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Analysis of Wind Power Generation Plant at Remote Area through HOMER Software

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Abstract- This Paper presented on wind power generation plant at remote area for doing fulfillment of electricity uses in the remote area. For this purpose we used a wind turbine and some initial data for research through homer software for analysis of wind power generation in remote area. Based on so chosen individual RES type, either PV or wind, .system design suitable for agro/horticulture irrigation, domestic/street light and micro/tinny/cottage or small scale industry with sufficient backup and energy storage; the research model shall be designed, developed and simulated on HOMER for early detection of short comings for improvement. To confidence of visualizing a vast vision towards independent, non-diminishing, with zero emissions RES at a village, farm, industry, institution, or a city level. All can be managed through automation of micro grid protecting all connected nodes (RES sources). Each such category can fix up its own RES through a systematic approach and hook up to local micro grid with net metering concept.

Keywords- Renewable Energy Resources (RES), Wind Farm, DC-DC converter, Virtual Metrological Data (VMD).

I. INTRODUCTION

Energy resources from nature are though available in abundance and vastly spread over the entire earth, but the human needs and the growing population are increasing disproportionately. Thus it is affecting the living environment due to usage of fossil fuels. There is a growing concern, though many organized international organizations and almost every nation member are rightly convinced and determined to reduce the carbon emission by adopting alternate Renewable Energy Resources (RES) for our healthy environment being affected by the global warming.

To choose RES which are techno-economically suitable and meet environmental provisions; thus creating harmony in utilizing the natural resources and biological balance is a big challenge today. The RES priority depends upon geographical location, metrological conditions, possible approach methodology and technical developments.

II. GAP IN THE STUDY

Our country has made massive plans for harvesting RES especially biomass, solar, wind and mini water turbine based hydro power stations. There is a priority for replacing diesel engine based water pumps for irrigation at remote locations. Firstly there is electricity shortage for induction motor driven irrigation water pumps for existing farming connections. Secondly adding electricity lines to connecting farms is costlier and even such availability is getting delayed. Thirdly there is good support and subsidy for photovoltaic based irrigation projects at individual farms by the government. Mostly permanent magnet AC synchronous motor based pump is being supplied which are less troublesome for maintenance and have cheaper service parts. There is good acceptance for LED lights in city and villages. It is considered as promising alternatives of incandescence bulb and tube lights.

A random project implementation is good to meet straightforward targets, but such approach is neither systematic nor sufficient in reference to RES based energy yield at village, city or regional based resources.

III. STATEMENT OF THE PROBLEM

Despite so much of development, it is a hard fact that people living at most of the remote places are deprived of basic human needs, simply because the government plans for rural electrification are not economically viable. In the absence of electricity, they are living in darkness, without clean water, road connectivity, proper communication, education and with full of limitations. To address these issues, RES options based on feasibility study, with systematic risk free, system design schemes, which are economically viable are needed. It will generate electricity locally for the community enabling a solution for most of their problems, narrated above and faced by them.

Brief overview of available types of RES with examples of implemented technologies, presently being used with their operational performance data and corresponding size of investments are studied. Further for a given site, which type of RES (such as wind, solar or hybrid) is appropriate is to be justified, based on local remote village load study, estimation of RES potential and techno-economically viable. A simulation based exercise, studying technical aspects and selecting appropriate technologies for wind and solar in details including corresponding technical standards for various sub parts of the generation, distribution, efficient utilization and metering are covered in the study. A system design of DC-DC converter is also covered. A village based load study; its classification and categorized solution for consumers are suggested.

IV. PURPOSE OF THE STUDY/RESEARCH OBJECTIVES

The main aim is to find a RES based solution, which should economically meet the energy requirements of a remote village as off grid using latest technology, based on local resources, environmental friendly, without any legal violations and damage to surroundings.

The research work proceeds with following objectives:

- Study of RES alternatives, covering its basis, resource sufficiency, potential base and choosing alternatives based on operational performance and suitability to local site selection requirements.
- After deciding RES type, a detailed local load study by questioner based survey of connected load and RES survey data based on NASA website or metrological centre for present and past trends for a reasonable period is aimed.
- Based on techno- economic feasibility and participation of people, with appropriate weighted factors; a decision for most feasible RES type will be ascertained.
- A solar based efficient system design solution referring to various standards after technology assessment is developed for different category of community users based on various RES sources especially comparing solar, wind, DG and battery energy source (BES).

V. TOOLS USED IN THE RESEARCH WORK

It is worth to mention the following four research tools used:-

- Survey tool to study electric load based on questionnaire from the villagers.
- Data tool to generate primary data related to photovoltaic irradiance, wind velocity and then utilize them for a technology selection.
- Simulation tool to study the result and net effect on technological aspects such as capacity, efficiency, utilization and investments required; by varying other inputs.
- Iterative approach can provide most optimized results for the RES plants performance with economy.

VI. WIND FARM CONCEPT

Wind power generation is to transform Wind energy into electricity. The pressure differences generated by the wind flowing through the wind turbine rotate the power generator to generate electricity. With the optimal power tracking technique, the wind turbine output power can be kept at the maximum power operating point. Then, the output is converted into DC power through a rectifier. Using a voltage step-up circuit, the converted high-voltage DC power is sent to the inverter before entering the transformer to convert the DC power into AC power. Finally, the AC power is then stepped up into high voltage level suitable for power grid, [141,142] where the power is sent back to the substation to convert the power into ultrahigh voltage to be distributed to other substations.

The control system keeps vast data files such as energy generation, meteorological stations, wind turbine, substation, wind profile and these are utilized for the current and future operation of the wind farm. The electrical system of a wind farm is a medium voltage network that varies between 11 kV and 33 kV. Due to the variety and difference in sizes of the wind turbines at a site; transformers are required to stabilize the voltage at the same level. The total delivered electricity is measured at point of connection (POC) at the grid.

Weibull probability distribution model is a mathematical model, where the probability density function, f(v) is used for modeling of the wind speed frequency curve. It describes the distribution characteristics of a site in terms of two parameters, the shape factor and the scale factor. This Weibull probability density function can be expressed as equation [1], [2] and [3]

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)k} \quad (1)$$

$$v = c\Gamma(1 + \frac{1}{k}) \quad (2)$$

Where Γ is the gamma function given by:-

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t}\, dt \quad (3)$$

1. Power Output of Wind Turbine:
Wind turbine converts the wind energy at its input to mechanical energy at the output, which in turn, runs a generator to generate electrical energy. Wind Turbine power output can be expressed as:

$$Pm = \frac{1}{2} A\rho C_P V^3 \quad (4)$$

Where Pm, is power at shaft of turbine,

2. Capacity Factor of a Wind Turbine:

Capacity factor describes the ability of the wind turbine to harness energy from a windy site. For a reasonably efficient wind turbine, the capacity factor at a potential site; may vary between 0.25 to 0.4. It is the ratio of the average power to the rated power of wind turbine as given below in equations (5) to (7).

$$\text{Capacity factor } C_f = \frac{P_a(a)}{P_r} \qquad (5)$$

Where $P_a(v)$ is the average power output of wind turbine and P_r is the rated power.

$$P_a(v) = \int_0^\infty P_n(v)\, f(v)\, dv = P_r \int_0^{vr} P_n(v) f(v)\, dv + P_r \int_{vr}^{vf} f(v)\, dv \qquad (6)$$

$$P_n(v) = \frac{v^3}{vr^3} \qquad (7)$$

3. Availability Factor of Wind Turbine:
Availability Factor (AF)is the percentage of time, a wind turbine is under working condition and the Availability Factor is given by:

$$AF = \frac{Nunber\ of\ hours\ WT\ is\ under\ operation}{8760} \qquad (8)$$

$$AF = \exp\left[-\frac{\pi}{4}\left(\frac{vc}{va}\right)^2 - \exp\left[-\frac{\pi}{4}\left(\frac{vr}{va}\right)^2\right] \qquad (9)$$

It is clear from equation 9 that the availability factor is not affected by rated speed of the wind turbine. For a particular wind energy conversion site, the wind turbine with highest capacity factor is preferred. But the availability factor, being the performance index and its high value is always desired.

3.1 Wind Energy Mapping, Resource Classification and Potential Assessment: The study literature reveals that wind speed below 4m/sec at 10m tower height is considered as not profitable but at the same location, wind power density at 50m height is nearly 28% higher, which is considered as moderate and it's economically feasible also. Other values up to 8m/sec are graded well within the beneficial zone. These wind class are applicable in discussion and are important in matching the wind turbine capacity.

3.2 Wind Potential Data Collection and Processing: The basic purpose of data collection is to mitigate uncertainties, taking precautionary and suitable corrective measures for reduced risk. For preliminary assessment wind resource data may be obtained from NASA (National Aeronautics & Space Administration), NREL (National Renewable Energy Laboratory) and National Centre for Weather Research. The realistic wind distribution patterns come with measurements at 50m and 80m turbine heights ensuring wind measurements over minimum 10 minute average time intervals; at minimum 2 or 3 elevations and at least one year data are required to minimize the investment risk, thus more realistic picture of financial data are worked out. Manual data generation is a laborious process, but an accurate one, at a particular instant and such measurements are to be seen with virtual metrological data (VMD) to correlate the past and future forecast. The investment on metrological station is quite high as various instruments such as anemometers and wind vanes are installed at 30 to 60 meter tower height for factual record of wind speed and direction data. The wind turbine height is proportionately scaled with respect to the used height of instruments. Matching of wind velocity and turbine characteristics are co-related through simulation on monthly and yearly basis.

An example of wind pattern variation is shown in Figure 1 which is based on simulation using Homer energy software.

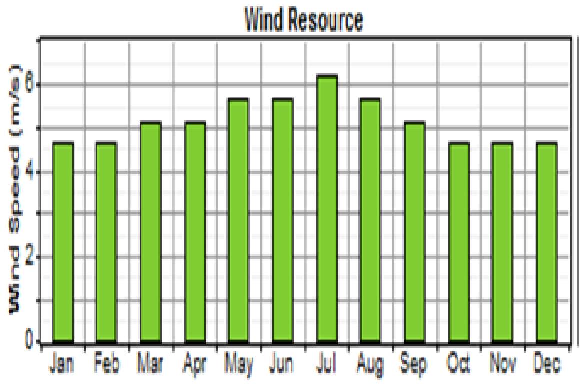

Fig 1. Study of Wind speed variation over a year to co-relate Wind Turbine selection.

For large scale data collection and map formation, a remote sensing method is used to examine the surface of the Earth; which is known as LIDAR (Light Detection and Ranging) type instrument consisting of laser, scanner and a specialized GPS receiver: is used.

VII. METHOD OF GLOBAL WIND REGIME DATA GENERATION

Weather Research Forecast (WRF) is consortium of more than 150 research organizations, industries and universities. VMD are generated with various inputs such as Modern-Era Retrospective Research Analysis and Applications (MERRA); along with satellite data of soil temperature, moisture, sea surface temperature, sea ice and snow depth at 25 Km resolution scale on 3 hourly interval basis and finally a sophisticated land surface model predicts, surface fluxes of heat and moisture in the atmosphere, reflected shortwave radiation and long wave radiations emitted to the atmosphere.

MERRA is a NASA re-analysis product, which performs numerical modeling involving large quantities of empirical

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data such as surface measurements, earth observations and satellite data to generate a long term profile. A resolution of 1/2 ° in latitude and 2/3 ° in longitude at a height of 50m above ground level is a sufficient basis for wind profile, surface mapping and temperature data. The data, so generated are applied for wind speed measurement and deciding the wind regime at a site.

1. Wind data collection using Anemometer
The meteorological station usually is a tower with 30 to 60 meters height and equipped with various instruments, wind vanes at different heights to record the wind speed, the wind direction and other metrological data.

Manual data generation is laborious but accurate at a particular instant and such measurements are to be co-related with VMD to decide past and future forecast. To illustrate this aspect, a forecast view of wind is presented in Figure 2 below:

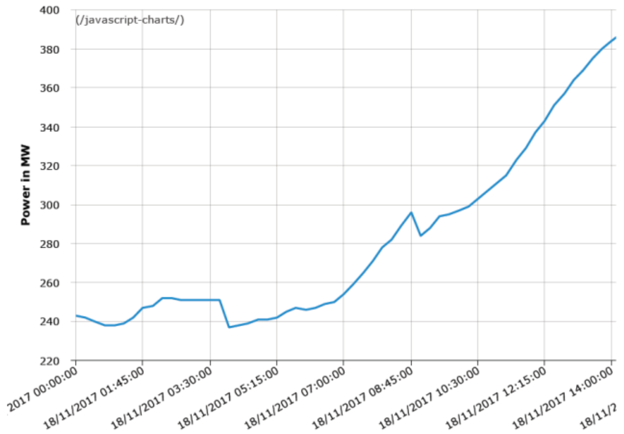

Fig 2. Showing a Wind Power Forecast pattern as per time punch.

For large scale data collection and map formation, an instrument LIDAR is used. LIDAR has three parts: Laser, Scanner and Specialized GPS Receiver. These are generally deployed for wind and surface nature study. The whole purpose is to mitigate uncertainties, taking precautionary and suitable corrective measures with reduced risk.

During wind site selection, a reliable wind measurement process may be started and logged in. This data storage is possible, only if a low power battery operated instrument suitable for any harsh environment is deployed. An ultrasound based anemometer, having low power microcontroller with digital view is preferred. Here we are briefly covering working principle and major specifications.

2. Anemometer Specifications:
Ultrasound based low power consumption, maintenance free and solid state instrument is needed for large data logging. It should be robust, corrosion free and suitable for outdoor environmental conditions, including offshore wind measurements. The sensor is mounted on pipe and using wind software data, logging on PC is achieved.
Following basic specifications are used as reference:
Wind direction range: 0-3590

Speed scales: 0-10 m/sec, 0-20 m/sec, 0-30 m/sec, 0-40 m/sec, 0-50 m/sec and 0-60 m/sec

Alternately in Knots, MPH, KPH are also expressed as per convenience

Accuracy: ±2% at minimum scale range (10 m/sec)

Options in digital version polar co-ordinate system data are displayed. An instrument EMC performance capability is governed by its standard EN61326.Other protections include ingress of external things as per IP66, humidity, temperature and noise immunity. Anemometer is typically connected to PC viaRS232 to USB converter using two pairs of twisted cable with RXD, TXD and ground connections.

Figure 3 below depicts the relationship between rotor diameter and power generation for typical turbine models.

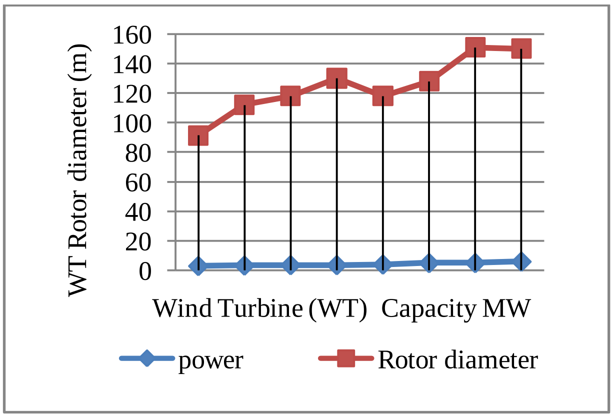

Fig 3. Rotor diameter role in power output for Wind Turbine.

A wind turbine classification is based on its average wind speed, capability against turbulence, capable of facing extreme 50-years gust, the design guidelines and test procedures are followed by IEC 61400. It is worth to mention that environmental conditions are aligned better for European nations rather than country like India.

3. Wind Farm performance factors:
This section covers the factors on which the wind turbine performance is depended. It is affected by many inter-dependent aspects and few of the important ones are mentioned below:

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3.1 Blade degradation: Physical degradation of the blade surface over prolonged operations, due to dirt and salt etc.

3.2 Grid Availability: This factor defines the expected grid availability for the project under peak loads or outage in grids.

3.3 Wind Array Efficiency is affected by high level of turbulence affecting the operational loads on alternate turbines (in general).It is shut down especially during high speeds.

3.4 Electrical Efficiency is due to the electrical consumption by the project elements, such as transformer (No load losses) and consumption by electrical equipment within the turbines and substation.

3.5 High Wind Hysteresis Losses: When wind speed reaches at shut down thresh hold level; the wind turbines are shut down; as it may cause significant fatigue loading. Frequent starts and shut down must be avoided through control scheme.

3.6 Power Curve Compliance: The factors such as pitch/yaw misalignment, controller performance, layout factors, site turbulence etc. cause various losses and thus the overall performance curve matching is uncertain. It is assumed as 99.5% as per experience, but power curves provided by manufacturer are of prime importance.

After consideration of all these factors, an overall Wind Farm Performance availability is taken as 98.0% under different scenarios in practice.

Following performance data of a 4 MW Wind turbine with project capacity as 150 MW at hub height of 80m at different wind speeds are presented in Figure 4; to show the overall gross energy produced and the net availability to grid by a wind farm.

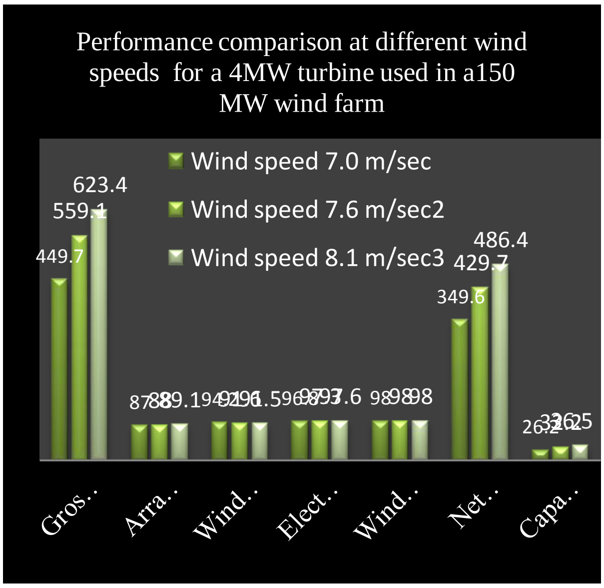

Fig 4. Simulated performance of a 4MW Wind Turbine used in a 150MW Wind Farm at different Wind speeds.

VIII. SIMULATED

Further as shown in Figure 5, the consideration of using DG set with PV or Wind Turbines as RES is beneficial. There is a significant difference in terms of Capacity Factor or plant Availability Factor to produce the energy. Other parameters, like change in DG set efficiency, CO2 emissions and net difference in levelized cost of electricity generated units are also shown.

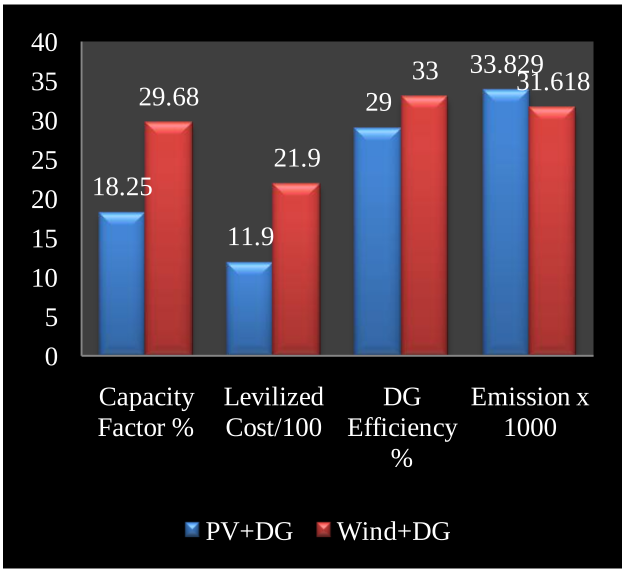

Fig 5. Performance Comparisons in Case III (PV+DG) and Case IV (WT+DG) Part (C)

1. Case V using (DG+PV+WT+BES+Convertor):
Here PV and WT are being used as RES and DG as larger backup source, despite of keeping BES for critical loads and to fill the time gap until DG set is started to full frequency and voltage values as needed for synchronization to Microgrid.

Table 1. Simulation Case I (DG+PV+WT+BES+Convertor)

Parameter considered	Case-V (DG+PV+WT+BES*+Convertor)					
	DG		PV		WT(3KW)	
Capacity DG KW ,Price ($)	23	11500	17	52457	6	36000
Capacity BES KWh, Price ($)	Li-on 1KWh x 20				6000	
Capacity Converter KW Price ($)	15				4626	
Load Demand Peak Load	20 KW peak, approx. 165 KWh /day					
Capital ($)	110583					
Annualized O & M in ($)	DG(1061)+PV(0)+WT(720)+BES (2000) =3781					
Annualized Fuel	9344					
Levelized Cost of Energy per KWH($)	0.361					

Excess Energy KWh/yr	9373					
Emission CO2 (Kg/year)	24460					
CO (Kg/year)	154					
SO2 (Kg/year)	60					
NO2 (Kg/year)	145					
Total (Kg/year)	24819					
Units Generated (KWh/yr) (%)	31090	42%	27951	37%	15599	21%
Total	74639					
RES	48%					
DG Operating (hours/year)	1537					
DG Electrical Efficiency	34%					
DGMinimum/Mean/ Maximum Output (KW)	7/20/23					
DG Number of Starts	1322					
DG Life (Years)	10					
PV/WT Operation Hours	4370	7679				
PV/WT Min/Mean/Max (KW)	0/3/17	0/2/6				
PV/WT per day Production KWh/day	109.8	85.47				
PV/WT Levelized Cost per KWh	0.119	0.219				
RES Penetration	46.41%	25.90%				
Capacity Factor	18.25%	29.68%				

Figure 6 shows the capital investment comparison for PV, WT, DG, BES and Converter, when they are used in combination to meet a given load. Actually, it is also a matter of using turbine size in the simulation.

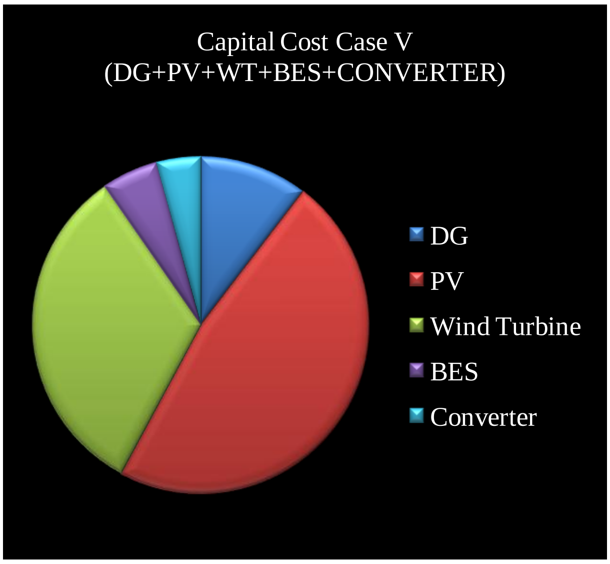

Fig 6. Capital Cost Composition, Case V (DG+ PV+ WT+ BES+ Converter).

In Figure 7 the contribution of DG set, PV system and Wind Turbine in generating the power is shown, which is highest for the DG set and depends upon irradiation and wind flow speed at that instant, while DG set generation is independent from weather conditions. However the combined share of RES is much higher, which is a beneficial aspect of the total scheme. It is further clear from the Pie diagram below.

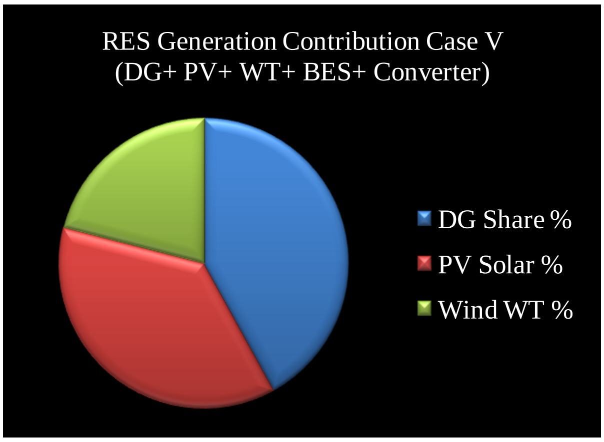

Fig 7. RES Generation Case V (DG+ PV+ Wind+ BES+ Converter).

Figure 8 is showing the simulated emissions of pollution gases due to DG set in which CO2 is dominant, while CO and NO2 are approximately equal.

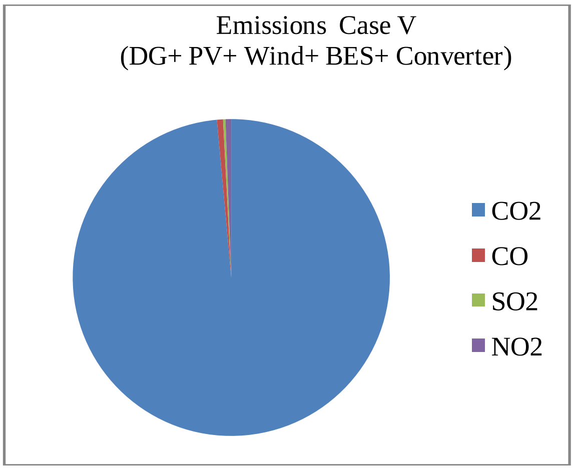

Fig 8. Emissions Case V (DG+ PV+ Wind+ BES+ Converter).

2. Case VI Simulation Results if (PV+BES) or Case VII (WT+BES) are deployed:

The capital investment is being more by 14% in Alternative I and thus Alternative II is economical. The operating cost of Alternative II is marginally higher by 18% but overall levelized cost of electricity production in Alternative II is lower due to lower investment in this case. The electricity generation difference is hardly 10% over a one year period after accounting for weather and irradiance variation, as well as change in higher maintenance of Wind Turbine parts. The excess energy is also reduced by 17.7% in Alternative II.

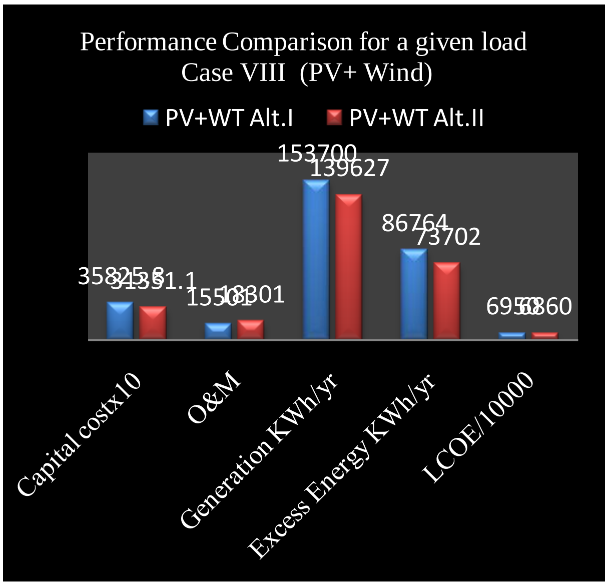

Fig 9. Performance Comparison for a given load Case VIII (PV+ Wind) between Alt.-I & II (A).

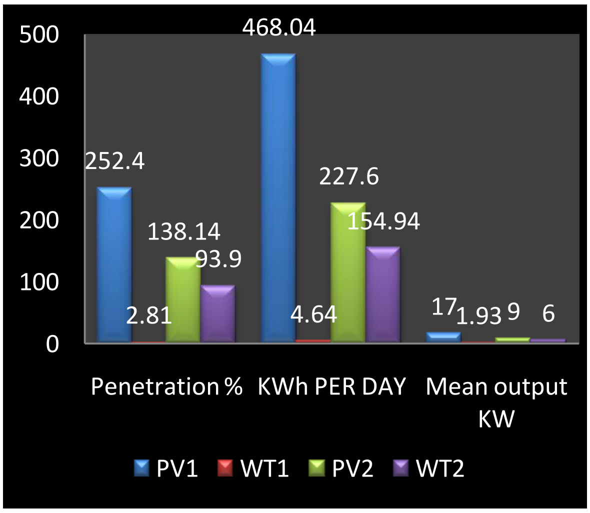

Fig 10. [A] Performance Comparison for a given load Case VIII (PV+ Wind) between Alt.-I & II (B).

Table 2. Converter Performance.

Parameter	Inverter	Rectifier
Capacity (KW)	22	22
Mean Output (KW)	3	4
Minimum Output (KW)	0	0
Maximum Output (KW)	20	22
Capacity Factor (%)	14	17
Hours of Operation(Hours)	4803	2150
Energy Input (KWh/Yr)	28480	35071
Energy Output (KWh/Yr)	27056	31564
Losses (KWh/Yr)	1424	3507

The inverter capacity utilization is 90.90% while rectifier is utilized to its 100% rated capacity especially during peak performance. The average capacity utilization of inverter is 13.63% and that of converter is 18.2% which are lower. It depends upon magnitude, duration irradiation and wind speed. Based on simulations, the efficiency of inverter and rectifier is 95% and 90%, which is satisfactory.

IX. CONCLUSIONS

The followings are concluded based on research achievements:-
The proposed research topic provides a confidence of visualizing a vast vision towards independent, non-diminishing, with zero emissions RES at a village, farm, industry, institution, or a city level. All can be managed through automation of microgrid protecting all connected nodes (RES sources). Each such category can fix up its own RES through a systematic approach and hook up to local microgrid with net metering concept.

The assessment of RES potential, site selection, design and sizing the major devices in the system, involving energy storage systems with sufficient capacity and period as per individual needs for normal, peak and critical loads is feasible through simulations by varying the sensitivity of system scheme and ensuring reduced risk of implementation and investment.

The proposed research work involves data generation, using equipments and gathering information using survey tools. Then designing a system scheme as per site perspective. Further it is implemented at the site after a sizable investment and based on feedback, the correction is incorporated. Though this second part has not been included, never the less, Homer simulation has met the objectives to a large extent.

It is expected that the village will be moving towards ‘Energy Security’ through sustainable and green solutions. There is possibility of moving out of power shortage situation and becoming a ‘load shedding free’ (or black out and brown out free) village. Local employment, as electricians, entrepreneurs will be coming up after training the village people on its awareness. The local women self help groups may get involved in many skill oriented employment categories for their overall development.

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