system and are connected to the main bus bar, which is DC. A 45kW three phase hybrid inverter is connected with the DC bus bar which is responsible for either charging the energy storage device or energizing the load. 120number of 1000Ah 2V VRLA tubular gel batteries are used for continuity of power in case of intermittency.

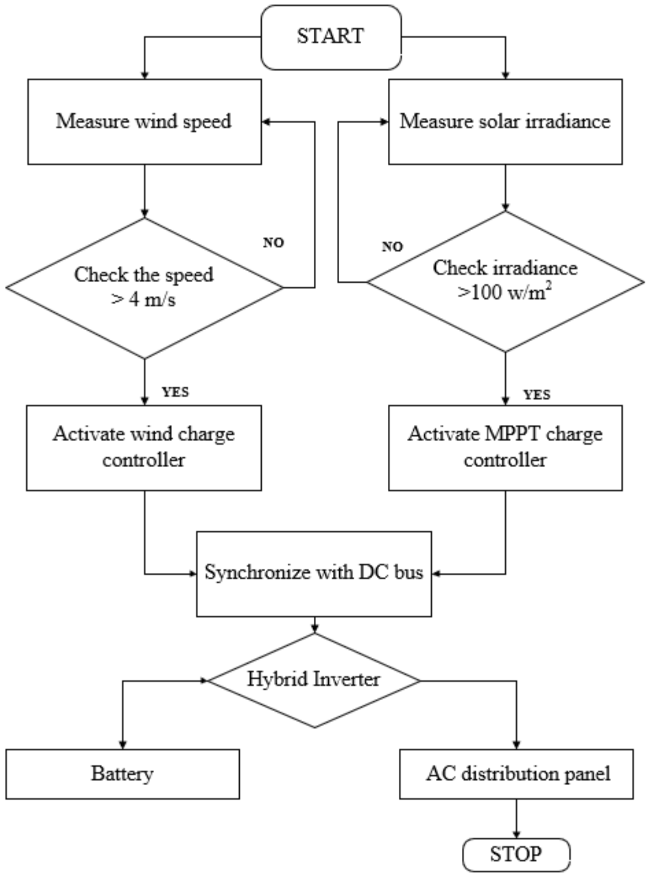

Fig -6: Flowchart of control of hybrid solar-wind system

Fig. 6 illustrates the block diagram of the flowchart of the hybrid wind solar power system in which the wind speed and the solar irradiance are measured. Wind turbine generator starts producing the power if the wind speed is greater than 4 m/s. Consequently, the wind charge controller is turned on, allowing the wind turbine to produce power at the appropriate voltage and other parameters. Similarly, the solar irradiance is measured. The maximum power point tracking (MPPT) charge controller is activated if the irradiance is greater than 100 w/m². The output power generated by both wind and solar system are synchronized at the DC bus with appropriate voltage magnitude. To maintain the DC bus voltage the charge controllers are separately employed in both wind and solar sides. In order to supply the AC power to the distribution system, the hybrid inverter is employed. The charging and discharging of the battery is performed based on the availability of the power generated by the hybrid system and demand. Battery is charged if the generation power is greater than the demand. Otherwise, the battery can also supply the power to the distribution system through the hybrid inverter if the demand is greater than the generation power.

Fig. 7. Shows a household wiring diagram, where the use of light bulbs other than conventional bulbs such as CFLs and LEDs were strictly limited in order to minimize energy consumption.

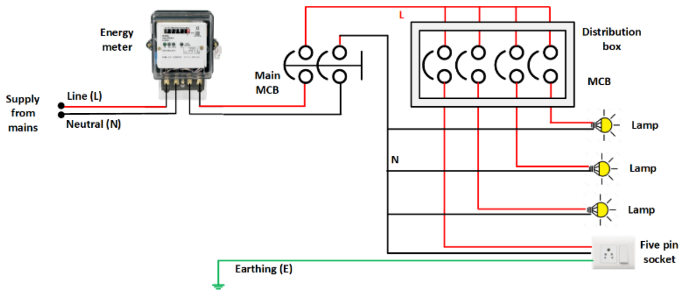

Fig -7: A simple household wiring diagram.

Fig. 8. Shows the demand curve for the village's household demand, with a peak demand of approximately 10.6 kW at around 9 pm. As a result, the factor of contribution is close to unity. Figure 9 depicts the demand curves for the company and power demand of the street light. The peak demand in this case is exactly 6 kW between 11 and 12 a.m. As results shows, the factor of contribution is almost non-existent. Fig. 10. Depicts the demand curve for Chisapani township, which shows that the maximum demand is at 21:00 hours of the day.

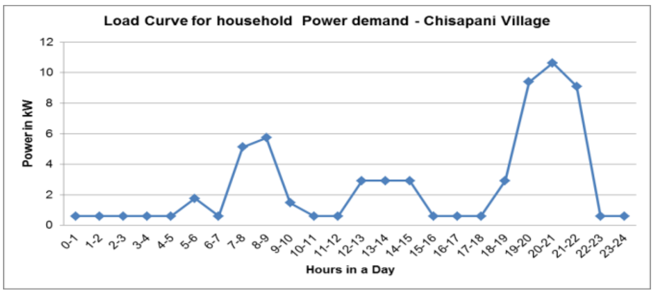

Fig -8: Demand curve for household

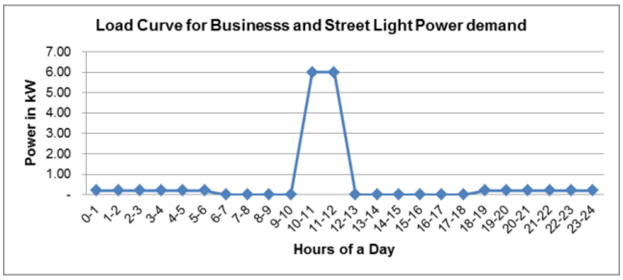

Fig -9: Demand Curve for Street Light and Business Power Demand

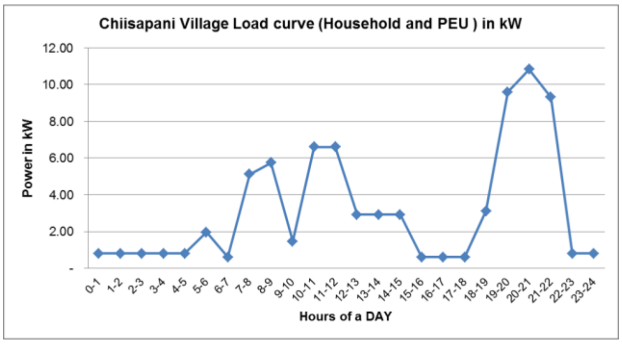

Fig -10: Demand curve of Chisapani Village

The least amount of electricity produced by solar is 14.07 MWh per year, and the least amount of energy produced by wind is 14.07 MWh per year for a 50% share. As a result, the annual average production of Solar-wind hybrid energy supply is 20.14 MWh.

6. SOCIO-ECONOMIC IMPACT

6 .1 Impact on society:

Increase in the activities have been observed by the introduction of electricity. This includes education, irrigation, technology usage, social activities, small scale industrial works and so on.

Prior to installation of hybrid system, people at HariharpurGadi relied on smaller solar panels. These includes solar charges torch lights and mobile chargers. They highly depended on availability of the Sun. So, during rainy seasons life came to a standstill. Besides, people had to go to 'ghatta' or water mill to have their grains grinded. These are located nearby rivers. They could be setup in few locations and are located out of the village. The villagers had to spend a considerable time of the day to have grains grinded. Due to difficulty to get water, the irrigation products were low. At night, children used to sleep early as they could not get proper lighting to study.

After installation of the hybrid system, people had ample light and electricity to fulfill their needs. Villagers no longer rely on monsoon rains for irrigation. Hence, the village has observed more than 50 percent growth in irrigation products. Electric mills have been installed, which has benefitted villagers have their grinded quickly.

The use of electricity for lighting and technology usage have been increased. Each house has a mobile phone and lights. Internet usage due to availability of 4G network in the area such as WiMAX has increased. Social networking has helped youth connect with their families living abroad. The students are able to study for longer period and access educational materials online. YouTube animated videos have enhanced their understanding capabilities.

Small scale industries have been installed in the village. Tailoring, knitting, handicraft industries were observed with high involvement of females of the village. Socializing and social security has advanced. Villagers are feeling safer relatively during evening time.

6.2 Impact on Environment:

Villagers completely relied upon firewood and kerosene for heating, cooking, and lighting purposes. Because they produce a large number of carbon-based pollutants, most people who are exposed to indoor air pollution suffer from serious health issues (like respiratory and vision issues). Besides collection of firewood by cutting trees requires high physical effort and time and results to deforestation. This deforestation can result to adverse effects such as landslide, scarcity of underground water, etc. After the introduction of electricity in the village, firewood and kerosene consumption has noticeably reduced. It is because, villagers no longer rely on them for lighting. A survey was done after six months of installation of hybrid plant to measure the reduction of firewood usage. The study did not measure considerable reduction, as people were highly using firewood for cooking and heating purposes. After organizing few awareness programs and providing incentives for electrical utensils, considerable change was observed. Villagers are aware of smokeless cooking stove and its usage has increased in the village.

6.3 Impact on Health:

In the electrified villages, each home has four light bulbs, light emitting diode (LED), that each consumes approximately 7.2 W. The luminous intensity from the used LED bulbs is 335 folds scintillating (470 lumens) than the traditional kerosene lamp “tuki” (1.4 lumens) and (-42) folds scintillating than tiny solar light (0.3 W) “tuki mara” (11.16 lumens) which is 8 folds scintillating than traditional kerosene lamp “tuki”22. The traditional "tuki" generated black shoot by burning the kerosene, which covered the walls and ceilings of the house and had an adverse effect on the respiratory system. After electrification, however, this is no longer the case. The villagers' hygiene quality has enriched because of the use of effective smokeless stoves, which has reduced the black smoke from the fire. The local health center has also benefited from the uninterrupted and reliable electricity, which has allowed them to keep primary vaccines and medications for longer time periods, potentially contributing to the elimination of diseases that are prevented with the help of vaccines.

Table -3: Salient feature of the project

Site address	Chisapani, HariharpurGadi-8, Sindhuli District
Coordinates	N 27° 21' 8.34" and E 85° 27' 44.28"
Elevation	355 meters
Households Targeted	83
Present PEU demand	6 kW
Max daily energy demand	87kWh/day (PEU has made a 15% demand)
Max daily energy demand	99kWh/day (considering losses)
Battery DoD considered	70 %
Autonomy days	2 days
Estimated peak load	22 kW
Peak sunshine hours	5 hrs.
Inverter efficiency	94 %
Average daily production	109 kWh (60 kWh Solar + 49 kWh Wind)
Average Wind Speed	3.21m/s (at 10m height), but spot measurement 6-8m/s

Horizontal Irradiation	5.18kWh/m²/day
Tilted (27°) Irradiation	5.75kWh/m²/day
Average Temperature (°C)	14.6

Table -4: Features of the Power transmission and distribution

Total transmission and distribution length	2,920 meters
Single Phase (2-wire system)	1,800 meters
Three Phase (4-wire system):	1,120 meters
Conductor Proposed:	ACSR (Aluminum Conductor Steel Reinforced)
Cable Name	Dog– 2800m (1400m Phase & 1400m Neutral=3080m with 10%) Rabbit– 5180m (3710m Phase & 1470m Neutral=5698m with10%)
Service Cable	6 square mm, total 1660 meter
Voltage Chosen	400 Volt (3-phase) and 230Volt (1-phase)
Voltage drop allowed	10%
Pole Type & number	26 numbers MS Tubular Pole (9m) & 43 numbers MS Pole (8m)
Insulator Type & number	Shackle type, medium size (Total 124 numbers) Shackle type, large size (Total 66 numbers)
Stay Set with accessories	Stay plate 300mm* 300mm* 6mm, thimble/stranded stay wire/turn buckle, and stay rod of diameter 16mm, length 1.8m, etc. all complete (total 17 numbers)
Earthing Type & number	Copper plate (600mm* 600mm* 3 mm), Total 6 numbers (Including 2 extra each for equipment body earthing & neural earthing at power house)
Lighting Arrestor	0.5kV, 1.5 kA, total 14 numbers
MCB for Households	1 Ampere SP230V, total 83 numbers
Energy Meter	1-phase, 2-wire, 230Volt, 5 Amp Static Type, total 83 numbers

7. CONCLUSIONS

This paper presents the detail analysis of the largest wind-solar PV hybrid power plant installed at HariharpurGadi, Nepal along with socio-economic impact on the lives of the villagers is presented. The power plant has helped to improve the living standard of rural people. The educational, social, environmental and health situation of the villages has ameliorated. Online education and entertainment have been added to lives of children besides lighting. Women safety, empowerment and self-employment has been observed. However, the local community must make required policies for maintenance, extension and upgrade of the power plant to facilitate the growing population of the village. With proper planning on alternative renewable power sources, the rural villages of Nepal with no grid connection can be electrified.

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