

Rural Electrification: Practical Exposition of Hybrid Solar PV-Wind for Grid Integrated Power Systems in India



Ravindrakumar Yadav, R. P. Singh

Abstract: *Reliable electric power supply is still remained a major problem in rural India. Off grid renewable sources of energy have been applied in the last few years to increase reliability but not succeeding to be realistic because of too high energy costs compared to the national grid. Grid Integrated Mini-grids with Storage (Grid Integrated Mini Grids) have potential to provide reliable power supply at reasonably priced by combining Mini-Grids and National Grid services. This research paper analyzed different aspects of the GRID INTEGRATED MINI GRIDS practicability. The feasibility of the use of hybrid - solar Photovoltaic (PV) systems and wind in Grid Integrated Mini-grids*

Keywords: *grid integrated mini-grid, photovoltaic (PV), rural electrification, renewable energy, grids with storage.*

I. INTRODUCTION

Today, the population who do not have access to electricity in world, one fifth of such population fail to access to reliable power reside in India, primarily in rural areas [1]. Even among these people, 80% of the population that have access to electricity but facing difficulties as long power cuts and poor electricity quality. Very common and uncommon reasons for these power cuts are shortages in the coal supply to utilities, large transmission and distribution losses, and poor financial management of distribution companies [2]. Moreover, India has an ecological calamity issues due to its rapid growth of population and subsequent energy demand growth. International Renewable Energy Agency (IRENA) shows, the execution of renewable energy sources in the next one or one and half decades, will be the turkey solution to secure energy provisions in India [3]. In order to address this sustainability crisis, the Indian government has set the objective to attain 175 GW of installed renewable energy by 2022, which seems to share approximately 20% of the expected electricity consumption of the country by that time. Diverse renewable energy sources based power system such as stand-alone solar systems and Mini Grids have been implemented in remote rural and urban areas to achieve an uninterrupted and good quality of electric power supply. However, in a setting structure of constant grid spreading out in the area, Grid Integrated Mini-Grids with Storage (GIMS) carrying the potential to provide consistent electricity access to rural communities. As well helping as power back-up to the main grid too, Grid Integrated Mini-Grids with Storage provide a sustainable power source from which excess electricity is available to run market -back through the national grid, may be great generating a source of revenue to get their O & M viable.

In such way utilities seems to be benefited from supplementary generation sources for remote power supply with reliable electricity at a price lower than the off-grid systems.

On the other hand, Grid Integrated Mini-Grids with Storage set up requires an investment, either new system to be installed or an existing mini-grid to be upgraded to connect with grid. This may lead to capital investment but in vice a versa O&M costs can be reduced considerably. In meticulous energy storage, consisting number of set of batteries holds big stack of Mini Grids principal expenditure

, and it is the most expensive component of the system. If by any means and calculation makes possibility to cut in the storage may result into significant cost savings. In India diversified renewable sources such as solar photovoltaic and wind power, storage system must be designed to meet with load reliably. The collective use of wind and solar power can endow with a stable power supply which plummeting into storage systems with more regular energy production reducing the time period of storage needed. Nevertheless, power resources with storage required depending on the resource availability locally in connection with requiring specific size based on these conditions.

II. GRID INTEGRATED MINI-GRIDS WITH STORAGE (GIMS)

Grid Integrated Mini Grids with Storage(GIMS) is Renewable Energy mini-grid systems, are connected to a national power grid in a way to provide viable and consistent electricity to a rural or remote area.

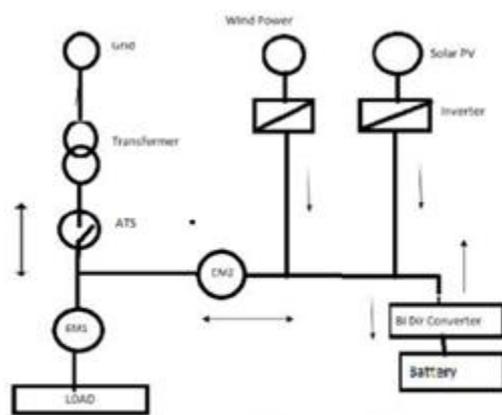


Figure1: Schematic

Conceptual layout of a Grid Integrated Mini Grids system
The connection of Grid Integrated Mini Grids with Storage to the grid may take place during their setting up or by upgrading an existing mini-grid post execution.

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Grid Integrated Mini Grids generally consist of a RE power generation system along with the inverters and additional power electronics controllers, a power storage bank consisting of a set of batteries, an AC/DC converter, an automatic mains transfer switch *i.e.* ATS, a transformer and all additional protective gear to secure connection. More over smart metering system must be incorporated in the system to measure the power delivered to the load and to the grid

The meters EM1 and EM2 shown in the figure are kept to measure the grid supply from the system to the load and the grid respectively. The interconnection of mini-grids to the distribution grid can gain techno operative and financial payback not only to the community but also to companies occupied in India. Though, the inter connection of mini-grids with the national grid is a newly implemented technology in the country [4]. The short of skill in this leads DISCOMs reluctant regarding grid integrated mini grids in view of safety point of view with grid. All safety concerns are generally linked to such grid integrated mini grids which export surplus power to the grid. Different power quality standards need to be inline by any system inserting power into the Indian grid [5].

The integrity of diverse gears such as switching apparatus and transformer, may lead to power quality issues such as voltage and frequency variations as sags and harmonic distortion [6]. Harmonic distortion problems are chiefly relevant for the connection of mini-grids into the national grid. Non-linear loads connected in power systems are responsible of THD in the power line and consequently twist of its waveform. THD promulgates through special components in a power system and can lead to unwanted phenomena such as over heating of cable, Equipment, efficiency drops in the system and increased resonance probability [7].

III. BENEFITS OF GRID INTEGRATED MINI GRIDS

Grid Integrated Mini Grids aims to improve the consistency of good quality power supply to a rural area and also provide a power back-up to the grid. Additionally, Grid Integrated Mini Grids can also feed excess power into the grid, which generates revenues. Thus Grid Integrated Mini Grids provide a source of income to fulfill running cost and monetary expenses due to wear and tear caused by operation. Besides, combination of power supply from the National grid and a mini-grid (Local) system reduce the outlay of reliable power compared to off-grid mini grids so client or end user need to pay for power from the mini-grid system only at time when power cut in the main grid, can say that enjoy both power reliability and the economic freedom of the national grid when available. Even beyond their advantages for end-users, grid integrated mini grids also aim to do good to DISCOMs and RESCOs. First, the encumber of grid annex of DISCOMs can be reduced by making use of on hand available infrastructure. The existing mini-grids can add. Moreover, main and most wondering fact that Grid Integrated Mini Grids can throw in to reduce power losses from theft, non recorded power consumption say unmetered to the grid by means of the EM1 and EM2, additional metering systems. By means of different grid interconnection methods, RESCOs' mini-grids can dole out DISCOMs in diverse generation as well distribution functions in rural remote area.

IV. CHALLENGES ASSOCIATED TO GRID INTEGRATED MINI GRIDS

In the past decades, the execution of mini-grids by diverse RESCOs in India, involves a grid integrated mini grids are bare to assorted challenges in terms of technological performance, maneuver, regulation, and viability. So these are divided as technical, operation and control (regulation), and financial challenges.

4.1 Technical challenges:

Modern gears have been used in the past decades for the implementation of mini-grids by various RESCOs in To avoid these, any power generation unit connected to the national grid must meet the requirements set in IEEE-519-2014 (IEEE directed Practice and Requirements for Harmonic Control in Electric Power Systems) [8]. This regulatory document specifies the limits of THD in voltage and current flows in system to be connected to the grid. The documented regulation standards and values are not referred to mini-grids but for any power system which aims to be connected to the national distribution grid.

4.2 Operation and regulation challenges

Grid integrated mini-grids are a newly researched and implemented technology in India. Due to the condensed experience in such, best practices have not yet been widely developed and approved [9]. Typical regulation for grid connection of mini-grids with storage exists at an international level. The existing regulation in India for the operation of mini-grids and grid connection of power systems presents laps and divisive information about the requirements and operational modus operandi. Due to lack of regulatory outline and homogeneity for grid interconnection of mini-grids leads to confusion and delay on the approval. Broad admin effort and human resources are necessary to reach agreements on the implementation procedure for such projects, resulting in long implementation periods.

In all the research, implementation and evaluation of decentralized renewable energy solutions in form of Grid Integrated Mini Grids are necessary for grid integrated mini grids development. The common transfer of officials this obstruct the implementation of long-term projects in a time bound manner. In India it is also seen that the lack of transparency in grid extension projects hinders the group effort between RESCOs and DISCOMs.

4.3 Financial challenges

Grid Integrated Mini Grids faces mini-grid related challenges such as electricity billing collection, replacement, breakdown and maintenance costs to be included to Grid Integrated Mini Grids. The interconnection requires the expensive components such as transformers and bi-directional grid converters, along with meters, which are not required for off-grid solutions. These projects are highly capital-intensive due to their long growth periods, which entail a higher cost throughout the whole project period compared to off-grid mini-grids.

V. HYBRID SOLAR AND WIND POWER SYSTEMS

Hybrid solar photovoltaic (PV) and wind power systems unite the use of photovoltaic panels and wind turbines in order to make the most of the total energy output and efficiency of the system. Wind power systems use the kinetic energy from a moving air wind by converting it into another form of useful energy by wind turbines. The rotation generated by the rotor blades is transferred to a generator attached to the turbine. This generator transforms the mechanical energy of the rotor in electricity. A gearbox is attached to the electric generator for speed control.

Wind and solar energy sources termed as variable renewable energies (VRE) due to their high variability with location and time. VRE can not be elated to a different place such as remnant or nuclear fuels. So in form of electrical energy through the grid. Second, too variability of solar irradiation and wind speed with time leads to variable power output from VRE systems.

VI. ECONOMIC ANALYSIS

In turn it comes to find most appropriate configurations which may be applicable in view of ability to meet the required demand. An economic analysis determines main product is the Life Cycle Cost or Net Present Value - NPV of each configuration. The Net Present Value of a system is the difference of current value of all the costs involved in the system throughout its complete lifetime and present value of all the revenues generated by the system during same period. The system costs comprise the capital investment costs, parts replacement costs, operation and maintenance - O&M costs, Grid power purchases, fuel costs (if any) and penalties for environmental issues if any. The system revenues account for the revenues generated from sell of power to grid and the retrieve value of the system [10].

[11]. The annualized cost of the system is calculated according to following equation (6.1):

$$C_{at} = NPV_{(r,t)}$$

Where C(at) is total cost per annum , NPV is "Net present Value" at interest rate "r" for life span of "t" period , equation (6.2)

$$C_{at} = NPV_{(r,t)} \times CRF_{(r,t)}$$

annually to energy supplied to load including all sources as well from Grid too per annum.

VII. TECHNICAL ASSESSMENT

To get assessment the technical feasibility of the system and the capability of each available sources' configuration to meet up the given system load [12]. This may be computed by calculating the energy balance for each time-slot all through a year with recording of the system electric load, in association with storage of energy which might be in use at time of non power producing / black out hours.[13].

7.1 Photo Voltaic array power output calculation Power output of the PV panels for the current time step in kW can be calculated by

$$P_{Output(t)} = C_{PV} (STC) \times F_{(t)} = \left(\frac{G_T}{G_{STC}} \right) \times (1 + \alpha_T (T_T - T_{TSTC}))$$

Where P out,(pv) is the rated capacity at STC - Standard Condition
 FPV is the de-rating factor of the solar subsystem in %
 GT is the solar radiation on the PV panels in the current time in kW/m²
 G STC is the solar radiation on the PV array in kW/m²
 α t is the temperature coefficient of power in % /°C
 Tt is the temperature of the PV array in the current time in °C
 Tstc is the temperature of the in °C.

7.2 Wind power output calculation

Wind speed for the real time at the hub height of the wind turbine is calculated by

$$V_{Hub\ height} = V_{Wind\ speed\ z_{reference\ height}} \times \frac{\ln(z_{hub\ height}/z_0)}{\ln(z_{reference\ height}/z_0)}$$

Where Z0 is the surface roughness length in m.

As the wind velocity at the wind turbine hub height is known , calculations lead towards the wind power output at standard air density using the power curve of the turbine, and it is given By Equation

where CRF is the capital recovery factor, which can be calculated according to Equation (6.3):

$$CRF = \frac{r(r+1)^t}{(r+1)^t - 1}$$

Where "t" is the number of years in which the invested capital must be recovered (in this case the project lifetime). By this way computation of energy supplied to system and mean cost of the system /kWh of energy supplied to system. At par cost of system is the ratio of Cost for total energy supplied

7.3 Battery charge and discharge power calculation

Now for storage aimed concept, its time to calculate the extent amount of power that can be used to charge battery storage system in each time cycle with consideration of kinetic storage model, highest charge rating and the highest charging current.

More over discharge losses happens when discharging power from the storage by Equation Pdischarge,max is the maximum discharge power of the battery set in kW

Pdischarge,max ,ksm is the maximum discharge

$$P_{Discharge,max} = P_{Discharge,max,ksm} \times \eta_D$$

Where P power calculated from the kinetic model in kW, ηD is the discharge efficiency in %



Figure 2: Real location of Simlet village showing on Google Map

Gram Panchayat name of the Simlet village is uninhabited. District Block is named Lunawada which is 18 Km from the village. District Head Quarter name is GODHRA and it's distance from the village is 35KM.[14]

VIII.METHODS

This research paper is based on feasibility study of grid integrated mini grids systems for Simlet villages in Gujarat, India, with different electricity demand levels, electricity tariff rates and meteorological conditions. Here residential electricity demands with some commercial load is considered for the for feasibility study of grid integrated mini grids, since village households are not connected or served by any stand-alone systems. The differences in resource availability and especially type of load is prime consideration to give an overview of the different types of rural electrification for which grid integrated mini grids may be a feasible solution.

The location in the state of Gujarat belonging India is shown in Figure 2. Here aspects of grid integrated mini grids feasibility are investigated. First, the feasibility of the use of hybrid, Solar PV and wind systems with storage is

Analyzed. To this aim, a techno-economic analysis was carried out for different solar PV, wind power and storage share to optimize the grid integrated mini grids design of each village in terms of technical performance and economic feasibility. The results of this optimization for hybrid and exclusively solar grid integrated mini grids were compared to

Simlet is a village situated in near Lunawada town in District Panchmahal in State of Gujarat in India. This village has population of approximately 750 as per census data of, in which population belong to 180 houses. The geographical area of Simlet village is 546.4 Hectares. The objectives to focus research on Simlet village among 18000 villages is that Simlet is an island surrounded by water of Kadana Dam and Hydro power plant reservoir and catchment area needed for and not connected with road or land in any way. Population density of Simlet is 1.5 (approx.) persons per Hectares. Total number of house hold in village is 180

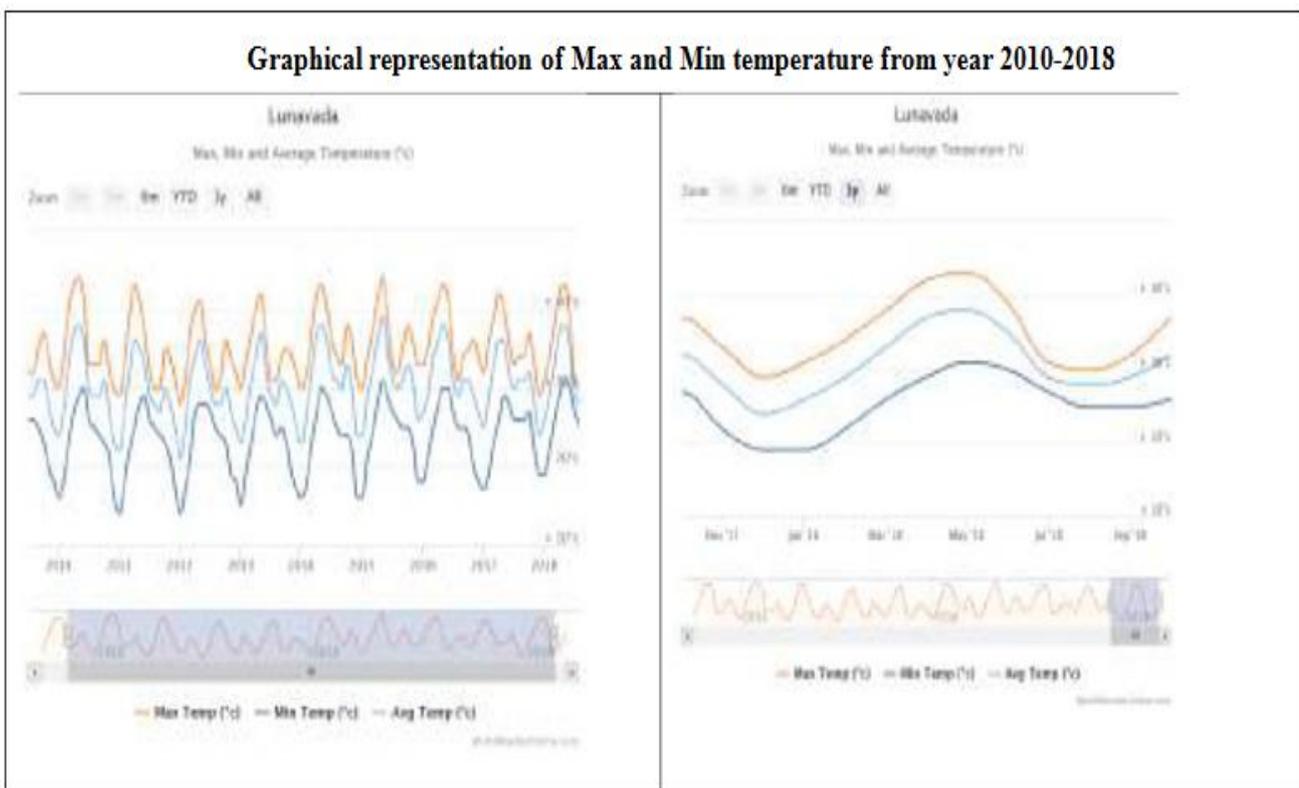
8.1 Historical weather on 28th November over the years

Data	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Weather										

Temp Max	34°c	32°c	32°c	32°c	34°c	37°c	33°c	37°c	34°c	32°c
Temp Min	20°c	21°c	22°c	19°c	21°c	20°c	18°c	20°c	21°c	21°c
Wind	5 Km/H	8 Km/H	12 Km/H	6 Km/H	13 Km/H	4 Km/H	11 Km/H	7 Km/H	5 Km/H	9 Km/H
Cloud (%)	5	13	13	0	9	0	9	0	0	44
Humidity	40%	67%	45%	34%	25%	30%	21%	26%	22%	30%

Historical Data of Simlet village found on 28th November 2018

Data of Simlet village regarding Solar radiation, rain , Temperature, wind for average one year. Here I assumed geographical and atmospheric weather equality of Simlet with Lunavada as their geographical location is too nearer. [15]



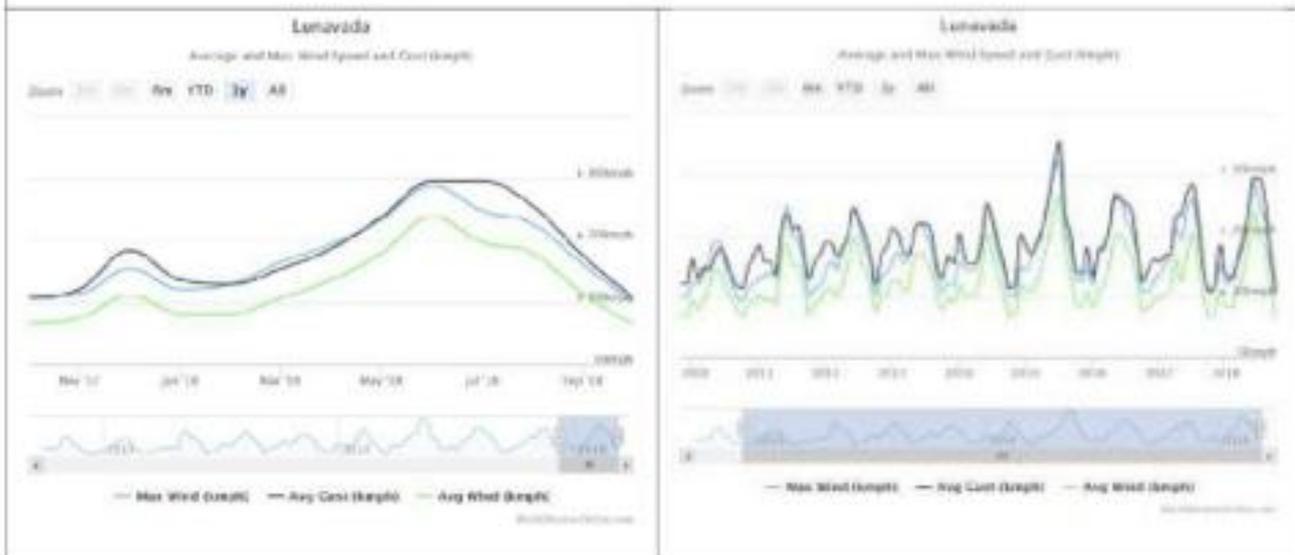
Graphical representation of Average Sun hours and days from year 2010-2018



Graphical representation of Average rain fall and rainy days from year 2010-2018



Graphical representation of Average wind speed and max speed from year 2010-2018



8.2 Load profile

Here the load profile of Simlet village is jointly considered for domestic and commercial including agriculture load. So the total power consumption from the village transformers would valid to assess the required load because both energy demands exist. The load profile of the commercial establishments in the village is estimated on the local need of typical rural Indian village. Normally Indian village of such locality and population may have one primary level school, part time operated clinic or dispensary, flour mill, milk dairy, one or two small grocery shop, a Panchayat building and few tailoring and cobbler or miscellaneous trade spot. The different appliances used in with their corresponding rated power or wattage will be approximately 20000 watts including lamp, tube light, fan etc . This load profile may be further categorized to the time of the day and the incidence with which they are used by season requirement.

The different usage patterns followed by lamp load for 2 -3 hours in morning and 4-5 hours in evening in domestic same way fan load to be considered only for hot days and According to the load patterns some “Intermittent Loads” which are not used regularly throughout all the times in their connections but in random times of the day. In order to avoid over sizing demand calculation the intermittent loads were considered as “Required load in specific times – Load(R) need not to supply every time when the grid is not available, hence avoiding the over sizing of the system for the use of irregular loads. According to the load patterns considered a The layout of the Grid Integrated Mini Grids shown in this case shows that main and primary load may be driven by energy sources from Grid solar and wind power system. Here to note that day time essential load of dispensary/ flour mill or somewhat agriculture farming irrigation load powered by solar and wind powered energy storage system and while find dip in voltage level opens up the possibility from main grid to level it. But in few days it is observed that load to be fed by solar and wind power system through storage does not having demand. At such condition power generated from source 2 and 3 will be typical daily load profile by adding the wattage of including all loads working during each hour in the day other load including Panchayat /clinic/school are less frequent and low in magnitude. Regular load may be only 25% of total demand shown for at par time.

fed by solar and wind power system through storage does not having demand. At such condition power generated from source 2 and 3 will be controlled by central controller and fed to main grid as power input drawing credit to consumption bill by KWH supplied. Here two energy meters with calibrated tariff with real power monitoring and computation required The layout of the Grid Integrated Mini Grids shown in this case shows that main and primary load may be driven by energy sources from Grid solar and wind power system. Here to note that day time essential load of dispensary/ flour mill or somewhat agriculture farming irrigation load powered One observation is found that if we set up this rural Electrification system with help of novel concept of and Wind through storage being supplied to main supply utility grid to earn remarkable revenue. Load- (R) which considered major but rarely operated must drive with grid power only

X. CONCLUSION

The objective of the paper is to study and analyze the aspects of grid integrated mini grids feasibility. The influence of using wind and solar - hybrid PV systems as GIMS generation technology and hybrid PV/Wind with main grid association Simlet area located in Gujarat, India. The potential savings by revenue generation by GIMS can be achieved by different model of rural electrification policy in India. Here the cost of reliability of power supply and load pattern is considered similar an individual typical Indian rural community. Notable cost of grid integrated mini grids systems could be saved by using hybrid PV- wind power generation units. However, these savings occurred depending on commercial as well domestic load profile, with its peak load occurring during the day, mostly in the early afternoon Community cooperatives can change the load profile by hours and gradually reduces dependency over main grid.[16],[17] And reconfigure their load pattern cycle to cover up in minimum timing and rest time power generated from Solar.

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IX. SOLUTION

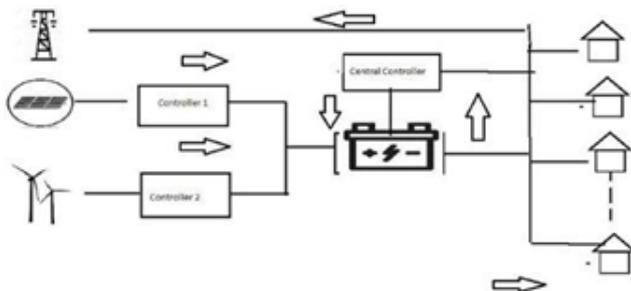


Figure 3: Schematic layout of Energy system

by solar and wind powered energy storage system and while find dip in voltage level opens up the possibility from main grid to level it. But in few days it is observed that load to be

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