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Leveraging on Repowering of Wind Sites for Potential Wind-Solar Hybrid Capacities: a Case Study

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ARTICLE INFO

Article history:
Received 28 June 2020
Received in revised form
14 October 2020
Accepted 01 December 2020

Keywords:
Hybrid power
Plant load factor
Repowering
Solar power
Wind power

ABSTRACT

Renewable capacities are eco-friendly and are being welcomed globally. Suitable framework helps in deployment of renewable capacities at good pace. In India, wind development started in early 80's and is well evolved today. The early wind generators were of kW series, ratings ranging from 200 kW to 800 kW. Many initially set up wind turbines are completing 30 years of operational life span. In India, repowering policy is being implemented to scale up the site capacity and to enhance generation. This paper intends to draw attention of researchers, policy and decision makers on repowering of sites and its utility from solar perspective. Developing wind-solar capacities together has a unique advantage of using of common resources optimally like, land, technical manpower and power evacuation infrastructure. At Kayathar, the National Institute of Wind Energy has wind turbine test bed with old wind turbines. Study is conducted by removal of old make turbines with that of modern turbines and using the set free area for solar installations. On comparing 40.86% more PLF is generated by 4 MW new turbines and 18 MW hybrid capacity produces ~17 times more energy from same site. The total GHG mitigated by the hybrid capacity is 27878.04 tonne of CO_2 annually.

1. INTRODUCTION

Being eco-friendly power generation source, renewables are being promoted universally. Renewable resources are distributed non-uniformly across geographies. To tap the renewable potential, it is essential to carry out the site-specific resource studies thoroughly. The emissions from conventional power plants are major reason for Greenhouse gas (GHGs) emissions. GHGs have adverse impact on flora and fauna. The visible impacts of global warming are change in weather pattern, change in rainfall pattern, change in cropping pattern, flooding, cyclones *etc.* [1] [2]. Renewable resources like solar and wind are of varying nature and are non-uniformly distributed. Solar resource is available all over India with different insolation levels. The useful wind speeds are largely prominent in southern and western part of India. June to September is the period when India receives monsoon and the larger amount of wind power generation happens during the same span. Almost 65% of wind power happens during monsoon *i.e.* during high wind season [3]. Although resource is non-uniformly scattered all over, the site-specific development is taken up based on availability of renewable energy resource, conducive framework and infrastructure. Ministry of New and Renewable Energy (MNRE) in India through its promotional policies is providing good platform for rapid development of renewable capacities [4]. Wind development started in early 80's in India with smaller wind turbine generator rating like 200 kW to 800 kW. Eventually with growing time and advancement wind technology is well evolved, the onshore wind turbine generator available today is with ratings 2000 kW to 3000 kW [5]. The typical life span of wind turbines is around 25 years [6]. The lower kW rating wind turbines generate lesser power as compared to modern wind turbines. The old wind turbine has low rating as well as their hub heights are lower. Wind speeds prevailing at lower height are lesser and is relatively low as compared to higher heights. Hence lower power is generated by the low rating wind turbines. The lower capacity wind turbines are becoming obsolete with time and there is good scope for redevelopment of sites. The latest make wind turbines will help in enhancing generation. Upon completion of operating life of old make turbines, new turbines are being introduced. This introduction of new turbines at operating site is termed as repowering [7]. The Government of India has come up with policy on repowering for old make wind turbine site locations. Sites can be upgraded with latest make wind turbine

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generators, with site upgradation and reduced number of wind turbine generators lot of area in wind farm is set free. This set free area can be used for installation of solar PV, which can help in optimizing on the site resources [8]. Developing solar-wind capacities together has a unique advantage. The advantages could be use of wind generator shadow free area for solar installations, having common power evacuation facility and shared site resources for taking up collective maintenance activities [9]. The repowering policy for wind has given good impetus for installation of latest make wind turbine generators in India. While repowering motto of enhanced generation can be attained, it is equally important to see what way site utility can be enhanced. Few more studies give close insight on developing the wind solar capacities together for various applications - study from Qatar highlights cogeneration from wind-solar plant, generating power as well as hydrogen [10], hydrogen production from solar and wind capacities [11] [12], use of wind and solar capacities for residential purpose, [13] use of wind, solar, biomass and fuel cells for electrification of tourist village [14]. One of the studies also helps in identifying suitable locations for wind solar hybrid capacities based on the meteorological data sets and software analysis [15].

The latest make wind turbine ratings are higher and hence a smaller number of WTGs are required for same capacity. This study is undertaken at Kayathar, National Institute of Wind Energy (NIWE) wind turbine test bed. NIWE is an Autonomous body under MNRE and is the apex body responsible for wind development in India [16]. The objectives of the study are:

i) Studying NIWE turbine test bed for PLF and energy yield.
ii) Comparing PLFs of old make turbines with modern turbines.
iii) Optimisation of site capacity with increased energy yield with constraint on area.
iv) Studying the energy yield of hybrid plant with old operating turbines.
v) Estimating Potential GHG mitigated from the hybrid capacity.

The study encourages to identify all the old wind turbine make operating sites/capacities all over India and recommend for introduction of hybrid promotional policy framework, so that the renewable energy generation from such old turbine make site locations can be realised more meaningfully for mitigating GHG.

2. MATERIAL AND METHODOLOGY

The data required for study and analysis is taken from the NIWE. The data considered is for the operating 11 number of 200 kW wind turbines. The site energy estimation is done based on the wind mast installed at the Kayathar test bed location. Energy yield of old make wind turbines is taken for comparing with new make wind turbines. The study covers repowering of the existing operating NIWE wind site with the new class 2000 kW wind turbine generator. The shadow free and obstacle free area is explored for installation of solar PV capacity. At Kayathar, NIWE has operating wind farm of 2.2 MW capacity *i.e.* 11 number of wind turbine generators of 200-kW capacity each. The land parcel where wind turbines are operating is a contiguous land. Considering the sun path shadow occurrence due to site features is eradicated. The site repowering and plant load factor (PLF) estimation is done with the help of wind WAsP software [17]. The site solar energy estimation is done with the help of PVsyst software [18]. The site historical wind data and the solar data is used for the site energy estimation. The site location falls in good solar insolation zone. The site has real time measured wind data, the same is used for carrying out the energy estimate with new class wind turbine generators. Site solar insolation data used for the study is satellite based. Both data sets are used for quantifying the energy yield based on the wind and solar technologies. Wind data is captured from 120 m high Kayathar wind meteorological station. Based on the site visit, the study site is found to be homogenous and is predominantly covered with agricultural land with scattered bushes. The mast location is situated about 3 km to the east of Usilankulam village and 1.5 km to the south west of Panikkarkulam village. The site is accessible through Chockanachialpuram road. The geographical coordinates of reference mast (120m) are given below:

Mast Name:	Kayathar
Latitude:	8°57'43.79"N,
Longitude:	77°43'12.53"E
Elevation:	88.08 m amsl

Period of wind data used: January 2014 – December 2015 (2 years). Figure 1 shows the location of wind monitoring station.

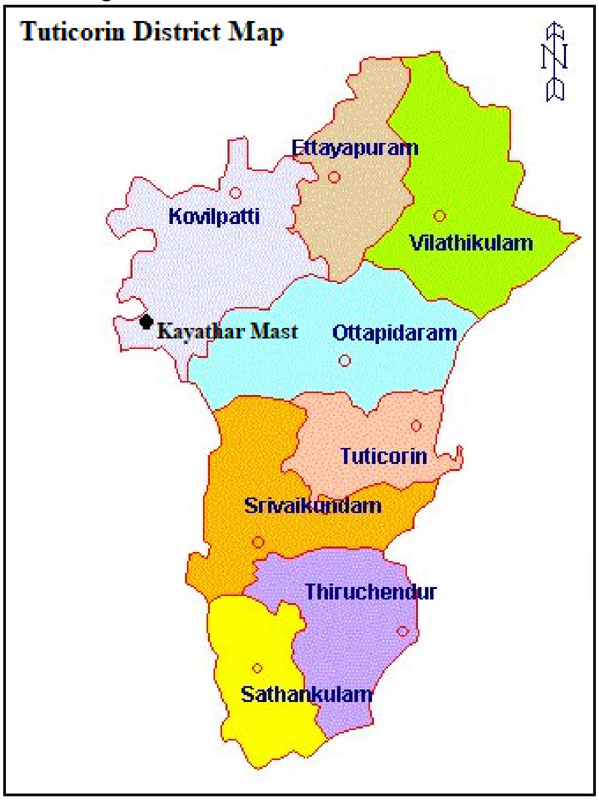

Fig. 1. Kayathar Meterological Station.
Source : NIWE, 2019

The analysis was carried out based on the time series wind data from 120m high mast installed at Kayathar site. The wind speed has been measured at multi levels viz., 120m (N&S), 90m and 50m agl. Wind direction has been measured at 120m and 90m agl. The Annual Energy Prediction (AEP) analysis has been carried out at 90m hub height considering normalized 2000 kW (RD-100m, HH-90m) model [19]. The wind characteristics of Kayathar site at 90m are shown in Figures 2 and 3. The details are derived by using 90m high wind speed measurement and 90m wind direction measurement. It can be seen from Figure 2 that the predominant wind direction at the site is west and west of south west.

2.1 Studying NIWE Turbine Test Bed for PLF and Energy Yield

Out of 11 wind generators, 9 wind turbine generators are considered for repowering. The entire 1.8 MW wind turbine capacity produces power of approximately 1.93 million units on annual basis. Equation 1 shows PLF calculated for 9 number of old make wind turbines.

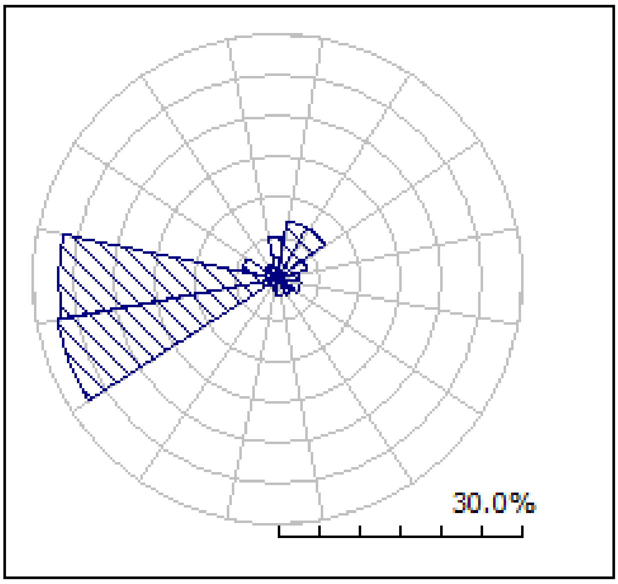

Fig. 2. Wind rose (90m).
Source: NIWE, 2019

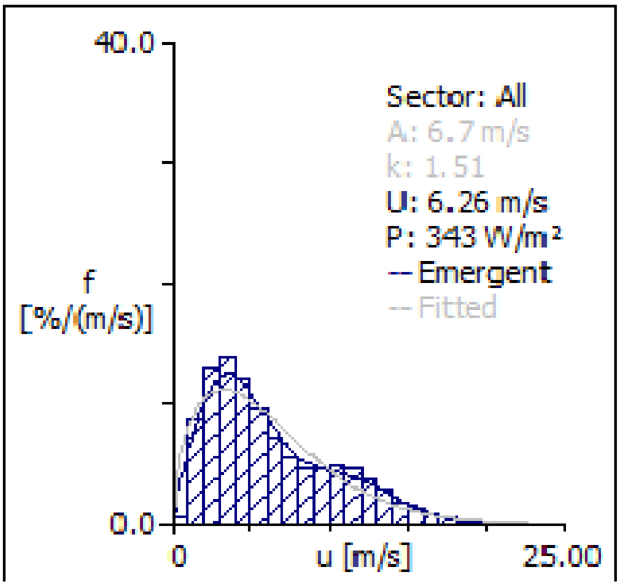

Fig. 3. Wind speed frequency distribution.
Source: NIWE, 2019

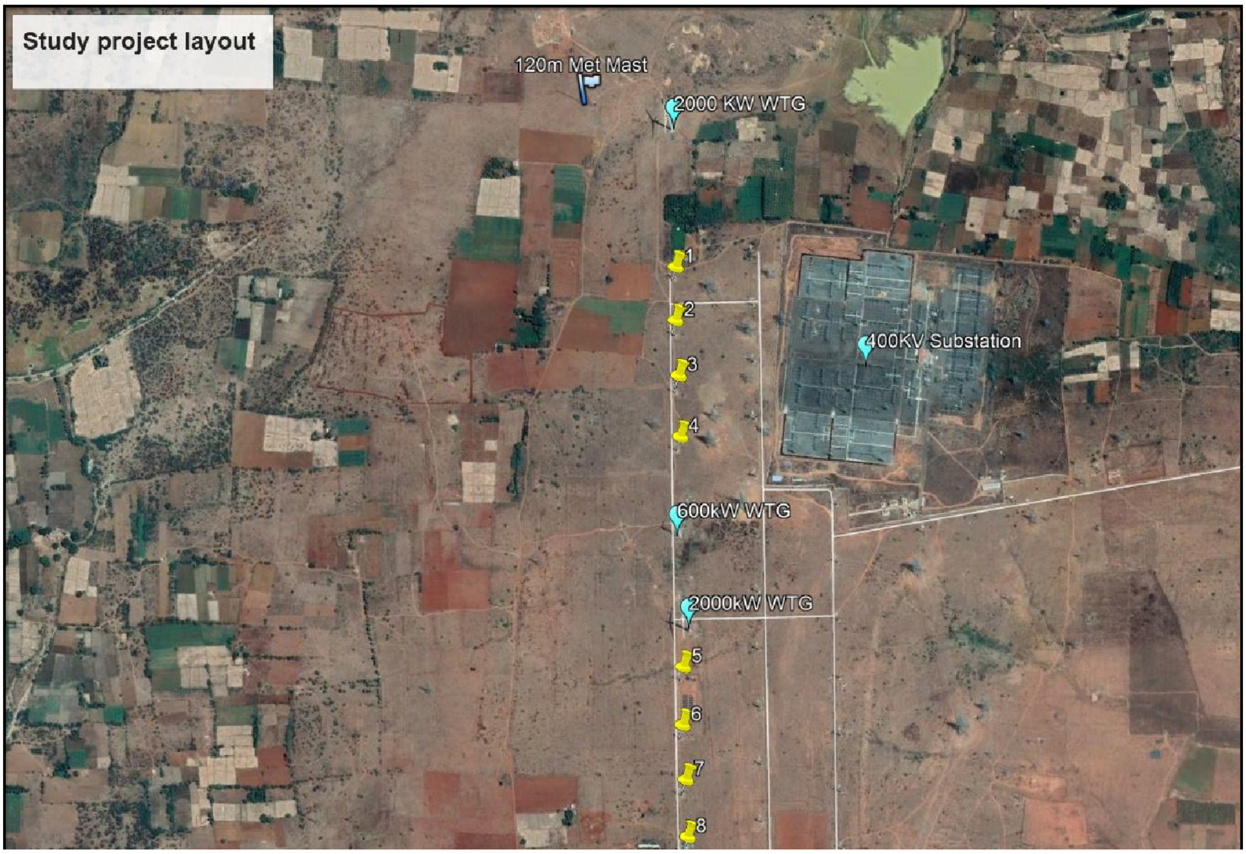

Fig. 4. Old class wind turbine generators, Kayathar test bed, Source: NIWE, 2019.

Plant Load Factor = (Total Power Produced by the Wind Turbine Generators) / (Total Capacity * Operating hours) (1)

The wind power generation data for nine (9) operational wind turbines is taken from the site. The PLF for 9 WTGs *i.e.* 1800 kW old class wind turbine capacity is 12.24%. Figure 4 shows the site location with old class 200 kW wind turbines.

2.2 Comparing PLFs of Old Make Turbines with Modern Turbines

As we go higher and higher the wind speeds increases, with increased wind turbine hub heights and the rotor diameter the power output from the new wind turbine generator increases proportionately [20]. Wind power is directly proportional to air density, wind speeds and swept area of the rotor. Equation 2 shows the wind power produced at the specified geographical location by the wind turbine generators.

$$\text{Wind Power} = \tfrac{1}{2} * P * A * V^3 \qquad (2)$$

where P: Air density
V: Wind Velocity
A: Swept Area

For the energy estimate new class wind turbine generator of 2000 kW is used. Table 1 gives the power output from the new class wind turbine generators.

Table 1. New class wind turbine generator estimate.

Site	X Coordinate	Y Coordinate	Gross [GWh]	Net [GWh]	P 50 [GWh]
WTG1	799280	991392	6.419	6.364	5.41
WTG2	799190	989994	6.32	5.984	5.09
Estimated Energy (GWh)			6.37	6.17	5.25
Estimated PLF %			36.36	35.24	29.95

The estimated PLF from new make wind turbine models is 29.95%. The site P50 PLF is arrived post factoring in the Machine availability, Grid availability and the line losses. With reduced number of wind turbine generator from 9 number to 2 in number the total area set free is 55 acres. The shadow free area is explored for installation of solar PV capacities. Equation 3 gives the percentage increase in generation with the modern make wind turbine generators.

Increased Output from Site = (Old Make WTGs PLF /New Make WTG PLF) * 100 (3)

Increased Output from Site = (12.24 / 29.95) * 100
Increased Output from Site = 40.86%

For the equivalent wind capacity introduction of new make wind turbine model helps in increased energy yield by 40.86%.

2.3 Optimisation of Site Capacity with Increased Energy Yield with Constraint on Area

The existing wind turbine generators are of 200 kW capacity are placed appropriately at site to harness maximum wind speeds reducing the wake effect. [21] With use of latest class wind turbine generators, the number of locations of old class wind turbine generator get reduced. The total area available is 65 acres. For optimal energy yield and enhanced generation, it is proposed to use 2 turbines of 2 MW each and shadow free area left for deployment of solar PV. Figure 5 shows the area available for solar installation post removal of 9 wind turbine generators.

The new wind turbines require area ~10-acre, area required is on account of bigger rotor diameter and to reduce wake effects. To avoid wake effects, using turbine placement principle of 5 times rotor diameter to 7 times rotor diameter. The predominant wind direction at site is West and South West, which means technically second wind turbine can be placed 5 times rotor diameter *i.e.* 550 meters adjacent, wind turbine generator rotor is ~110 meter in diameter. Post deployment of 2 modern turbines, shadow free area left is 55 acres. The set free area can accommodate 14 MW of solar PV capacity, *i.e.* approximately 3.8 acres per MW. For latitude longitude 8.95° N, 77.72° E, solar insolation levels are 1955.80 kWh/m2. Table 2 shows the energy output based on prevailing solar insolation levels. Optimal tilt of 9 degrees is calculated with the help of PVsyst software for enhancing energy output from the solar PV. The total energy produced from the 14 MW solar PV plant is 23.09 GWh.

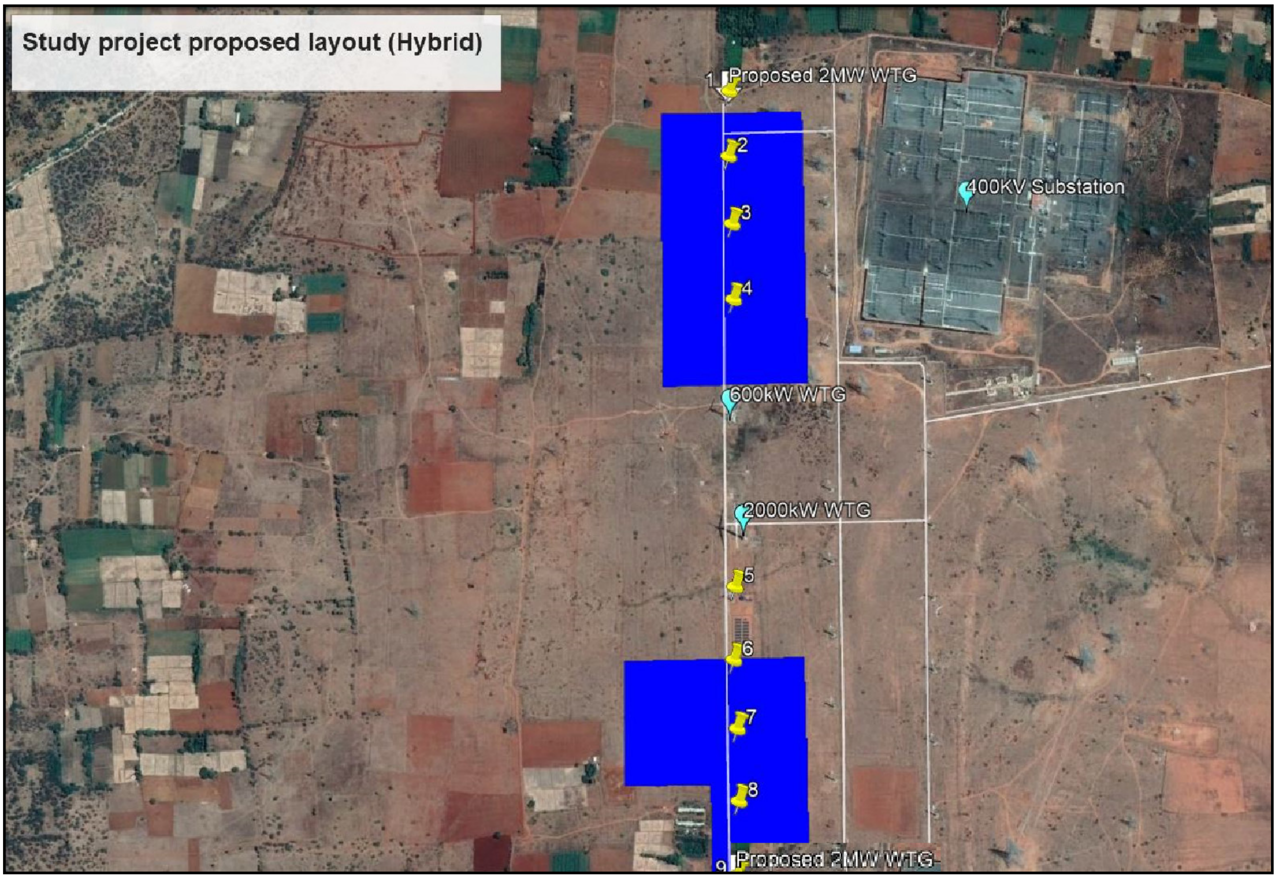

Fig. 5. Area for solar PV installations.
Source: National Institute of Wind Energy, 2019.

Table 2. Site solar insolation.

Month	GHI kWh/m^2	DHI kWh/m^2	Earray	E_Grid MWh
January	161.9	65.45	2113	2037
February	160.4	65.02	2028	1955
March	191.2	75.58	2325	2241
April	176.4	82.38	2088	2012
May	172.8	81.52	2001	1929
June	146.2	83.6	1707	1647
July	156	87.52	1826	1761
August	171.8	83.36	2038	1964
September	174.8	79.37	2128	2050
October	158.1	75.85	1979	1907
November	136.6	71.25	1757	1692
December	149.6	65.12	1964	1893
Year	1955.8	916.02	23954	23088

2.4 Studying Energy Yield of Hybrid Plant with Old Operating Turbines

The power produced by 9 WTGs is 1.935 GWh on annual basis. Similarly, the 4 MW modern wind turbines considered for repowering produce 10.50 GWh annually. The 55 acres free area accommodates 14 MW solar PV plant producing 23.09 GWh of solar power annually. The total power produced by the hybrid capacity is 33.59 GWh. With the introduction of new wind solar hybrid capacity, the potential site energy output increases by ~17 times higher from the same site.

2.5 Estimating Potential GHG Mitigated from the Hybrid Capacity

The power produced from solar capacity is 23 GWh and the total power produced from newly repowered wind turbine generators is 10.5 GWh. The total power produced by the hybrid capacity is 33.59 GWh. The weighted average grid emission factor notified by Central Electricity Authority of India is 0.83 tonne of

CO_2 per MWh [23]. Equation 4 gives the total GHG mitigated from the 18 MW hybrid capacity.

GHG mitigated by the hybrid capacity = Total power produced in MWh*grid emission factor (4)

GHG mitigated by the hybrid capacity = 33588 * 0.83

GHG mitigated by the hybrid capacity = 27878.04 tonne of CO_2 annually

The 18 MW hybrid capacity had potential to mitigate 27878.04 tonne of CO_2 on annual basis.

3. RESULTS AND DISCUSSION

With long history of wind power in India for about four decades, the segment has witnessed several challenges. The industry has made path-breaking development in turbine capacity, efficiency and increased level of reliability. In Tamil Nadu, more than 60 per cent of lower rating wind turbines (<500 kW) installed before to year 2000 are operating with PLF range of 10% to 15%, while the modern wind turbines can technically operate in a PLF range of 27% to 34% at the same sites. Replacing old, low performing wind turbines with modern ones would offer better returns and greater power output than before. It opens a beneficial opportunity to the developer as well as user. Some of the benefits of repowering are:

i. Fewer wind turbines - The number of turbines are reduced in large number with higher efficiency.
ii. Lower costs - modern turbines make better use of available wind energy, as they are higher in height, thus improving efficiency of the wind farm and lower the operating cost, improved performance - modern turbines rotate at lower speeds and thus have lesser noise level.
iii. Better grid integration - modern turbines offer much better grid integration.
iv. Grid compliant - new machines fulfil the grid code requirements.
v. Reactive power - new machines consume lesser reactive power.
vi. More power output from the same area – Increased wind generation without requiring of additional land, efficient use of potential land.
vii. Technological development - more rapid development will encourage repowering.
viii. Wind resource - higher-quality wind resource areas potentially open by new transmission will encourage further greenfield investment.
ix. Operation expenditure - more rapid cost escalation as facilities age will make repowering more attractive earlier.
x. Repowering cost savings - potentially higher costs for repowering will discourage repowering investment.

Some of the challenges that could be encountered during repowering are on account of presence of existing wind turbines in and around the site, maintaining space requirement be a major constraint. Multiple owners of wind farmland may create complications relating to land ownership. The decommissioning costs and disposal of old wind turbines are some of the key challenges. The case study reveals based on the life of the old class wind turbine generator, there is need of repowering at Kayathar site. The advantage of repowering is large number of small capacity wind turbines would be removed and less wind turbines with larger capacities would be installed. As smaller number of higher rating wind turbines are installed good amount of area would be set free. Repowering of site would help in maintaining wind sites in better manner as number of wind turbines would be reduced. The shadow free area is utilized for installation of solar PV capacities. The Kayathar test bed is contiguous land parcel and has capacity to area of approximately 65 acres. The power generated by 200 kW WTG is 0.214 million units on an annual basis which corresponds to the PLF of 12.24%. Similarly post repowering PLF achieved with new class 2000 kW WTGs is approximately 29.95%. With repowering of site 40.86% PLF rise is observed. The old turbine starts power generation at 4 m/s and the modern wind turbines starts generating power at 3 m/s. For the same wind speeds higher energy output is realized from the new make wind turbines. Figure 6 shows the wind histogram and the power curve details for 200 kW and 2000 kW wind turbines. It shows more wind is captured by the higher rating wind turbines and hence more output.

Further, it is found that with installation of 2000 kW wind turbine generator 2 in number the area set free is 55 acres shown in Figure 5. This shadow free area is explored for the installation of solar capacity. Based on 55 acres area, site can accommodate solar capacity of approximately 14 MW. Solar power generated from 14 MW is 23088 MWh. Figure 7 shows month wise total power produced from the 14 MW solar PV plant. It is evident except peak monsoon months *i.e.* July and August the power generated is uniform throughout. There is lesser drop observed in power output for the peak monsoon months as they receive high rain and the weather is cloudy for good amount of time. The site location is rich in wind as well as the solar resources, collectively the site can accommodate 18 MW hybrid capacity. The energy output from the wind and solar is complementing each other, while greater amount of solar generation would happen during the day, wind would generate power during the night. Use of wind and solar together is good way of optimizing the site infrastructure and resources. For such site locations common shared resources would be land, power evacuation network and manpower.

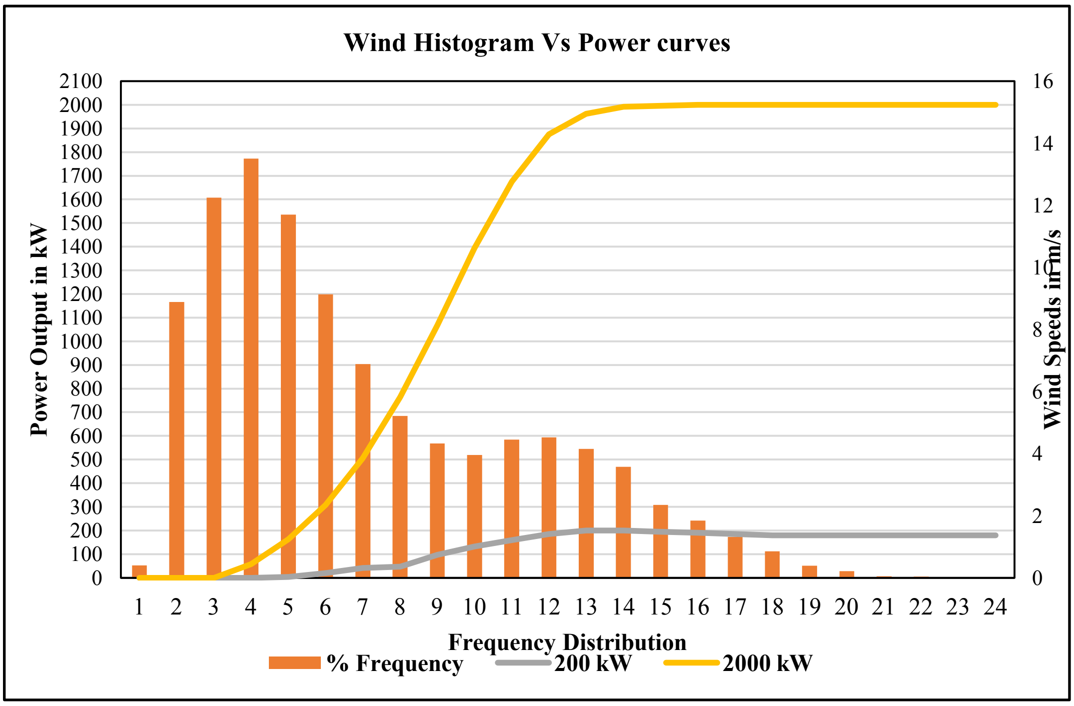

Fig. 6. Wind histogram and power curve comparison.

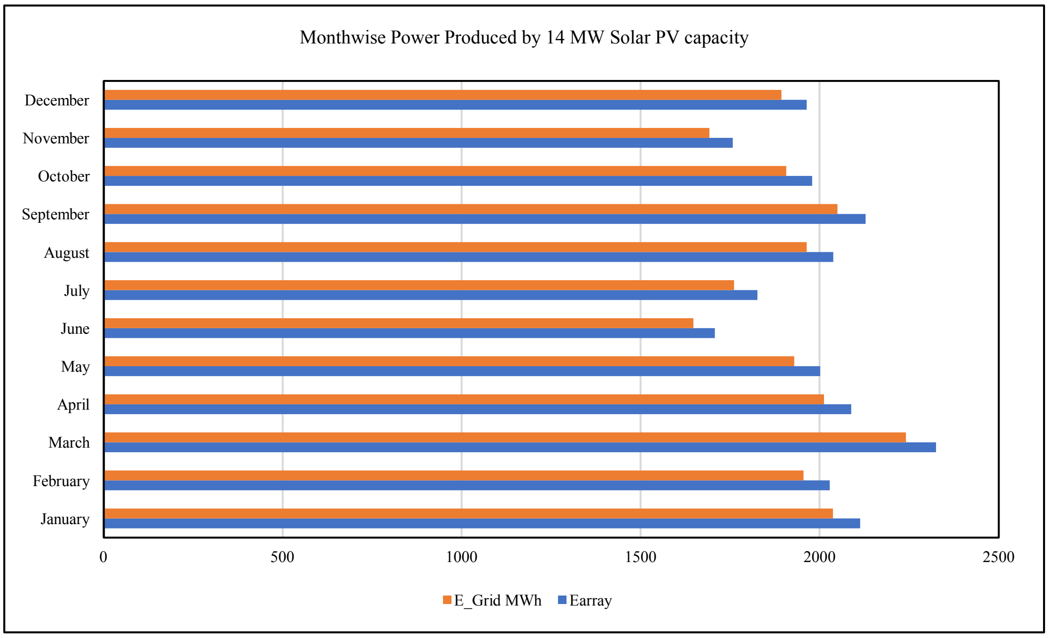

Fig. 7. Power produced from 14 MW solar PV.

The developer can benefit in terms of cost optimization on account of shared resources. Repowering of site with additional solar PV capacities would increase utility of site from renewable capacity perspective. While the capacity is scaled up parallel optimal study on loading and unloading of site infrastructure needs to be carried out thoroughly. [22] It is advantageous to have power generation from both the sources, however, before installation of such new capacities, a thorough study needs to be carried out from power evacuation perspective. Studies have shown, solar and wind resources are complementary to each other. Hybridization of these technologies not only would help in minimizing the variability but would also utilize the site infrastructure optimally including land and transmission system. The total power produced by the hybrid capacity is 33.5 GWh. The weighted average grid emission factor notified by CEA is 0.83 tonne of CO_2 per MWh. Applying grid emission factor to the hybrid power produced at the site location. The potential GHG mitigated is 27878.04 tonne of CO_2 annually.

The existing wind farms have scope for addition of solar PV capacity, similarly, there may be wind potential in the vicinity of operational solar plants, so the possibility of adding wind capacity with that of solar can be explored. Present hybrid policy does encourage developers for installation of hybrid capacities but is silent on hybridization at new potential repowering sites.

Repowering policy document should provide guidelines on wind solar hybrid development. Policy makers should notify at such locations the developers should also go for the installation of solar capacities, as during low wind and lull wind hours solar can make use of infrastructure loading it optimally.

4. CONCLUSIONS

Repowering of site with new turbine make model enhances site generation. On repowering of the site, wind capacity can be scaled up to 4 MW from that of 1.8 MW capacity *i.e.* 45% more capacity installation is realized. As the number of wind turbine locations are reduced the 55 acres of area is set free. This area can accommodate 14 MW of solar PV capacity generating 23088 MWh of power on annual basis. The site can accommodate 18 MW of hybrid capacity. The old class wind turbines generate PLF of 12.24% and the newly introduced wind turbine generate PLF of 29.95%. On comparison it is realized that 40.86% more PLF can be generated on repowering, which certainly enhance the revenue realization from the same site. With introduction of hybrid capacity, the potential energy yield from site increase ~17 times higher than that of the conventional operating capacity. As the power produced is ecofriendly and does not pollute environment, the total GHG mitigated by the hybrid capacity is 27878.04 tonne of CO_2 annually.

ACKNOWLEDGEMENT

Author express his gratitude towards National Institute of Wind Energy, Chennai, India for providing opportunity to undergo Internship training and provide data for completing the research study. Author is also thankful to Google Earth Software.

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