A True Hybrid Solar Wind Turbine Electric Generator System for Smaller Hybrid Renewable Energy Power Plants

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Abstract Contemporary Hybrid Solar-Wind farms are implemented using separate solar Photovoltaic (PV) cell arrays and wind turbines, where electricity generated from both devices are combined. However, this solution requires a large amount of space to cater for the PV arrays and wind turbines of the system. This paper proposes a new type of renewable energy electric generator with a small power production footprint (PPF) that allows reduction in land usage. The technology introduced in this True Hybrid Wind-Solar (THWS) generator allows for the solar panels to rotate along with a VAWT wind turbine it is attached to through a specially designed electromechanical coupling mechanism. The working principal behind the connections described in this paper. The design of a hybrid circuit module that serves to combine current generated via the solar cells and wind generator and also automatically disconnects inactive wind or solar generators is also described. This is important in order to eliminate unwanted loads generated from the inactive generators from within the THWS itself.

1 Introduction

In the past decade, the world has seen an exponential increase in energy demand. Fig 1. shows the source of actual energy consumption from 1990-2015 and its projected path from 2016 to 2040 [1]. This ever increasing trend is due to population growth of the world.

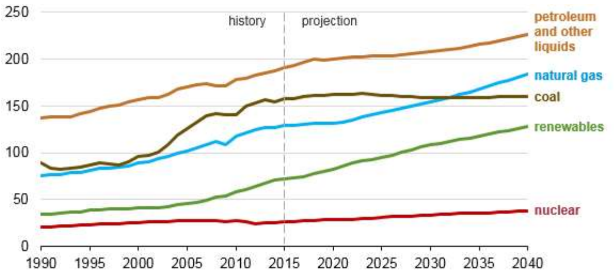

Fig. 1. Energy Demand Trends [1].

Simple analysis of Fig.1 shows that since 1990, the average energy demand from petroleum, natural gas and coal has risen by approximately 50 Quadrillion Btu at the end of 2017. Along with this unprecedented increase, a side effect of CO2 emission has also risen to levels of public concern [2] leading to Carbon taxation policies in the developing and developed nations[3].In contrast, it is observed that from 1990 to 2007, the demand for renewable energy is almost stagnant. However, from 2008, the rate has increased to approximately 2.63 Quadrillion Btu/year and is comparable to the rate of increase in the demand of petroleum and natural gas. This increase in the popularity of renewable energy sources during this period is due to its ability to mitigate CO2 emission problems as well as advancement in technology for producing renewable energy. For example, a study conducted in Thailand predicts that that the use of solar and wind as a means of electricity generation will in approximately 50 years lower CO2 emission by 69.66% [4].

The sources of renewable energy available today include solar, wind, biomass, ocean tides, geothermal, hydro power and etc [5]. Although all of these sources are able to produce electricity with zero or negligible CO2 emission, solar and wind generation methods are the most popular. For example, unlike ocean tide electric generators that must be built near the ocean, solar and wind farms can be implemented almost anywhere. Similarly, this is why solar and wind are preferred to when compared to geothermal and hydro power generation. However, the area required to produce solar or wind energy is extremely large. This will bring forth socio-economic issues such as lack of land for agriculture and housing.

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This paper proposes a new renewable energy generating device that utilizes both solar and wind energy for the production of electricity in one embodiment. The main objective behind the design objective is to minimize the area required when an array of this new hybrid generator is used for large scale RE power generation.

2 Solar, Wind and Hybrid Wind-Solar Farms and Land Area Usage

Along with the rise in world demand for energy from renewable sources, a multitude of information is easily obtained concerning operators of large scale solar, wind and hybrid wind-solar energy for the public. These corporations have a public obligation to inform the public on the specifications of their plants. Table 1 shows five operational large scale solar power plants.

Table 1. Operational Large Scale Solar Power Plants.

Reference	Operation Start Year	Location	Number of Panels (million)	Output Capacity (MW)	Area (Hectar^2)
[6]	2016	Kamuthi, India	2.5	648	1000
[7]	2017	Qinghai, China	4	850	300
[8]	2017	Kurnool, India	4	900/1000*	2352
[9]	2016	Datong, China	NA	1000/3000*	NA
[10]	2016	Ningxia, China	NA	1500	4300

Note: * targeted capacity

It is clear that the area required is large to produce MW capacity plants. For example, the solar power facility in Kurnool with a targeted capacity of 1GWatt requires an area of 2,352 hectars^2. Once a piece of land has been commissioned to build a mega scale solar plant, it is rendered unusable for agriculture and settlement for at least a 20 year period which is as long as powers purchase agreement. This is one of the disadvantages of large scale solar energy generation.

Table 2. Operational Large Scale Wind Power Plants.

Reference	Operation Start Year	Location	Number of Wind Turbines	Output Capacity (MW)	Area (Hectar^2)
[11]	NA	Gansu, China	7,000	6,000/20,000*	NA
[12]	NA	California, USA	750	3,000	12,950
[13]	1986	Tamil Nadu, India	3,000	1,500	NA
[14]	2001	Rajathan, India	NA	1,064	NA
[15]	2012	Oregon, USA	NA	845	20,720

Table 2 shows five existing mega scale wind farms, their locations and output capacity. These farms are installed with large HAWT rated around the 1 MW capacity each. Again it is seen that thea rea requirements is extremely high. For example, 12,950 hectars^2 of land is required to produce 3GW from the facility in California [12]. This is mainly to adhere to safety regulations for placement distances between adjacent wind turbines.

Table 3. Operational Large Scale Hybrid Wind-Solar Power Plants.

Ref	Name/Location	Solar Cap. (MW)	Wind Cap. (MW)	Total Cap. (MW)	Area (Acres)
[16]	SECI-NREDCAP/India	120	40	160	1000
[17]	Arena Gullen/Australia	10	165.5	175.5	70
[18]	Fakken Wind Farm/Norway	20	54	74	NA
[19]	Hero Future Energies/India	28.8	50	78.8	NA

Recently, several hybrid wind-solar power plants have also been reported and are shown in Table 3. Information on its respective solar, wind and total output capacity is presented. These hybrid plants have dedicated land to house PV cell arrays and wind turbines to produce electricity. Similar to the solar and wind RE plants, the area required to produce hybrid RE power is also quite large. However, when compared to pure large scale solar or wind farms, the usage of land for the generation of hybrid RE power is much more efficient since only 0.16 acres to 2.5 acres of land is required to produce a capacity of 1MW [16,17].

The use of large amounts of land for generating green power is seen as a social-economic problem because once a piece of land is commissioned for a large scale solar, wind or hybrid wind-solar power plant, it cannot be used for agriculture or residential purposes for a period of at least 25 years or is based on the period of a power purchase agreement between the RE power producer and the government where the plant is erected. The land requirement for generating RE energy is large due to the dimensions of the devices used to produce electricity. For example, the most efficient and well-designed large scale solar or wind farms require on average 4 acres of land to generate 1MW of electricity at full capacity [6-15].

3 Available Hybrid Wind-Solar Generators

PV cells produce electricity by means of the photovoltaic effect while wind generators induce electrical current in a coil by cutting a moving magnetic flux through the rotation motion of the propellers of the wind turbine [20, 21]. Contemporary hybrid wind-solar farms are designed by connecting a solar farm with a wind farm, making them also a clean source of renewable energy [22]. As discussed in the previous section, although energy production is clean, socio-economic impact due to the use of large amounts of land for long periods of time is also an unwanted effect of hybrid wind-solar plants.

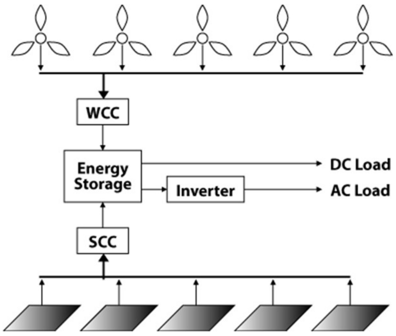

Fig. 2. Conventional Hybrid Wind-Solar Farm.

The simplified schematic of a conventional hybrid wind-solar farm is shown in Fig.2.When the wind blows, the turbines generate DC current that is fed directly to the wind charge controller (WCC) and when the Sun is shining, the solar panels also generate DC current that is fed to the solar charge controller (SCC). Both of the charge controller's charges the system's battery. The battery's DC output is then fed to an inverter which converts it to an AC power signal. The AC signal is then fed to a transformer and stepped up according to specifications of the host grid. It is concluded that the conventional type hybrid plant uses dedicated solar panels and wind turbines to generate hybrid renewable energy.

A hybrid wind-solar generator on the other hand is defined as renewable energy device capable of generating electricity from wind power and solar irradiation in one embodiment. These devices are a combinatioin of either a Horizontal Axis Wind Turbine (HAWT) or a Vertical Axis Wind Turbine (VAWT) system coupled with Photovoltaic Cells. Hybrid wind-solar genrators have a combined capacity of its wind generating components and solar generating components and are placed stratigically at areas of high wind density and high solar insolution. Although not yet reported, these new hybrid RE generators are promosing devices when it comes to implementing high capacity hybrid wind-solar farms that use up a small area. Such a device was first introduced commercially in 2008 by a company called Windstream Technologies situated in India.

Fig. 3. SolarMill,SM1-1P [23].

As shown in Fig.3, the SM1-1P has a PV panel placed on top of a 3×1 array VAWT. It is noted that the PV panels are stationary. It generates at full capacity 740W where 500W comes from the VWAT system and the remaining 240W from its PV cells [23].

Fig. 4. TOYODA, TYD-WS4 [24].

Fig.4 shows another hybrid wind-solar generator from Tangsyan Toyoda Technology, China. Again, this device generates wind power using a VWAT system (300W). A 240W solar panel is mounted at the bottom of the wind turbine giving it a total capacity of 540W. It also houses a 100W street light [24].

Fig. 5. SkyWolf [25].

Another hybrid wind-solar generator known as the SkyWolf is shown in Fig.5. This system's capacity is 3.5kW. It uses a Diffused Augmented Wind Turbine (DAWT) system where the turbine is enclosed in several solar panels arranged in a conic configuration to maximize rotation speed via the wind tunnelling effect. The turbine's angle can be rotated by computer control to maximize for optimum wind and solar generation [25].

It is concluded that these commercially available hybrid wind-solar generators have fixed solar panels. Through the course of a day, the temperature of these panels will rise causing its efficiency to drop. Moreover its capacity or footprint is too small, thus, a large area is required to arrange a large number of these devices to generate energy at a massive scale.

In this paper, we propose that rotating solar panels that move along with a wind turbines blade is to be used for the next generation of hybrid wind-solar generators. This will allow a much more compact device with high capacity. Moreover, the temperature of the PV panels are lower since the panels can rotate with the turbine's blade. In order to allow the solar panels to move in a circular motion with the blades.

4 Proposed True Hybrid Wind-Solar Electric Generator

The proposed True Hybrid Wind-Solar (THWS) Electric Generator is presented in Fig.6. Labels A, B and C are three different modules of the system are are called the Solar Blade Module (SBM), Moving Contact Module (MCM) and the Hybrid Output Module (HOM), respectively. This particular design is targetted for a total output capacity of 3.5kW.

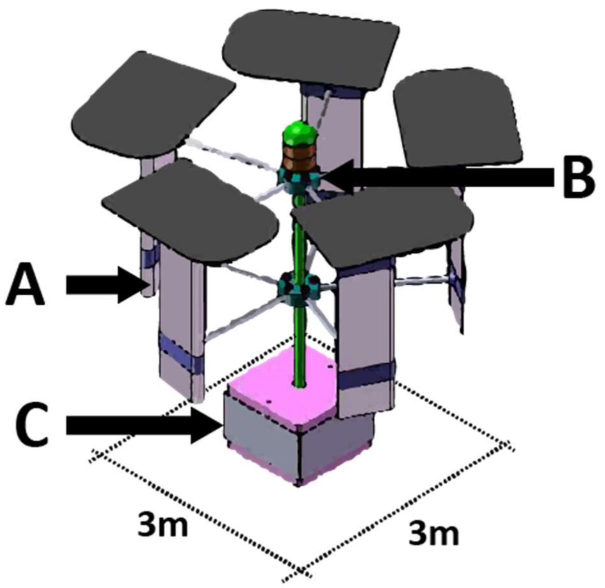

Fig. 6. True Hybrid Wind-Solar Electric Generator.

Each SBM is a modified Darrieus type blade where a 100W PV panel is attached to a plate fitted perpendicular to the Darries type blade. Since there are five SBMs, the expected capacity is 500W. The size of the blade and dimensions of the THWS generator is determined by the dimension of the PV cells used. In general, a 1m × 0.5m PV has a capacity of 100W, thus the THWS generator's footprint will 3m × 3m.

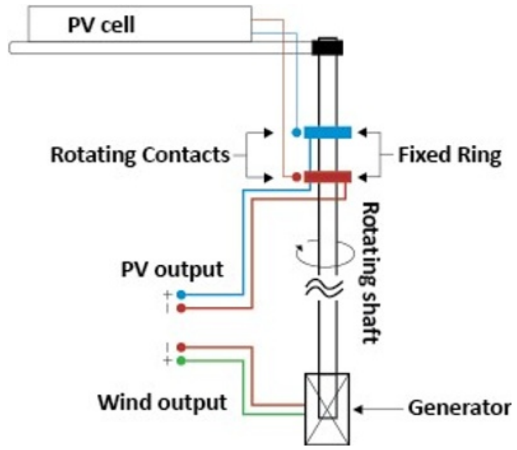

Fig. 7. True Hybrid Wind-Solar Modules Schematic.

Since all of the SBMs rotate, the problem of extracting the power signal produced by the PV cells is anticipated and the MCM is designed to tackel this problem. Fig. 7 shows the simplified circuit schematic of the TWHS generator. The MCM comprises of two fixed rings. The top fixed ring maintains connection from the PV cell's positive terminal to the PV cell output port of the THWS generator while the bottom ring does the similar for the negative terminal. The contacts of each respective PV output terminal orbits it's respective fixed ring as the SBM rotates in the wind. Electricity is tapped as the PV output terminal directly from the fixed ring with a voltage of 24V.

On the other hand, the HOM serves two purposes. The first is to generate electrical energy from the wind via the Generator shown in Fig.7. It is important to use a DC output generator for ease of combining solar and wind energy as the end product. A 3kW capacity output is expected from a VAWT with a footprint of 3m × 3m footprint of this design.

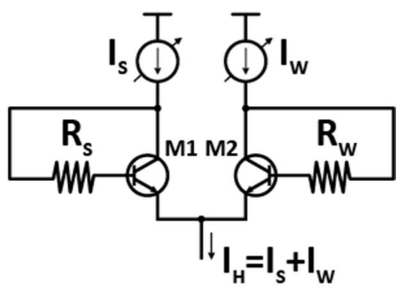

Fig. 8. Hybrid Power Selection Module.

The HOM's second purpose is to electrically isolate non-generating RE generators within the THWS generator. For example, on a windy night, the PV cells are dormant, thus the HOM will electrically isolate all of the SBM from the system. This also acts to prevent loading from the PV cell's juntion capacitance onto the system. Fig.8 shows the circuit contained in the HOM responsible for this task. Two power transistors, M1 and M2 capable of carrying 5A currents are used. I_S and I_W denotes the solar and wind currents, respectively. A base resistance, R_S and R_B are connected to M1 and M2 in order to induce a voltage drop when I_S and/or I_W are/is present. The generated voltage accross these resistances will turn on each respective transistor. When no voltage is induced, the transistor will turn off. In the case that the PV cells are not producing electricity, M1 turns off and $I_H=I_W$. When no wind is present, M2 turns off and $I_H=I_S$. However, when both PV cells and wind generator are producing current, both transistors are turned on, thus $I_H=I_S + I_W$.

5 Estimation of the THWS Electric Generator Power Production Footprint

The Power Production Footprint (PPF) is defined for the first time in this work as the area required by a plant to produce 1MW of electricity. PPF can be used to measure the land usage efficiency for RE plants for monitoring socio-economic effects or simply as data for the planning of a large scale RE plants. In this paper, it is used to compare between the efficiency of land usage for a plant composed of THWS Generators and a plant composed of PV cell arrays or wind turbine generators.

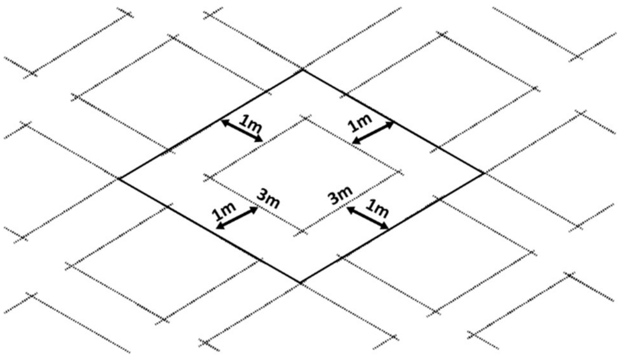

Fig. 9. THWS Generator Layout for Large Scale Power Plant.

Fig.9 is a depiction of the layout of several THWS generators arranged in a rectangular grid for the implementation of a large scale power plant. The raw footprint of one THWS is marked as 3m ×3m. To allow for safety and as a path for service and maintenance, it is suggested that the distance between two raw footprints is to be 1m. This results in a footprint of 3.5m^2 between two adjacent THWS generator units.

Since the capacity of one THWS generator is designed to be 3.5kW, 290 units are required to produce 1MW. With a footprint of 3.5m^2, the total area required using the arrangement in Fig.9 is 3552.5m^2 or equivalent to 0.88 acres of land. If a 20% more allowance is considered for other plant facilities such as transformers and inverters, the PPF of the THWS is approximately 1.06 acres/MW.

6 Conclusion

Analysis on area usage between large scale hybrid wind-solar power plants and their counterparts, either large scale pure solar or wind plants shows that the hybrid RE plants have a much smaller PPF, making them much more area efficient. For example, the hybrid facility in Australia has a PPF of only 0.16 acres/MW [17]. However, these RE power plants use the traditional hybrid wind-solar topology where dedicated PV cell arrays and wind turbines are used separately to produce hybrid renewable energy. Nontheless, it is noted that hybrid type farms are more area efficient and in the long term will lower the negative socio-economic impact such as shortage of land for agriculture and housing.

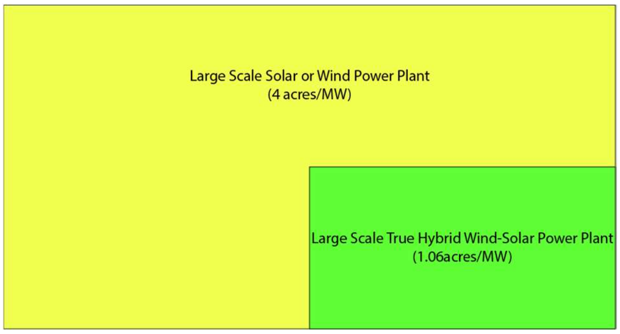

Fig. 10. THWS Generator Power Plant Land Size Comparison.

The recent emergence of hybrid wind-solar RE generators into the market have opened the opportunity for the development of large scale true hybrid wind-solar plants. However, either the generation capacity is too low or the PPF is too high in the existing models. Thus, the THWS electric generator is proposed in this paper. It is designed with a moving contact module that in the not so distant future will allow the blades of a wind turbine generator to be fabricated from PV material. In this work, placement of the PV cells in the porposed configuration not only allows a small PPF but also introduces a cooling effect to the PV panels which in turn boost the efficiency of the cells. The hybrid output is tapped out of the THWS generator via a dedicated HOM circuit. The THWS electric generator is designed for a 24V output with solar capacity of 500W and a wind capacity of 3kW giving a total output capacity of 3.5kW with a footprint of 3.5m^2. Arrangement of the THWS generator units in a rectangular grid will allow a PPF of only 1.06 acre/MW. As depicted in Fig.10, the PPF of a large scale THWS plant is approximately a quarter of the PPF of a conventional large scale solar or wind farm.

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