Hybrid Solar PV and Wind Energy System

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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. Voltage and frequency fluctuation and harmonics are major power quality issues for both grid-connected and stand-alone systems with the bigger impact in case of a weak grid.. The paper presents a review of the state of the art of both grid-connected and stand-alone hybrid solar and wind systems.

I. Introduction

The global penetration of renewable energy in power systems is increasing rapidly especially for solar photovoltaic (PV) and wind systems. The renewable energy counted for around 19% of the final energy consumption worldwide in 2012 and continued to rise during the year 2013 as per 2014 renewables global status report [1]. The report highlighted that for the first time the PV installation capacity was more than the wind power capacity worldwide. Table 1 below summarizes some important selected indicators from that report and the previous year report which shows the global rapid increase of renewable energy. Although Europe has dominated the PV market worldwide, the rest of the world starts picking-up with the lead from China and India [2-3].

		2010	2011	2012	2013
Renewable power installed capacity (with hydro)	GW	1250	1355	1470	1560
Renewable power installed capacity (without hydro)	GW	315	395	480	560
Solar PV installed capacity	GW	40	71	100	139
Wind power installed capacity	GW	198	238	283	318
Concentrating solar thermal power installed capacity	GW	1.1	1.6	2.5	3.4

Solar and wind power is naturally intermittent and can create technical challenges to the grid power supply especially when the amount of solar and wind power integration increases or the grid is not strong enough to handle rapid changes in generation levels. In addition, if solar or wind are used to supply power to a stand-alone system, energy storage system becomes essential to guarantee the continuous supply of power. The size of the energy storage depends on the intermittency level of the solar or wind. This paper provides a review of challenges and opportunities for a hybrid system of solar PV and wind. The paper reviews the main research works related to optimal sizing design, power electronics topologies, and control for both grid-connected, stand-alone hybrid solar and wind systems.

II. Hybrid solar PV-wind systems

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 a 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, linear programming, and probabilistic approach 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. 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 of those indicators and the different sizing methods. A review of control strategies for a hybrid renewable energy system was carried out in and another review was done in for optimization of the hybrid renewable energy system with more focus on wind and solar PV systems. The reviews are applicable for both types; grid-connected and stand-alone systems.

A. Grid-connected system

The integration of combined solar and wind power systems into the grid can help in reducing the overall cost and improving the 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.

1. Optimization

A solar PV and wind systems can't provide a continuous supply due to the fact that those systems will generate electricity only during sunny and windy days. Hence, a combination of these two sources improves overall energy output especially if they are connected to the grid. A proper optimization is required to ensure having optimal number and size of PV and WT. The traditional sizing method for hybrid solar PV and wind systems was based on the availability of long-term weather data, such as solar radiation and wind speed. Since long-term weather data is not always available, artificial intelligence techniques such as fuzzy logic, genetic algorithms and artificial neural network are used. Furthermore, optimization performance indicators such as Net Present Value, Energy Index Reliability and Energy Expected Not Supplied,Cost of Energy, etc. have been used and reported. Those indicators are used to decide whether to proceed with a particular project or not and how reliable is a project will be.

With the aim of maximizing the Net Present Value of a hybrid PV-wind systems connected to electrical grid, Dufo-López et al. concluded that only with high wind speed rate and current prices of components, intermittent hydrogen could be economically viable for external selling if the selling price is at a minimum of 10 €/kg. Tina and Gagliano presented and analyzed a probabilistic model of a PV/WT system using a fixed tilt angle, a one-axis, and a two-axis tracking system. They found out that the two-axis tracking system has a better performance in terms of monthly power generation in comparison with single-axis tracker which reached a maximum of 7% in particular at summer. Another probabilistic method was proposed by Niknam et al. It was for energy and operation management of micro-grids that cover uncertainties in load demand, market price and available output powers from WT and PV units. Essalaimeh et al. conducted a feasibility study using payback period for hybrid PV-wind system to utilize its energy for heating and cooling purposes for Amman city in Jordan. They pointed out that clean PV panels could produce extra power, with 31% to 35% of the maximum solar intensity, compared to panels with dust. Ahmed et al. [30] simulated and controlled a hybrid PV-wind generation system connected to a grid. They highlighted that as a result of constant rotational speed, the DC voltage at high wind speed is almost constant. Kolhe et al. described a hybrid PV, wind, and battery storage energy system that can be interfaced with different remote monitoring and control components. An energy dispatching of a wind/PV/hydrogen/battery hybrid power system in Algeciras (Spain) was presented and carried out through a predictive controller.

2. Power electronics topologies and control

There are two topologies for grid-connected solar PV and wind hybrid system as can be seen from Fig. 1 and Fig. 2. Fig. 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. The battery bank is charged when there is an extra power and discharged (by supplying power) when there is a shortage of power from the renewable energy sources. On the other hand, Fig. 2 shows that renewable energy sources are injecting power directly to the grid through individual DC/AC and AC/DC-DC/AC units.

Many types of research have proposed and presented experimental results of PV-wind-battery hybrid systems along with power management schemes and control systems. Their proposed systems were capable to operate in different modes of operation and able to transfer from one mode to another easily. Ahmed et al. presented a utility hybrid PV/wind/fuel cell power system with MPPT. With the DC bus line output voltage from each converter is set to be fixed and controlled independently in that system, the controller of wind and PV has MPPT functionality whereas the controller of the fuel cell (FC) takes care of compensations of the system for the load power fluctuation. The voltage converters play an important role in controlling the amount and the type of voltage whether AC or DC and the duty cycle of those converters can be used to improve the quality of power. Huang et al. highlighted that the response of the duty cycle of a DC/DC converter is relatively fast in MPPT control process. They added that the charging current of a battery is changing with the automatic adjustment of the duty cycle. Liu et al. proposed a hybrid AC-DC microgrid in order to reduce multiple DC/AC/DC or AC/DC/AC conversions in an individual AC or DC grid. The authors concluded that although the hybrid grid could reduce the processes of DC/AC and AC/DC conversions in an individual grid, there were many practical problems for applying the hybrid grid based on current AC dominated infrastructure. A controller was designed by Hossain et al. to ensure both dynamic voltage and transient stability for a specific PV integration level that can lead to a higher potential penetration of PV units without requiring network reinforcements or violating system operating constraints. A fuzzy control was used for grid-connected hybrid PV/FC/battery power system in to control the flow of power via DC/DC and DC/AC converters.
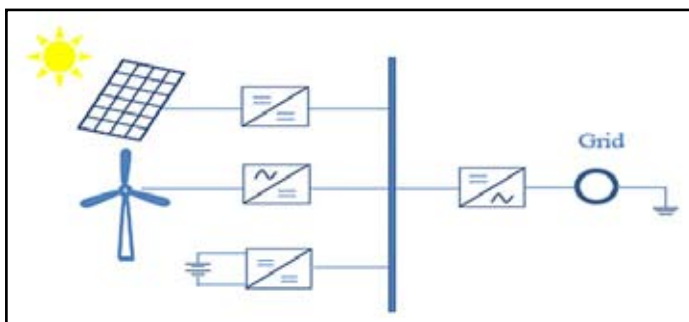
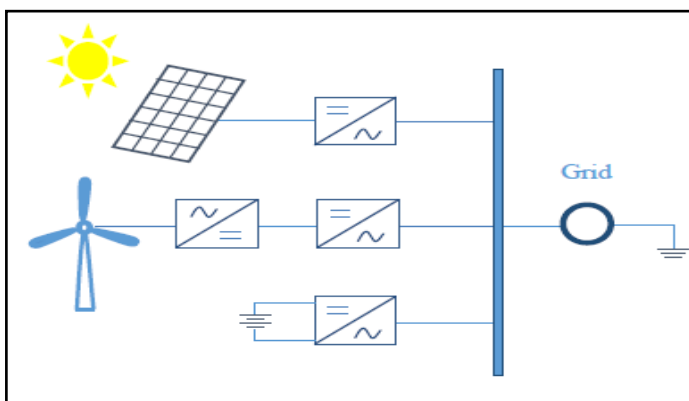Fig. 1: Grid-connected hybrid system at common DC bus

Fig. 2 Grid-connected hybrid system at common AC bus

3. 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. A system operator can adjust other dispatchable generation elsewhere in a system to deal with any deficit or surplus power from renewable power generation. This will reduce the impact of the fluctuations from the generation of the renewable energy sources. In addition, the distribution of RES to a larger geographical area in small units instead of large unit concentrating in one area can control the intermittency effect of power generation from RES. 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.

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. Similarly, power compensators such as fixed or switched capacitor can be used to resolve reactive power issue. 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.

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 micro grid. 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.

B. Stand-alone (autonomous) system

The stand-alone or autonomous power system is an excellent solution for remote areas where utility 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. 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. 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 lifetime 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. 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 the cost-effective solution for resolving less usable renewable energy during the year. 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.

1. 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. A comparison was made for many optimization techniques of hybrid systems. For remote areas which represent most of the

stand-alone 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 stand-alone systems in comparison with traditional sizing method based on long-term weather data.

Habib et al. achieved minimum capital cost with an optimal solar/wind ratio of 70% in terms of the size of a hybrid PV-wind energy system for a constant load in Dhahran area, Saudi Arabia. For a Loss of Power Supply Probability (LPSP) of 0, Diaf et al. found that in order to obtain a total renewable contribution of an autonomous hybrid PV/wind system, more than 30% of the energy production was unused unless the battery capacity was very large. Koutroulis et al. proposed a methodology for optimal sizing of stand-alone PV and wind generator systems to minimize the 20-year total system cost. This was including the number of battery chargers, PV modules, tilt angle and wind generator installation height that highly affect the resulting energy production and the installation and maintenance costs. Ekren and Ekren optimized the size of a PV/wind hybrid energy conversion system with battery storage using OptQuest tool in ARENA 12.0 software based on an hourly operating cost.

Many types of research such as have presented experimental results of PV-wind-battery hybrid systems. They proposed optimized models with the aim to reduce the life-cycle cost and increase the reliability of the proposed system. Various significant hybrid RES aspects and techniques such as unit sizing and optimization, modelling of system components and optimal energy flow management strategies were reviewed by Bajpai and Dash. Kaabeche et al. recommended an integrated PV/wind hybrid system optimization model that utilizes iterative optimization technique following deficiency of power supply probability, relative excess power generated, total net present cost (TNPC), total annualized cost (TAC) and break-even distance analysis (BEDA) for power reliability and system costs. They found that the configuration with the lowest TNPC, TAC and BEDA gave the optimal one. The lowest Levelized Cost of Energy for stand-alone hybrid PV/wind power generating systems which meet the desired LPSP depends largely on the renewable energy potential qualityAn energy management strategy for a hybrid solar PV and wind system was presented. It gave a reduction up to 88% in LPSP as a result of using prediction of the future generation.

Rajkumar et al used an adaptive neuro-fuzzy inference system to model and optimize the sizing of a hybrid stand-alone power system. The optimized configuration was produced with the lowest cost and excess energy for the desired LPSP. Kaldellis et al. developed a methodology for stand-alone PV-battery configuration with minimum life-cycle energy requirements. They highlighted that in all cases examined, the contribution of the battery component exceeded 27% of the system life-cycle energy requirements. Hiendro et al. carried out a techno-economic feasibility study of a PV/wind hybrid system using Hybrid Optimization Model for Electric Renewable (HOMER) software and highlighted that WT and battery were essentially required to meet demand loads at night hours although they represent the highest cost to the system. Notton et al. found that for windy sites, more than 40% of the total production is provided by the WT, whereas the WT contribution represents only 20% of total production energy for non-windy regions. Further sizing, optimization, and review of hybrid PV-wind system can be found in references.

2. Power electronics topologies and control

There are two main topologies for stand-alone solar PV and wind hybrid system as mentioned before; DC-common bus and AC-Common bus. Fig. 3 below shows a stand-alone solar PV and wind hybrid system with DC common bus. One of its main advantages is to include DC interface bus for coupling different generation sources, which do not have to operate at a constant frequency and in synchronism. The DC bus line output voltage from all streams is set to be fixed and the output current from each source is controlled independently. 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, combined in parallel and go through one common DC/AC inverter which acts as an interface between the power sources and the loads to provide the required power to the load by regulating the AC output voltage. The battery bank is interfaced by a DC/DC converter which regulates the DC-link bus voltage by charging (in case of extra power) or discharging the battery (in case of shortage of power). The renewable energy sources act as current sources and supply directly the loads. The interface common unit regulates the magnitude of the load's voltage. The individual AC/DC and DC/DC units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems and the common DC/AC inverter will control the magnitude of the load's voltage. The battery bank acts as a voltage source to control the common DC bus voltage by charging or discharging.

In a conventional way for controlling the complete hybrid system, power electronics converters are used for maximum energy extract from solar and wind energy resources. In addition, advanced controlling techniques can remove the power fluctuations caused by the variability of the renewable energy sources. Fig. 4 below shows stand-alone solar PV and wind hybrid system with AC common bus. The form of pure AC bus bar system is widely used worldwide with a lot of advantages, such as simple operation, plug, and play scenario, low cost and easy extension according to the load's requirement. On the other hand, controlling AC voltage and frequency and energy management are some of the challenges for this type of topology. In this topology, the AC outputs' voltages from individual solar PV, wind, and battery bank stream, through individual DC/AC and AC/DC-DC/AC units, are feeding the loads directly. The renewable energy sources can act as current sources provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. Hence, the individual units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. The battery bank is charged when there is an extra power and discharged and can supply power in case of shortage of power from the renewable energy sources.

Droop control is normally applied to generators for frequency control and sometimes voltage control in order to have load sharing of parallel generators. It can also be used to perform proper current sharing in a microgrid. With droop control, decentralized control for each interfacing converter is achieved. At the same time, no communication or only low bandwidth communication, such as power line communication, can be used in AC systems. A line interactive UPS and its control system were presented by Abusara et al. Power flow was controlled using frequency and voltage dropping technique in order to ensure seamless transfer between grid-connected and stand-alone parallel modes

of operation. A supervisory control strategy was designed in for a DC distributed solar micro grid to have MPPT and decide on power flow direction.
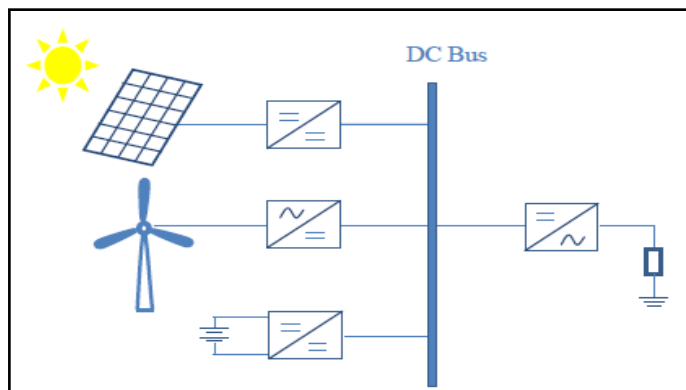

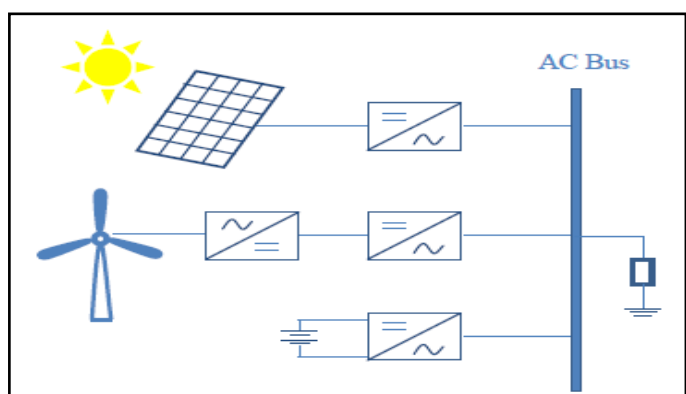Fig. 3 : Stand-alone hybrid system at common DC bus

Fig. 4 : Stand-alone hybrid system at common AC bus

3. Power quality

Intermittent energy from solar and wind has a huge impact on loads security since those loads have no connection with the grid. So, any shortfall in power generation from those sources may leave the connected loads without power supply. Voltage fluctuation, frequency fluctuation, and harmonics are major power quality issues. The voltage fluctuation as a result of irradiation changes could make the PV system unstable which will have an impact on the overall reliability of the hybrid stand-alone solar PV and wind system. The same thing is applicable with respects to variations in wind speed which affects the performance of the wind system and ultimately the overall hybrid system. Accurate forecasting and scheduling systems can minimize the impacts. The frequency stability of a generator should be taken into account based on load requirements and whether the generator is connected to AC loads with critical power frequency requirements or not. High-frequency fluctuations can be suppressed by using storage devices such as electrolytic double layer capacitor. An experimental investigation was carried out in to assess the wind impacts on PV module. The mean pressure magnitude on the PV module was measured for both cases; under smooth wind exposure and open terrain wind exposure where the magnitude was smaller in the latter case.

C. AC Microgrid

Fig. 5 below shows a hybrid solar PV and wind system along with battery bank which is connected to an AC Microgrid. The system can work in grid-connected mode or stand-alone mode. The DC outputs' voltages from individual solar PV and wind stream, through individual DC/AC and AC/DC-DC/AC units,

are integrated and combined in parallel on the AC side to provide the power to the grid/loads even with only one source available. Hence, in the grid-connected mode of operation, the renewable energy sources act as current sources and inject power directly into the AC bus. The battery system interfaced by a bi-directional converter and can be charged or discharged depending on the situation of the generation, load and its state of charge. However, in the stand-alone mode, the renewable energy sources act as current sources feeding directly the loads and the battery bank acts as a voltage source controlling the AC bus voltage by charging or discharging. The battery converter regulates the magnitude and frequency of the load voltage. The individual RES units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems in the grid-connected mode. The same thing can be applied in the stand-alone mode provided that the battery bank exists as a voltage source to control the AC bus voltage by charging or discharging.
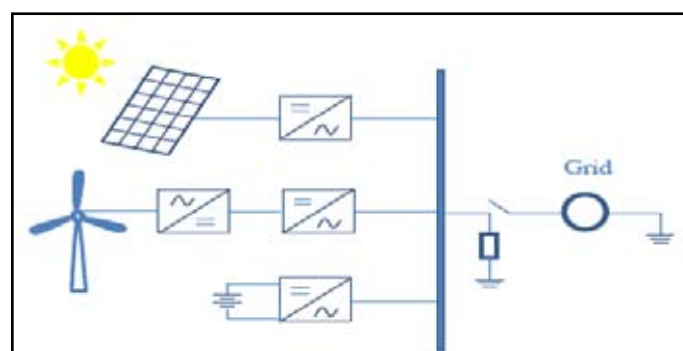

Fig. 5 : Hybrid system with AC Microgrid

III. Summary and findings

Table 2 summarizes main challenges for grid-connected hybrid solar PV and wind systems with possible solutions or mitigations. Similarly, main challenges and solutions/mitigations for stand-alone systems are summarized in Table 3.

IV. 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 a 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 the 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 the 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.

Voltage and frequency fluctuation and harmonics are major power quality issues for both grid-connected and stand-alone systems with a bigger impact in case of a 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. The paper gave an overview of different research works related to

optimal sizing design, power electronics topologies, and control for grid-connected and stand-alone hybrid solar PV and wind systems. Solar PV and wind hybrid system can be connected to a common DC or common AC bus whether they are working in a grid-connected mode or a stand-alone mode.

Table 2 : Main challenges and possible solutions for grid-connected system

No.	Challenges	Solutions
1	Voltage fluctuation due to variations in wind speed and irregular solar radiation	Series and shunt active power filters. Power compensators such as fixed/switched capacitor or static compensator. Less sensitive customer's equipment to power disturbance/ voltage distortions and utilities line conditioning systems
2	Frequency fluctuation for sudden changes in active power by loads	PWM inverter controller for regulating three-phase local AC bus voltage and frequency in amicrogrid.
3	Harmonics by power electronics devices and non-linear appliances.	PWM switching converter and appropriate filters.
4	Intermittent energy's impacts on networksecurity	Accurate statistical forecasting and scheduling systems. Regression analysis approaches and algorithms for forecasting weather pattern, solar radiation and wind speed. Increase or decrease dispatch able generation by the system operator to deal with any deficit/surplus in renewable power generation. Advanced fast response control facilities such as Automatic Generation Control and Flexible AC Transmission System.
5	Synchronization	The most popular grid synchronization technique is based on phase-locked loop. Other techniques for synchronization include detecting the zero crossing of the grid voltages or using combinations of filters coupled with a non-linear transformation.

Table 3 : Main challenges and possible solutions for stand-alone system

No.	Challenges	Solutions
1	High storage cost	Combining both PV solar and wind powers will minimize the storage requirements and ultimately the overall cost of the system.
2	Less usable energy during the year.	Integration of renewable energy generation with battery storage and diesel generator back-up systems.
3	Intermittent energy / power quality	Integration of renewable energy generation with battery storage or fuel cell and in some cases with diesel generator back-up systems.
4	Protection	Suitable protection devices need to be installed for safety reasons including up gradation of existing protection schemes in particular when distributed generators are introduced.
5	Storage runs out	Integrate PV and wind energy sources with fuel cells.
6	Environmental and safety concerns of batteries and hydrogen tanks.	Integrating PV and wind energy sources with fuel cells instead of large lead-acid batteries or super storage capacitors, leads to a non-polluting reliable energy source and reduces the total maintenance costs.

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