A Maximum Power Extraction Technique for Wind and Hybrid Renewable Energy System: Review

Anand Kumar[1], Prof. Manju Gupta[2]
M. Tech. Scholar, Department of Electrical & Electronics Engineering, OIST, Bhopal
Associate Professor, Department of Electrical & Electronics Engineering, OIST, Bhopal

***Abstract*— Due to the fact that solar and wind power is intermittent and unpredictable in nature, higher penetration of their types in existing power system could cause and create high technical challenges especially to weak grids or stand-alone systems without proper and enough storage capacity. By integrating the two renewable resources into an optimum combination, the impact of the variable nature of solar and wind resources can be partially resolved and the overall system becomes more reliable and economical to run. This paper provides a review of challenges and opportunities / solutions of hybrid solar PV and wind energy integration systems. Voltage and frequency fluctuation, and harmonics are major power quality issues for both grid-connected and stand-alone systems with bigger impact in case of weak grid. This can be resolved to a large extent by having proper design, advanced fast response control facilities, and good optimization of the hybrid systems.**

Keywords: - Solar PV, Wind Energy, Renewable Energy, Maximum Power Extraction

I. INTRODUCTION

Recent research and development in Renewable energy sources have shown excellent potential, as a form of supplementary contribution to conventional power generation systems. Renewable energy sources such as photovoltaic and wind energy provide a realistic alternative to engine-driven generators for electricity generation in remote areas. Hybrid energy systems can significantly reduce the total lifecycle cost of standalone power supplies in many situations; also the combination of renewable energy sources provides much more reliable power supply at the same time [1]. The electric power generation system, consisting of renewable energy sources and fossil fuel generators together with an energy storage devices and power transformation unit is known as a hybrid power system [2]. Disadvantage of wind and solar photovoltaic energy system is that wind turbine output power varies with wind speed whereas solar power varies with the duration of the day and month of the year. Thus, a very accurate pre-feasibility study based on weather data (wind speed and solar insolation) and load requirement for specific site is necessary. Most promising applications of renewable energy technology is the installation of renewable hybrid energy systems which are not grid connected or where the extension of grid is costly and the cost of fuel increases drastically with the remoteness of the location. A battery bank (energy storage bank) is connected or integrated with the wind and solar photovoltaic-system to ensure that the system performs under all conditions [3].

With increasing load demand and global warming, many are looking at environment-friendly type of energy solutions to preserve the earth for the future generations. Other than hydro power, many such energy sources like wind and photovoltaic energy holds the most potential to meet our energy demands. While some others like fuel cells are in their advanced developmental stage. The world's fastest growing energy resources, a clean and effective modern technology that provides a hope for a future based on sustainable, pollution free technology. Today's photovoltaic and wind turbines are state-of-the-art of modern technology-modular and very quick to install. These generation systems have been attracted greatly all over the world. The integration of renewable energy sources and energy-storage systems has been one of the new trends in power-electronic technology. The increasing number of renewable energy sources requires new strategies for their operations in order to maintain or improve the power-supply stability, quality and reliability. There are some previous works on hybrid systems comprising of wind energy, photovoltaic and fuel cell have been discussed in [4]-[5]. A maximum power point tracking (MPPT) is discussed on wind and photovoltaic energies in [6]-[7]. Dynamic Modeling and Control of a Grid-Connected Hybrid Generation System was analyzed [8]. Dynamic performance of a stand-alone wind and solar system with battery storage was analyzed [9]. A few systems consider the battery as just a back-up means to use when there is insufficient supply from renewable sources [10]-[11]. This paper focused on system engineering, such as energy production, system stability and reliability. In this paper, an alternative multi-input of a wind turbine generator, photovoltaic (PV) array and fuel cell is proposed for hybrid wind/solar energy systems. This addresses modeling and control of a load-connected wind–PV–battery hybrid system. The wind and PV are used as main energy sources, while the back-up energy source can operate with and without use of battery to get constant power.

II. LITERATURE REVIEW

Hybrid solar PV and wind generation system become very attractive solution in particular for stand-alone applications. Combining the two sources of solar and wind can provide better reliability and their hybrid system becomes more economical to run since the weakness of one system can be complemented by the strength of the other one. The integration of hybrid solar and wind power systems into the grid can further help in improving the overall economy and reliability of renewable power generation to supply its load. Similarly, the integration of hybrid solar and wind power in a stand-alone system can reduce the size of energy storage needed to supply continuous power. Solar electricity generation systems use either photovoltaics or concentrated solar power. The focus in this paper will be on the photovoltaics type. Detailed descriptions of the different technologies, physics and basics of PV can be found in many textbooks and papers such as [4-7]. Kurtz [8] pointed out that ten years ago the concentrator cell was only ~30% efficient compared with more than 40% today with the potential to approach 50% in the coming years. Si cells have efficiencies of 26% and multi-junction III-V-compound cells have efficiencies above 45% (48% in the laboratory) as pointed out in reference [9]. PV modules produce outputs that are determined mainly by the level of incident radiation. As the light intensity increases, photocurrent will be increased and the open-circuit voltage will be reduced [10]. The efficiency of any photovoltaic cell decreases with the increasing temperature which is non-uniformly distributed across the cell [11]. The solar output power can be smoothed by the distribution of solar power in different geographical areas [12]. Electricity from solar PV and concentrated solar power plants is significantly expensive and requires significant drop in cost or change in policies by either subsidizing or forcing the use of these technologies to be able to achieve significant market penetration [13]. Global wind report (2012) indicated that the annual market grew by around 10% to reach around 45 GW and the cumulative market growth was almost 19% [14]. Detailed descriptions of the wind energy can be found in references [4] and [15]. Wind turbines (WTs) are classified into two types: horizontal-axis WT (HAWT) and vertical-axis WT (VAWT). The highest achievable extraction of power by a WT is 59% of the total theoretical wind power [15]. Hybrid solar-wind systems can be classified into two types: grid connected and stand-alone. Literature reviews for hybrid grid connected and stand-alone solar PV and wind energies were conducted worldwide by many researchers who have presented various challenges and proposed several possible solutions. Due to the nature of hybrid solar PV and wind energies, optimization techniques can play a good role in utilizing them efficiently. Graphic construction methods [16], linear programming [17-18], and probabilistic approach [19] are few examples of optimization techniques that have been developed for techno-economically optimum hybrid renewable energy system for both types. Luna-Rubio et al. [20] conducted a review of existing research of optimal sizing of renewable hybrids energy systems with energy storage components for both stand-alone and grid-connected systems. The authors gave brief descriptions about those indicators and the different sizing methods. A review of control strategies for a hybrid renewable energy system was carried out in [21] and another review was done in [22] for optimization of hybrid renewable energy system with more focus on wind and solar PV systems. The reviews in [21] and [22] are applicable for both types; grid-connected and stand-alone systems.

Grid-connected system

The integration of combined solar and wind power systems into the grid can help in reducing the overall cost and improving reliability of renewable power generation to supply its load. The grid takes excess renewable power from renewable energy site and supplies power to the site' loads when required. Fig. 1 and Fig. 2 show the common DC and common AC bus grid-connected to solar PV and wind hybrid system, respectively

Power electronics topologies and control

There are two topologies for grid-connected solar PV and wind hybrid system as can be seen from Figure 1 and Figure 2. Figure 1 shows that the DC outputs' voltages from individual solar PV, wind and battery bank stream, through individual DC/DC and AC/DC units, are integrated on the DC side and go through one common DC/AC inverter which acts as an interface between the power sources and the grid to provide the desired power even with only one source available. Hence, the renewable energy sources act as current sources and can exchange power with the grid and the common DC/AC inverter controls the DC bus voltage. The individual units can be employed for maximum power point tracking (MPPT) systems to have the maximum power from the solar PV and wind systems and the common DC/AC inverter will control the DC bus voltage.

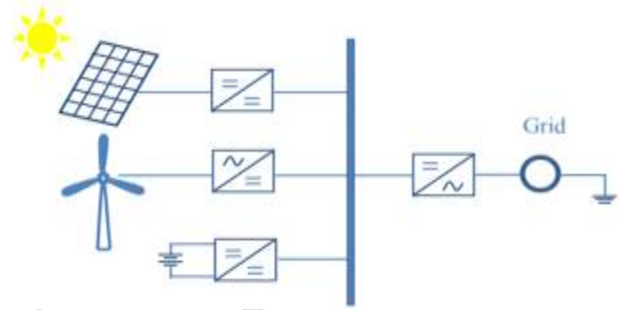

Figure 1: Grid-connected hybrid system at common DC bus

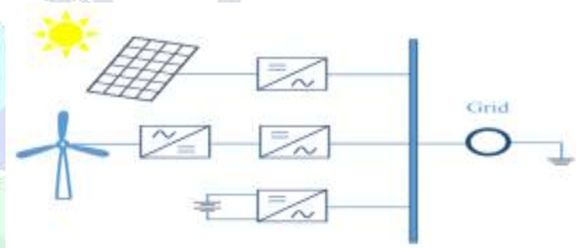

Figure 2: Grid-connected hybrid system at common AC bus

The battery bank is charged when there is an extra power and discharged (by supplying power) when there is shortage of power from the renewable energy sources. On the other hand, Figure 2 shows that renewable energy sources are injecting power directly to the grid through individual DC/AC and AC/DC-DC/AC units.

Power quality

The increased penetration of grid-connected renewable energy sources has an impact on the grid power quality in particular weak grids. Voltage fluctuation, frequency fluctuation and harmonics are major power quality issues. Furthermore, intermittent energy from solar PV and wind has a huge impact on network reliability. However, accurate forecasting and scheduling systems can minimize the impacts. Various statistical forecasting and regression analysis approaches and algorithms are used to forecast weather pattern, solar radiation and wind speed [12-13]. System operator can adjust other dispatch able generation elsewhere in a system to deal with any deficit or surplus power from renewable power generation [14]. This will reduce the impact of the fluctuations from the generation of the renewable energy sources. In addition, the distribution of RES to larger geographical area in small units instead of large unit concentrating in one area can control the intermittence effect of power generation from RES [15]. Energy storage devices like batteries or Uninterruptable Power Supply (UPS) can work as a balancing devises that provide power when there is an energy deficiency in renewable generation and store excess energy when there is surplus power from renewable generation [16-17]. Variations in solar radiation and wind speed with time can cause voltage fluctuation. The characteristics of voltage fluctuation depend mostly on the load type and size in addition to the strength of the connected electrical grid and its size. Active power filters such as dynamic voltage regulators, static synchronous compensators and unified power quality conditioners can be used to resolve voltage fluctuation [18], [19]. Similarly, power compensators such as fixed or switched capacitor can be used to resolve reactive power issue [20]. They are the latest interfacing devices between grids and consumer appliances. Sudden changes in active power drawn by a load could cause system frequency fluctuation in AC grids. These changes represent unbalance situations between load and generation. In view of the above, it is important to design control loops for power and frequency control to mitigate quality issues [21]. Bae and Kwasinski highlighted that a primary goal of a pulse width modulation (PWM) inverter controller was to regulate three-phase local AC bus voltage and frequency in a microgrid. Harmonics are normally caused by power electronics devices and non-linear appliances. Appropriate filters and PWM switching converter can be used to mitigate harmonic's distortion.

Stand-alone (autonomous) system

The stand-alone or autonomous power system is an excellent solution for remote areas where utilities facilities, in particular transmission lines, are not economical to run or difficult to install due to their high cost and/or difficulties of terrain, etc. The stand-alone systems can be sub-classified into common DC bus or common AC bus. Variable nature of solar and wind resources can be partially overcome by integration of the two resources into an optimum combination and hence the system becomes more reliable. The strength of one source could overcome the weakness of the other during a certain period of time [22]. For stand-alone applications, storage cost still represents the major economic issue. Combining both PV solar and wind powers can minimize the storage requirements and ultimately the overall cost of the system [23]. Increasing PV panels and capacity of wind turbines could be a better choice compared to the increasing of batteries since batteries are much more expensive with a shorter lifespan compared to the life time of a PV or WT. However, for high reliability systems, too few batteries can't meet the reliability requirements, which will incur more cost since too many PV modules or too large WTs will be required [24]. For a small islanded electricity system in New Zealand, with winter peaking demand, I. G. Mason found that the average storage ratio for solar PV to wind was 1.768:1 in comparison to 0.613:1 (residential) and 0.455:1 (farm dairy) with summer peaking demand. Huang et al. highlighted that when a single 400w wind turbine of a hybrid solar PV-wind power system was replaced by 8 smaller wind turbines with a capacity of 50w each at three different locations in China, the power output of the overall system increased by 18.69% (at Shenyang), 31.24% (at Shanghai) and 53.79% at Guangzhou) due to the fact that small wind turbines can capture wind at a lower speed in comparison to larger ones. Integration of renewable energy generation with battery storage and diesel generator back-up systems is becoming cost-effective solution for resolving less usable renewable energy during the year. [25]. However, if storage runs out, there is no way of importing energy. Therefore, integrating PV and wind energy sources with fuel cells is a promising alternative back up energy source for hybrid generation systems. Distributed generators can help fluctuations in power supply since generations' units will be close to the loads. However, introducing distributed generators will require an up gradation in the existing protection schemes [26].

Optimization

As mentioned earlier, a combination of solar PV and wind sources improves overall energy output. However, energy storage system is required to have a continuous power supply and cover any deficiency in power generation from the renewable energy sources. The storage system can be battery banks, fuel cells, etc. with a more focus here on battery banks. Various optimization techniques have been reported which could be applied to reach a techno-economically optimum hybrid renewable energy system [16-19]. A comparison was made for many optimization techniques of hybrid systems in [18]. For remote areas which represent most of the standalone application for hybrid solar PV and wind systems, it is not always easy to find long-term weather data, such as solar radiation and wind speed that are used for sizing purposes. Hence, more artificial intelligence techniques such as fuzzy logic, genetic algorithms and artificial neural network are used for sizing standalone systems in comparison with traditional sizing method based on long-term weather data.

Wind Energy Systems

Wind energy has the biggest share in the renewable energy sector [1], [3]. Over the past 20 years, grid connected wind capacity has more than doubled and the cost of power generated from wind energy based systems has reduced to one-sixth of the corresponding value in the early 1980s [3]. The important features associated with a wind energy conversion system are:

- Available wind energy
- Type of wind turbine employed
- Type of electric generator and power electronic circuitry employed for interfacing with the grid.

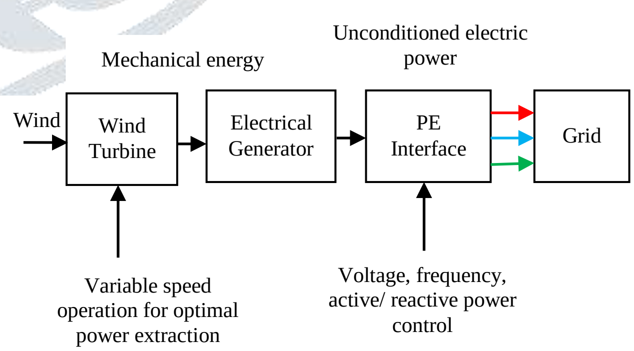

Figure 3: Variable speed wind energy conversion system

Wind energy – Wind speeds, air pressure, atmospheric temperature, earth surface temperature etc., are highly inter-linked parameters. Due to the inherent complexity, it is unrealistic to expect an exact physics based prediction methodology for wind intensity/sustainability. However, distribution based models have been proposed, and employed to predict the sustainability of wind energy conversion systems [4]. Detailed explanation of the wind energy resources is beyond the scope of this paper. Based on studies it has been reported that the variation of the mean output power from a 20 year period to the next has a standard deviation of less than 0.1 [4]. It can be concluded with reasonable confidence that wind energy is a dependable source of clean energy. Based on the aerodynamic principle utilized, wind turbines are classified into drag based and lift based turbines. Based on the mechanical structure, they are classified into horizontal axis and vertical axis wind turbines. With respect to the rotation of the rotor, wind turbines are classified into fixed speed and variable speed turbines. Presently the focus is on horizontal axis, lift based variable speed wind turbines [2], [3]. Power electronic circuits play a crucial enabling role in variable speed based wind energy conversion systems. Fixed speed wind turbines are simple to operate, reliable and robust. However the speed of the rotor is fixed by the grid frequency. As result, they cannot follow the optimal aerodynamic efficiency point. In case of varying wind speeds, fixed speed wind turbines cannot trace the optimal power extraction point. In variable speed wind turbines, power electronic circuitry partially or completely decouples the rotor mechanical frequency from the grid electrical frequency, enabling the variable speed operation. The type of electric generator employed and the grid conditions dictate the requirements of the power electronic (PE) interface. Figure 4 depicts a variable speed wind energy conversion system. The electrical generator popularly e m p l o y e d for partially variable speed wind energy conversion systems are doubly- fed- induction generators [5]. It depicts a doubly- fed induction- generator where the rotor circuit is controlled by the power converter system via the slip rings and the stator circuit is connected to the grid. This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system [5]. The power converter system employs a rotor side ac- dc converter, a dc link capacitor, and a dc- ac inverter connected to the grid as shown in Figure 4.

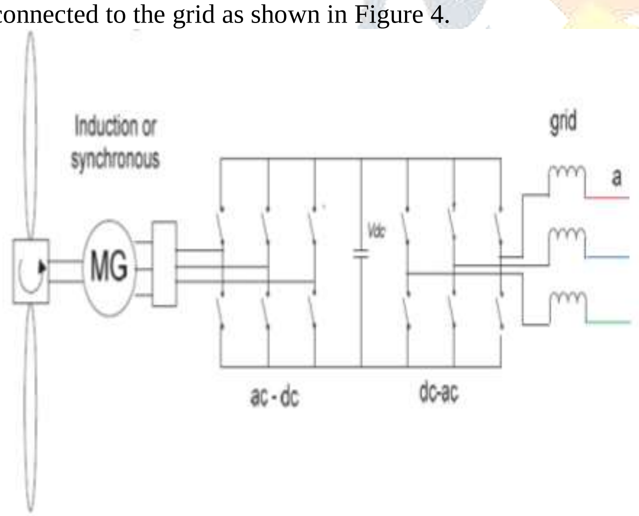

Figure 4: Fully variable wind energy conversion system

III. CONCLUSION

This paper has provided a review of challenges and opportunities on integrating solar PV and wind energy sources for electricity generation. The main challenge for grid-connected system as well as the stand-alone system is the intermittent nature of solar PV and wind sources. By integrating the two resources into an optimum combination, the impact of the variable nature of solar and wind resources can be partially resolved and the overall system becomes more reliable and economical to run. This definitely has bigger impact on the stand-alone generation. Integration of renewable energy generation with battery storage and diesel generator back-up systems is becoming a cost-effective solution for stand-alone type. The wind-battery-diesel hybrid configuration can meet the system load including peak times. Energy management strategies should ensure high system efficiency along with high reliability and least cost. Good planning with accurate forecasting of weather pattern, solar radiation and wind speed can help in reducing the impact of intermittent energy.

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