An Innovative Micro-Grid Hybrid Power System using Hydro, Wind, and Solar Photovoltaic Energy Sources in Remote Village

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Abstract:

Before implementing a full-phase power generating system based on renewable energy sources, several aspects must be addressed. Before making any judgments on the implementation of such systems, long-term essential data (for one year if feasible) should be collected. We evaluated solar irradiance, wind speed, and ambient temperature at two high altitude locations in Andhra Pradesh, India, the chippapalle and Sankupartiin Visakhapatnam District, to correctly determine the potential of available resources. We provide two realistic, cost-effective hybridization approaches for tiny micro-grid systems that are totally powered by renewable energy sources, including solar photovoltaic (PV), wind, and micro-hydro. One of the strategies was evaluated experimentally, and the results may be used to assist accomplish Millennium Development Goal 7: Environmental sustainability. In terms of worldwide installed capacity, hydro, wind, and solar photovoltaic energy are the leading renewable energy sources. However, no reports of micro-grid hybrid systems combining all three sources have been published, making this deployment the first of its sort anywhere. This study might be used as a practical guide for building comparable systems in different regions. One of the four micro-grid PV systems established for rural electrification in Andhra Pradesh villages by the authors was further hybridised with wind and hydro power sources. This study describes an innovative method for linking renewable energy sources to a utility mini-grid.

Keywords: Hybrid Energy, Solar Energy, Wind Energy, mini grid, and Distributed generation.

1. Introduction

Most of the 1. 3 billion people on the planet live in rural areas, where governments frequently struggle to supply even the most basic energy infrastructure. As a result, micro-grid power solutions are sometimes the only means to satisfy the energy demands of people living in rural areas. Many distant systems, such as repeater tower stations and radio communications stations, are completely reliant on micro-grid power systems. Because of the growing depletion of fossil fuels throughout the world, it is also vital to lessen reliance on these nonrenewable energy resources. One method is to use the vast potential of renewable energy sources to fulfil the ever-increasing need for energy. However, the intermittent nature of renewable energy sources is the primary impediment to their fast application. Energy storage devices and conventional generators are commonly utilised as backup systems to improve the dependability and power quality of renewable energy (RE) systems[1]. Distributed generation employing two or more renewable energy sources, on the other hand, can greatly improve dependability[2]PV-battery, PV-diesel, wind-battery, wind-diesel, PV-wind-battery, and PV-wind-diesel-battery systems are examples of commercially feasible hybrid renewal energy systems (HRES).

Long-term solar irradiance and wind speed data are necessary in the case of PV and wind power systems to enhance energy production projections. The difference in available energy between PV and wind systems needs the deployment of battery banks with sufficient capacity to meet the demand for electricity[3]. Several research[4] have focused on optimising renewable energy hybrid power systems with/without backup conventional generating systems. Kose, Faruk et al. ,[5]did a theoretical evaluation of hypothetical wind and hydroelectric facilities. Aghahosseiniet al. , [6] investigated a solar-hydro hybrid system capable of supplying continuous electric power. Bhandariaet al. [7]investigated the features of an off-grid hybrid RE system and their implications for system dependability. In the event of a power outage, Tay et al. [8] conducted a feasibility assessment of a wind-pumped hydro storage system supplemented by a diesel generator. The system is set up so that the wind farm provides the load first. Bekele and Tedesse[9] proposed a PV-hydro-wind hybrid system capable of giving continuous energy to an Ethiopian community. HOMER was utilised to optimise the potential of six small hydropower plants in conjunction with wind PV systems. Power management solutions for battery assisted PV-wind-hydro hybrid systems were studied by Mishra [10]. The energy balancing model, dc-link voltage control, and drop control were used to design a control approach that predicts the load. Goel et al. [11] conducted research on stand-alone solar and hybrid systems, where the solar-wind hybrid, solar-hydro hybrid, solar-wind-diesel hybrid, and solar-wind-diesel-hydro/biogas hybrid were discussed, and the viability and significance of solar energy (both standalone and hybrid) in global electrification were demonstrated. Sharma et al. [12] presented a solar-hydro hybrid system that is grid-connected. They proposed a grid-connected solar system to produce power during the summer when solar energy is abundant and the hydro system is shut down. Similarly, during the rainy season, when water is plentiful, the grid-connected hydro system is activated and the solar system is turned off. Debnathet al. [13] conducted a feasibility assessment as well as a techno-economic analysis of a PV system with batteries and a micro turbine functioning as a backup supply. Iterative component sizing and optimization were used to reduce the cost of energy (COE) production. Allani et al. [14] built and studied a PV-wind-diesel hybrid system for a Palestinian family residence, taking efficiency and dependability into account as well as the dumped electric power. Song et al. [15]suggested a hypothetical hybrid system with wind-solar-biogas-micro hydro hybrid as primary energy sources and a diesel generator as an emergency backup source. Almost all of the articles serve diverse goals such as off-grid application design, analysis, modelling, optimization, socioeconomic studies, and so on. The one thing that all of the foregoing papers have in common is that no publication has ever documented the effective installation of a tri-hybrid system constituted of PV-Wind-Hydro systems with storage devices. The authors and village volunteers erected four PV micro-grid installations in diverse locations of Andhra Pradesh. A HRES integrating three RE power systems - hydro (20 kW), PV (5 kW), and wind (3 kW) - was implemented in the isolated villages of chippapalleand Sankupartiin VisakhapatnamDistrict, Andhra Pradesh, for this study. The two communities are depicted in Fig. 1.

2. System specifications

2. 1. PV-Wind Hybrid system

The PV-wind hybrid system was erected at chippapalle, a community with an elevation of 800meters above sea level located at $18^{0}17'42''$ N and $83^{0}04'38''$ E. (asl).

In combination with the 5 kW PV system, a FZY-3KW type wind turbine with a 3-kW rated output was installed. The Rain Wise Wind Log, which was installed at the power plant site in chippapalle, was used to measure wind speed. For three days (September 25–27, 2021), the average wind speed and gust wind speed are displayed in Fig. 2. The PV system consists of 42 KMO120 PV modules in total. The details of the FZY-3kW wind turbine and KMO120 solar panel are listed in Tables 1 and 2, respectively. The quantity of solar irradiation that is accessible at a specific place at a given time is crucial information for PV system design. A day's worth of sun radiation varies. A typical sun irradiation for an entire day is depicted in Fig. 3. (February 25th, 2021). To hybridise the two systems, an inverter and hybrid charge controller were employed. The battery bank for the power system has a 4800 Ah capacity. The hybrid PV-wind system installed in chippapalle is seen in Fig. 4.

2. 2. Micro-hydro power plant

A micro-hydro system should typically be constructed in an area with year-round access to plenty of stream water (river run-off). Consequently, a thorough investigation of the probable location was done. The existing hydroelectric system generates 20 kW of total electrical power at a flow rate of 27 litres per second (lps) and a net head of 130 m. The micro-hydro power (MHP) plant was built at the Sankuparti hamlet in the Visakhapatnam District, 2. 5kilometres from chippapalle(18^{0}17’29” N and 83^{0}03’40” E, 488metresasl). A three-dimensional CAD model of the MHP can be seen in Fig. 5, while a captioned image of the MHP facility can be seen in Fig. 6, and the MHP's specs can be found in Table 3. The authors carried out a thorough analysis, design, manufacture, and installation of the full hydro system.

2. 3 Grid tie inverter

A mini-grid system's grid voltage changes a lot due to the high load ratio during peak and off-peak hours. As a result, hybridising more than two systems cannot be done with fixed frequency inverters. A power inverter that converts direct current (DC) to alternating current (AC) and feeds it into an existing electrical grid is known as a grid tie inverter (GTI), sometimes known as a "synchronous inverter" or "grid-interactive inverter" (normally 50 or 60 Hz). GTIs generally cannot be employed in stand-alone applications without access to grid power. The GTI sends extra electricity into the grid when the generating sources are producing more than they need to. Power can be returned to the load when power generation is insufficient. In this investigation, a GTI was employed to direct surplus energy into the mini-grid linking the two communities. In order to keep the voltage from going beyond the grid voltage, a GTI employs an internal oscillator. The voltage, current, and phase angle of GTIs are all exactly matched with the AC power grid, and the GTIs have a set power factor of unity. Another benefit of employing GTIs to synchronise numerous distributed generators (DG) is that, in the event of a grid failure, GTIs are built to immediately cut themselves off from the grid. The details of the GTI utilised in the current system are listed in Table 4.

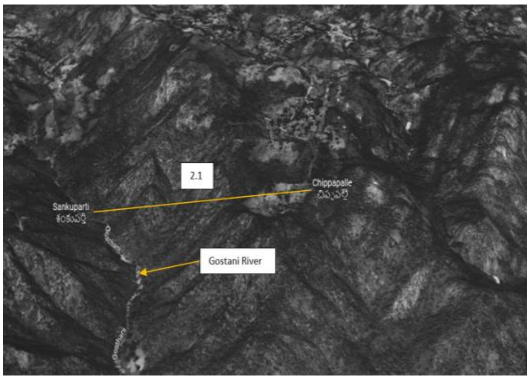

Fig 1. Aerial image of the location of the towns of chippapalleand Sankuparti hybrid PV-wind and hydro system.

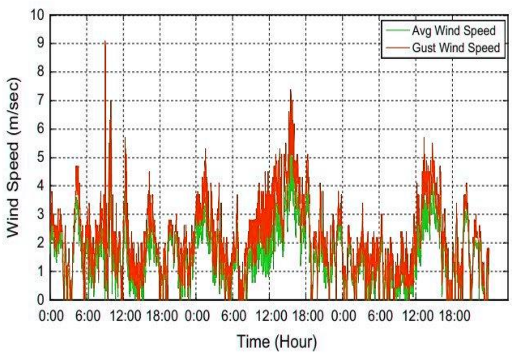

Fig 2. Data on wind speed in chippapalle, at a height of 3. 5 metres (1 min interval).

Fig 4. Solar radiation levels at chippapalleon an average day (5 min interval).

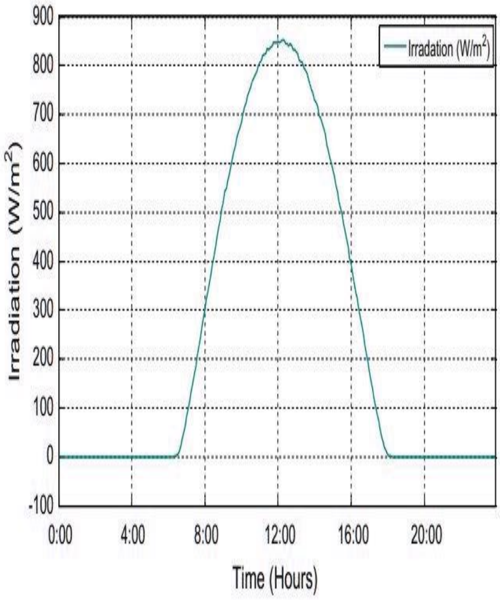

Fig 3. Solar radiation levels at chippapalleon an average day (5 min interval)

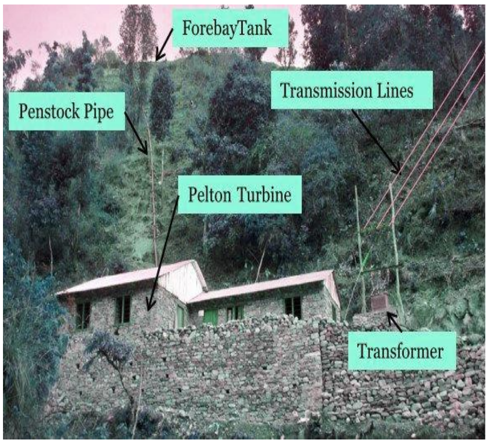

Fig6. Hydro power plant detailed labeled view in chippapalle

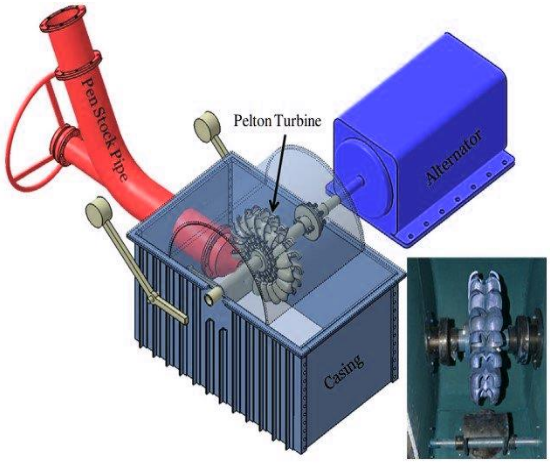

Fig 5. Based on real, produced turbine parts, a 3D CAD model of the Pelton turbine micro-hydro power system is presented.

Table . 1 Specifications of the FZY-3 kW.

Power	3kW
Type	Permanent magnet generator
Rotor diameter	4. 5 m
Rated speed	260/min
Start wind speed	3 m/s
Rated wind speed	10 m/s
Working wind speed	3-25 m/s
Speed regulations	Yaw & magnetic resistance

Table 2Specifications of the KMO 120

Open circuit voltage	21. 24 V
Short circuit current	7. 11 A
Maximum voltage	17. 64 V

Maximum current	6. 80 A
Maximum power at STC	120 Wp
Maximum system voltage	600 V
Working temperature/humidity	-40 ^{0}C to +85 ^{0}C/85%

Table 3 Specifications of the MHP installed inSankuparti

Turbine type	Pelton
Flow rate	27 l/s
Gross head	135 m
Penstock diameter	150 mm
Pelton pitch circle diameter	295 mm
Generator	Synchronous
Generator capacity	50kVA

3. Methodology

The present system uses two different types of distributed generators: synchronous generators for hydro systems and inverter-based systems for hybrid PV-wind systems. Both generator types have unique traits that should be taken into account while connecting to the mini-grid. As opposed to inverters, which are solid-state electronic devices that convert DC power to AC, synchronous generators base their output frequency on the turbine's rate of rotation. Hydro power predominates in the current system, thus the hybrid PV-wind system should synchronise its output in accordance with hydro power production.

3. 1 PV-wind system and micro-hydro system hybridization

Hybrid system research spans several academic disciplines. In comparison to synchronising tiny hybrid systems with a mini-grid, synchronising hybrid systems with a national utility grid is very different. The fundamental distinction is that a mini-voltage grid's and current are of poorer dependability and quality. A MG is subject to quick variations in frequency and voltage, whereas a national utility grid maintains a set frequency (50 Hz or 60 Hz) and voltage. We suggested two hybridization methods that make use of GTI and battery charger.

The previous method of hybridization is seen in Fig. 7, where a hybrid charge controller (HCC) is used to combine the output of the PV and wind generators, and the electricity from the HCC is delivered into the battery bank to charge the batteries. Additionally, a battery charger with the right capacity is used to charge the batteries using the MHP's power. The DC electricity in the battery bank is subsequently transformed into AC power by an inverter and sent into the grid. This arrangement is straightforward and inexpensive to set up, but if the producing systems are far apart, it can be less affordable because two separate networks are needed to send electricity to the customer and charge the batteries. The latter hybridising method employing GTI is shown in Fig. 8. Similar to the earlier method, an HCC is used to hybridise PV and wind generators in order to charge the battery bank. The second methodology was utilised to hybridise the three RE systems, but instead of utilising a battery charger, this method directly synchronises the hybrid PV-wind system with the mini-grid to provide a dependable power supply for the towns. Using a step-up transformer, medium voltage (MV) transmission lines (11,000 V) were built to connect the two communities. To reduce the power to 380 V (phase-to-phase voltage) and deliver it to the homes, two step-down transformers were erected in various places.

Table 4 Specifications GTI and its ratings

Operational mode	Output control mode Input control mode	Grid-connected type (not insulated) MPPT
Input	Max. open-circuit voltage MPP voltage range Max. input power Max. input	500 VDC 130-430 VDC 3. 3 kW 17 A

	current	
Output specification	Phase	Single phase
	Capacity rating	3 kW
	Voltage rating	AC 200-260 V
	Frequency rating	50 Hz/60 Hz
	Distortion factor	Under 2. 9%
	Power factor	Over 0. 99
System specification	Peak efficiency	96. 3%
	Euro efficiency	95. 2%
	Overload capacity	110%
	Cooling method	Natural air cooling
Environmental parameters	Operating temperature	-10-55 0C
	Humidity/IP	Under95, No dew Condensation/ IP 65

Table 5 Residential electricity consumption

Appliances and small electronic devices	42 %
Heating and cooling	28 %
Lighting	14 %
Water heating	9 %
TV's	7 %

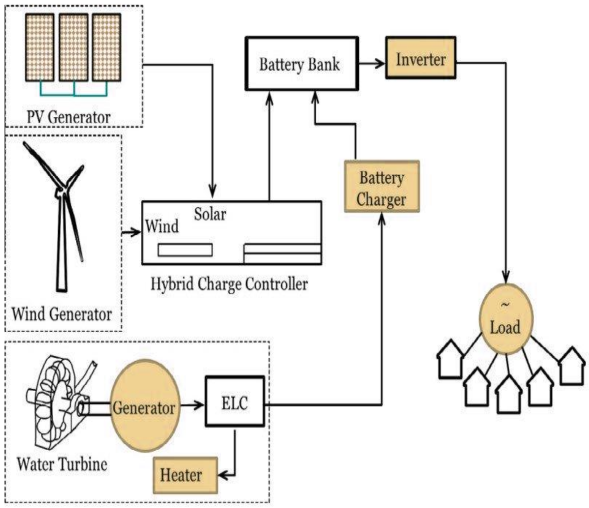

Fig 7. PV, wind, and hydroelectric generators that are hybridised using a hybrid charge controller and battery charger.

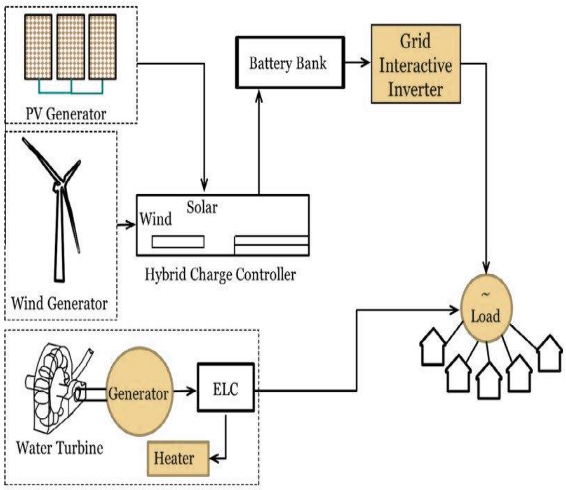

Fig 8. using a grid tie inverter to synchronise the hybrid PV-wind and micro-hydro power systems.

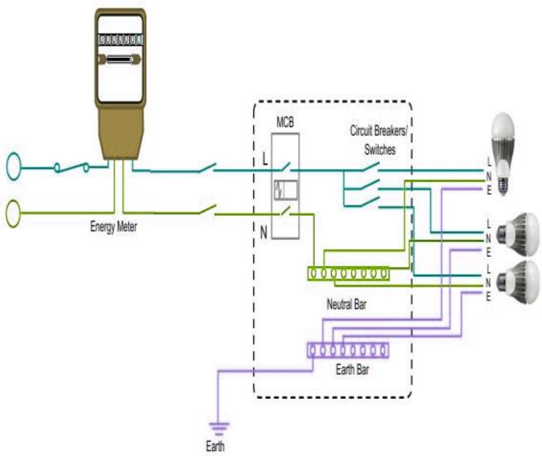

Fig 9. Schematic wiring layout of a simple household

4. Results and Discussions

The average annual energy use of a U. S. home utility customer in 2010 was 11,280 kWh, or on average 940 kWh per month, according to the U. S. Energy Information Administration [31]. Due to the widespread use of air cooling and heating, developed countries often have the greatest power demand. The 2010 figures for home power usage in the US are summarised in Table 5. Average power usage in underdeveloped nations is significantly lower than in industrialised nations. The communities had a combined total of 173 homes and a population of around 1200 at the time of this investigation. Three small-scale businesses existed there: a grinding mill, a mushroom farm, and a poultry farm. Each home had three LED light bulbs, each of which used 8 W of power. A wiring diagram for a house is shown in Fig. 9. The usage of light bulbs other than CFLs and LEDs was rigorously controlled to save energy consumption. A pilot study was carried out in chippapalleto estimate the monthly power usage in the villages of chippapalleand Sankuparti.

Over the course of a month, readings were obtained daily at 6 AM, 9 AM, 12 PM, 3 PM, and 6 PM by trained volunteers who kept detailed records for six families. Prior to the pilot research, precise guidelines on power use were established: households were only allowed to use 2. 2 kWh of electricity each month, and electricity was only to be used for lights and phone charging. During the one-month trial period, electricity use for other reasons was rigorously controlled, and the resulting village load profile was documented. . The typical daily power use of a chippapallehousehold throughout the pilot study period is shown in Fig. 10, which demonstrates that families made an effort to abide by the limited-use regulations. The majority of villagers, however, have a tendency to mechanise household tasks and farming in order to save time and labour and boost productivity, thus if these regulations are disregarded, it is apparent that electricity demand would rise. The demand resulting from increasing household power use from basic illumination (maximum 2. 2 kWh/month) to moderate domestic usage is summarised in Table 6.

Table 6 An agriculturally based distant village's average daily power requirement.

Particulars	Power	Hours	Energy/day
Straw/grass chopper	2 kW	1 h	2 kWh
Water pump	750 Watts	1 h	0. 750 kWh
Fan	100 Watts	4 h	0. 4 kWh
Television	100 Watts	4 h	0. 4 kWh
Computer	250 Watts	2 h	1 kWh
Mobile charger	10 Watts	2 h	0. 02 kWh
Radio	50 Watts	2 h	0. 1 kWh
Total			4. 67 kWh

An estimated load profile was created using data on electrical appliance power usage, frequency, and general time of day. Figure 11 displays the load profiles, charging and discharging of a storage device, as well as the power generation of the PV, wind, and hydro systems during a typical day. This graph makes it clear that the combined demand of the two villages cannot be met by either the hybrid PV-wind system in chippapalleor the MHP in Sankuparti. The dependability of the power supply is increased and the demand is met by combining the two power plants into a single mini-grid. This procedure also guarantees that there will be enough extra power to recharge the storage device during non-peak times.

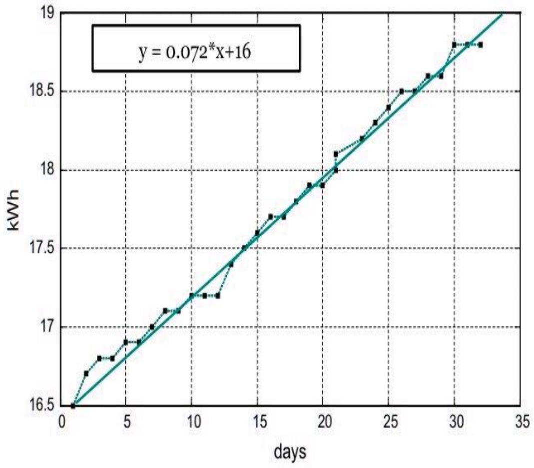

Fig 10. Usage of residential energy on a monthly basis (lighting only)

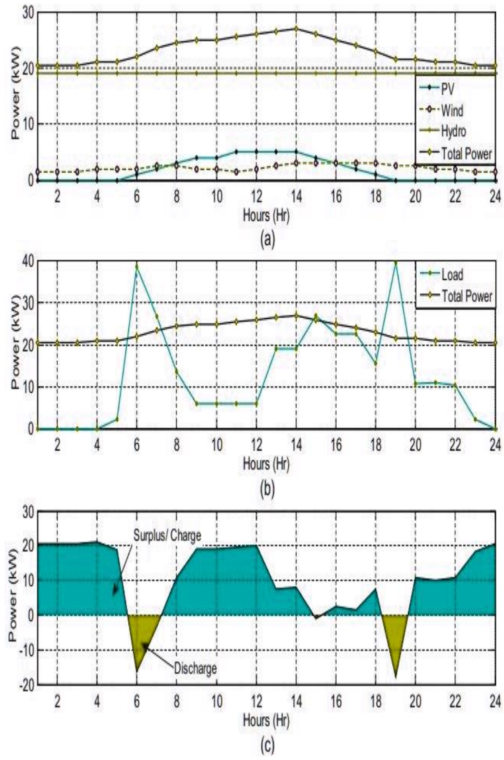

Fig 11. Diagram that is simplified to represent the a) power generation from different sources, b) power generation the load profiles, c) charging and discharging profiles.

The extent of the current investigation is depicted in Fig. 12. In all, power was delivered to 120 homes in Sankuparti and 53 homes in chippapalle. Sankuparti houses are further apart than those in chippapalle. Along with a scale bar, Fig. 12 also depicts the positions of the transformers and the medium- and low-voltage transmission lines. It will be several years before the two settlements can connect to the national grid.

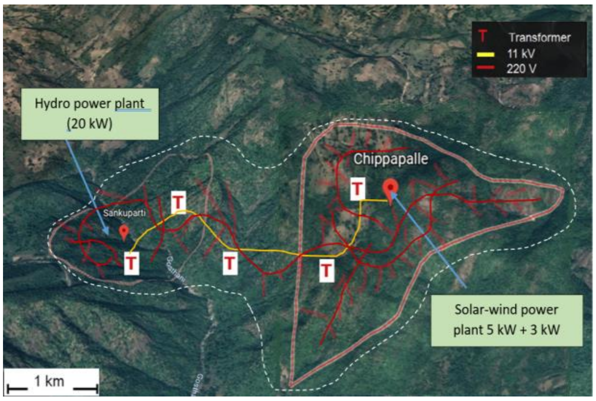

Fig 12. Detailed distribution network may be seen in this comprehensive aerial image of the villages.

5. Conclusion

This study is the first of its type because the authors were unable to locate any published studies illustrating the use of a tri-hybrid renewable energy system, which consists of PV, wind, and hydro systems and is meant to generate electricity for micro-grid applications. Wherever there is strong potential for all three of these RE sources, such as in mountainous nations like India, this study lays the path for the creation of comparable rural energy networks. In places where the national utility grid is costly, an HRES is a comparatively cost-effective alternative, making it appropriate for power applications in distant locations. The dependability and quality of the power are improved when scattered producing units are integrated into a mini-grid.

In order to combine PV, wind, and hydroelectricity into a single small grid, the article presented two hybridising strategies. One method was used to link a hybrid PV-wind system to a hydro-dominant system via a mini-grid that connected the villages of chippapalle and Sankupartiin Andhra Pradesh'sVisakhapatnamDistrict. The findings showed that these systems may be made hybrid by using a hybrid charge controller, a GTI, and an appropriate electronic load controller (ELC). Other micro-grid systems might benefit from the use of such a strategy. Utilizing and blending the energy sources already at our disposal will advance environmental sustainability by lowering our reliance on fossil fuels and wood, as well as by encouraging active, healthy lives. Therefore, our results will contribute to achieving Millennium Development Goals 8: Create a Global Partnership for Development and Millennium Development Goal 7: Ensuring Environmental Sustainability.

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