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A Comparison on an Efficient PV-Wind Integration For Standalone And Grid Connected System

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Abstract–Solar photovoltaic (PV)-Wind hybrid system has emerged as an important one because of the complimentary nature of PV and wind. Various PV-wind integration system has been proposed. Here the PV-wind integration, which takes into account the efficiency, cost, etc., for standalone off-grid system and grid connected system is compared. For the stand-alone off grid system, an efficient wind–photovoltaic hybrid generation system using doubly excited permanent-magnet (PM) brushless machine is proposed. Maximum power from the wind turbine can be extracted using flux control of the wind generator and duty cycle control of the singleended primary inductance converter (SEPIC) is performed so as to harness the maximum power from the PV panels. For the grid connected system, a cost-effective, efficient, and compact integration of the solar PV and doubly fed induction generator (PV-DFIG)-based wind turbine system is proposed. Here, the grid- and rotor-side power converters associated with DFIG are used to inject PV generated power into the grid and there is no dedicated power converter for PV source. Maximum power point tracking (MPPT) of the PV installation is realized in conjunction with the dc bus voltage control to extract optimum power from the PV source. The wind turbine system is controlled with the maximum power extraction algorithm in conjunction with pitch control to avoid overloading in case of high wind velocity.

Index Terms –PV-PhotoVoltaic, PM-Permanent Magnet, SEPIC-Single Ended Primary Inductance Converter, DFIG-Doubly Fed Induction Generator,MPPT-Maximum Power Point Tracking, VSC-Voltage Source Converter

1 INTRODUCTION

Every device we use in our day-to-day life such as mobile phone, computer, induction cookers, washing machines, vacuum cleaners, etc., requires electric power supply. With increase in population, our energy need is growing day by day. Our non-renewable energy sources are declining. Thus there is an increasing need to look for renewable energy sources such as PV, wind, biomass, tidal, etc. Out of these, solar PV and wind are popular sources as they are both clean and cost effective sources which do not require any fuel[1]-[3].

Solar energy is one of the major renewable energy resources that can be used for different applications, such as solar power generation, solar water heaters, solar calculators, solar chargers, solar lamps, and so on. It is renewable, inexhaustible and environmental pollution free. Solar charged battery systems provide power supply for complete 24 hours a day irrespective of bad weather. By adopting the appropriate technology for the concerned geographical location, we can extract a large amount of power from solar radiations. Moreover solar energy is expected to be the most promising alternate source of energy.

Wind energy is also one of the renewable energy resources that can be used for generating electrical energy with wind turbines coupled with generators. There are various advantages of wind energy, such as wind turbines power generation, for mechanical power with windmills, for pumping water using wind pumps, and so on.

Wind energy is the kinetic energy associated with the movement of atmospheric air. Wind energy systems convert this kinetic energy to more useful forms of power. Wind turbines transform the energy in the wind into mechanical power, which can then be used directly for grinding etc. or further converting to electric power to generate electricity. Wind turbines can be used singly or in clusters called 'wind farms. In the DFIG-based wind energy system, lower rating power converters for rotor power conditioning, for megawatt range wind energy system installation, is required [4]. However, because of topological and configuration constraints, the converters used in the rotor circuit are not utilized effectively. During operation near the synchronous speed, rotor power is considerably less. Another issue with the conventional wind-DFIG system is that part of the power simply circulates in the machine during its sub synchronous operation

PV-Wind hybrid Power system is the combined power generating system by wind mill and PV panel. The integration of hybrid solar and wind power systems into the grid can help in improving the overall economy and reliability of renewable power generation to supply its load. Using this system power generation by windmill when wind source is avail-

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able and generation from PV module when light radiation is available can be achieved. Both units can be generated power when both sources are available. 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.

For the stand-alone off grid system, an efficient wind–photovoltaic hybrid generation system using doubly excited permanent-magnet brushless machine is proposed. Maximum power from the wind turbine can be extracted using flux control of the wind generator and duty cycle control of the single-ended primary inductance converter (SEPIC) is performed so as to harness the maximum power from the PV panels. Hence, this hybrid generation system forms a highly independent generation system from day to night.

For the grid-connected system, a pv-wind energy system is proposed, where both the pv and wind sources are associated with their own power converters even though these converters are not properly utilized because of highly intermittent nature of the two sources. Another issue with the conventional system is that part of the power simply circulates in the machine during its sub-synchronous operation. Further, there is no large PV integration with power capacity above its dedicated inverter rating. This paper does not consider prominent features such as efficiency, reduction in circulating power, cost, etc.

Thus a cost-effective, efficient, and compact integration of the solar PV and doubly fed induction generator (PV-DFIG)-based wind turbine system. In the proposed scheme, the grid- and rotor-side power converters associated with DFIG are also used to inject PV generated power into the grid. Thus, the proposed configuration and control scheme provide an elegant and economical integration of PV source and DFIG-based wind energy source

2 PV-WIND INTEGRATION FOR STANDALONE OFF-GRID SYSTEM

The purpose of this paper is to present a new stand-alone wind–PV hybrid generation system for remote or isolated areas. . Maximum power from the wind turbine can be extracted using flux control of the wind generator and duty cycle control of the single-ended primary inductance converter (SEPIC) is performed so as to harness the maximum power from the PV panels. Hence, this hybrid generation system forms a highly independent generation system forms a highly independent generation system from day to night.

2.1 System Configuration

Fig. 1 shows the configuration of the proposed wind–PV hybrid generation system for the standalone off-grid system. This hybrid generation system consists of a wind power generation branch and a PV power generation branch. The wind power generation branch consists of a doubly excited PM brushless machine and a three-phase rectifier and the PV power generation branch consists of an array of 3 × 3 PV panels, a SEPIC and a dc/dc converter. Both of them shares a battery bank and an inverter. While the SEPIC performs the MPPT for the PV panels, the dc/dc converter functions to step up the SEPIC output voltage so that the same battery tank is shared by both the wind power and PV power branches. The inverter is used to convert the dc voltage to the ac voltage so that a typical household can freely utilize electricity from the ac grid.

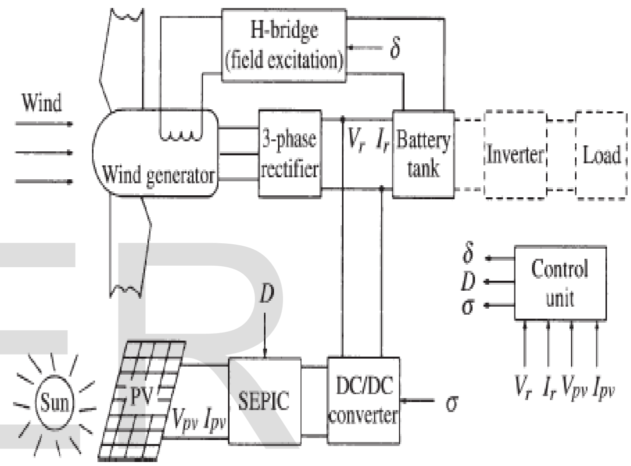

Fig. 1. Proposed wind–PV hybrid generation system.

2.2Control Schemes of PV-Wind System

A) MPPT for Wind Power Generation Branch

The maximum power can be extracted from the wind turbine by performing flux control of the wind generator [5]. Fig. 2 shows the dc field current control circuit. Flexible flux control for efficiency optimization is achieved by providing bidirectional control of dc field current so that the dc field coil can provide positive field to strengthen the PM field or provide negative field to weaken the PM field. The amplitude of the field current can easily be regulated by adjusting the duty cycle δ of the H-bridge circuit.

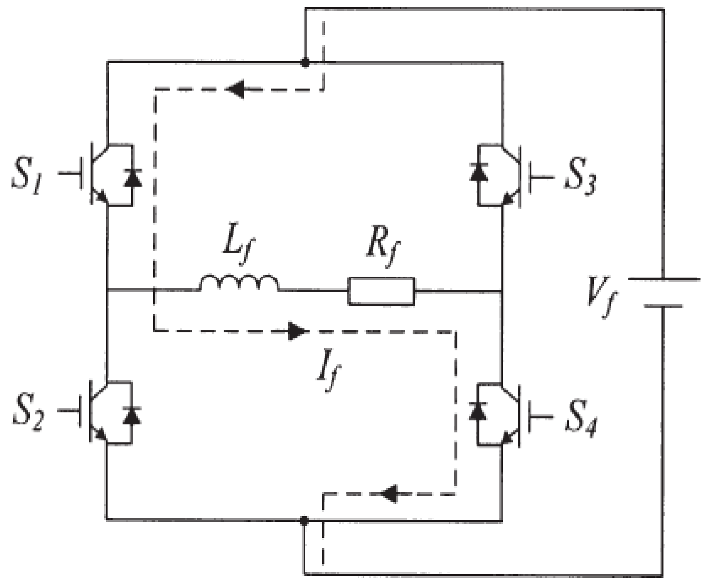

Fig. 2. DC field current control circuit.

Fig. 3 shows the MPPT process based on the PAO method. If the starting point is from the left-hand side of the maximum power point, the voltage is adjusted in the direction of *dP*rect/*dVr*. Thus, the increment of *Vr*increases *P*rect. In contrast, if the starting point is from the right-hand side of the maximum power point, the voltage is adjusted in the opposite direction of *dP*rect/*dVr*. Thus, the decrement of *Vr*increases *P*rect. Therefore, if there is an increase in power, the subsequent perturbation will be kept unchanged until the maximum power point is reached; otherwise, if there is a decrease in power, the perturbation will be reversed.

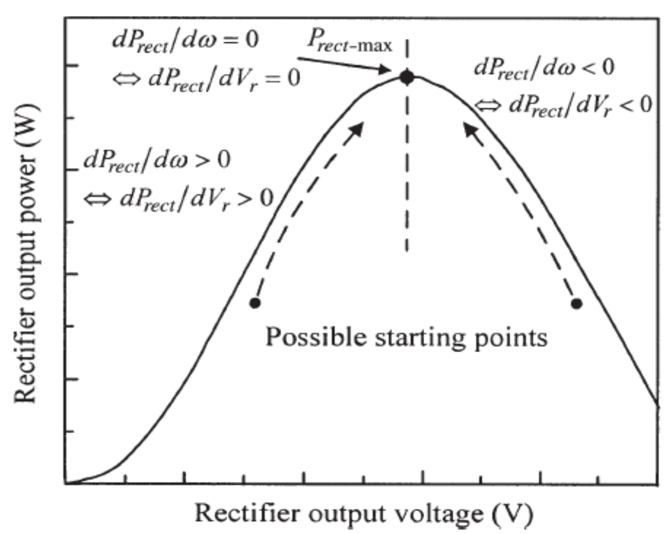

Fig. 3. MPPT process for the wind power generation branch.

The flowchart of the whole MPPT process is shown in Fig. 4, where *Vr*intis the initial value of *Vr*, *V*maxand *V*min are the maximum and minimum settings of *Vr*, *δ*0 and Δδare the initial value and step size of the duty cycle of the H-bridge.

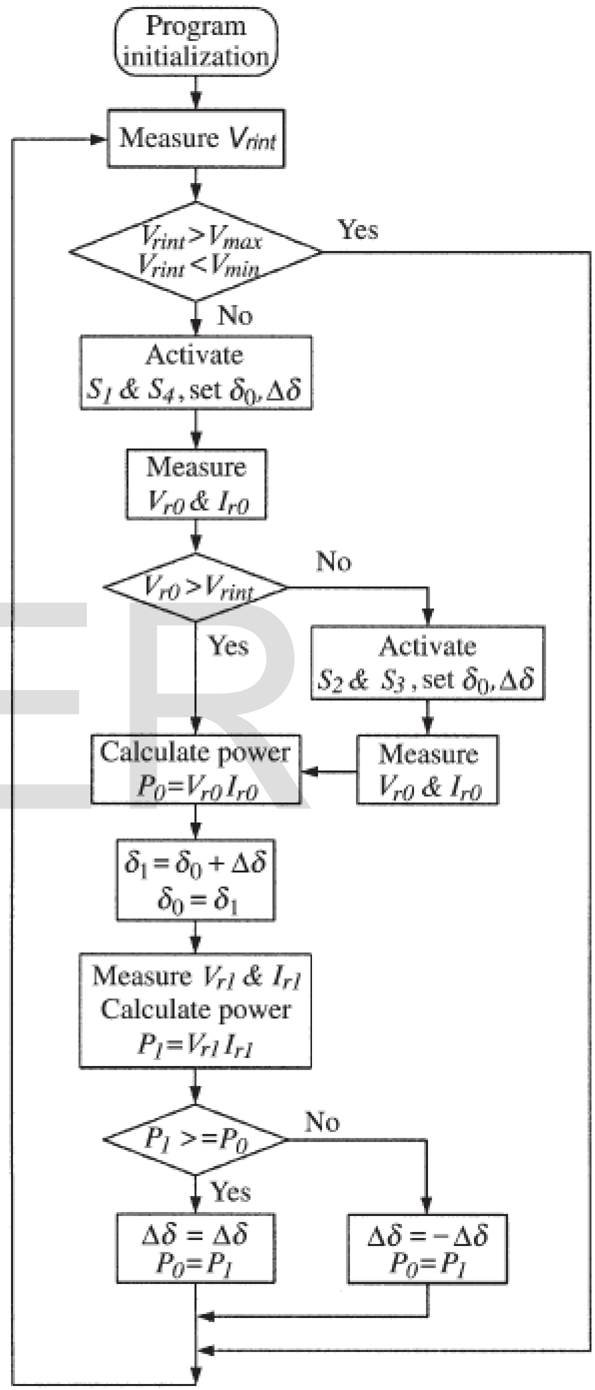

Fig. 4. MPPT flowchart for the wind power generation branch.

B) MPPT for PV Power Generation Branch

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Fig. 5 shows the circuit topology of the SEPIC for the PV power generation branch, where *V*pvand *I*pvare the output voltage and current of the PV panels, respectively, *L*1 and *L*2 are the circuit inductors, *C*1 and *C* are the circuit capacitors, and*RL* is the load resistor.

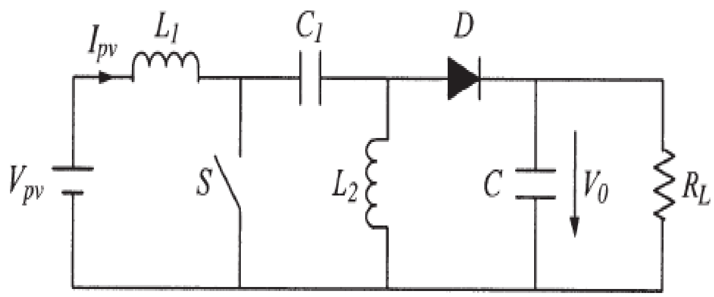

Fig. 5. SEPIC circuit topology.

Fig. 6 shows the typical set of current–voltage curves of the PV module. It can be seen that when the voltage increases, the current goes down. Therefore, the maximum power point occurs at the corner. Hence, by properly tuning the output voltage, the MPPT can be performed under different irradiance levels.

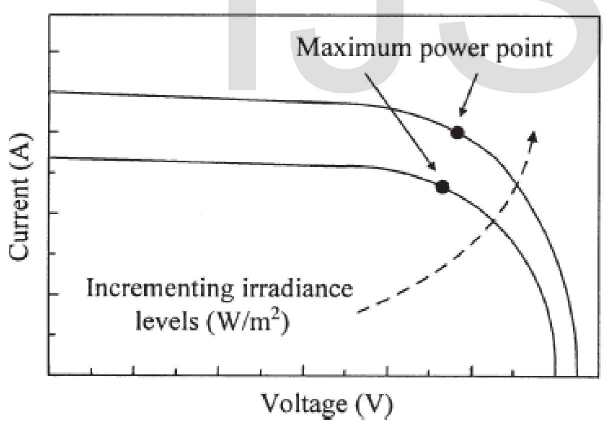

Fig. 6. Typical current–voltage curves of the PV panel.

Fig. 7 shows the corresponding flowchart for the MPPT, where *V*batmaxis the maximum charging voltage of the battery tank, *D*0 and Δ*D* are the initial value and step size of the duty cycle of the control signal, respectively, and *V*pvkand *I*pvkare the *k*th steps of *V*pv and *I*pv, respectively.

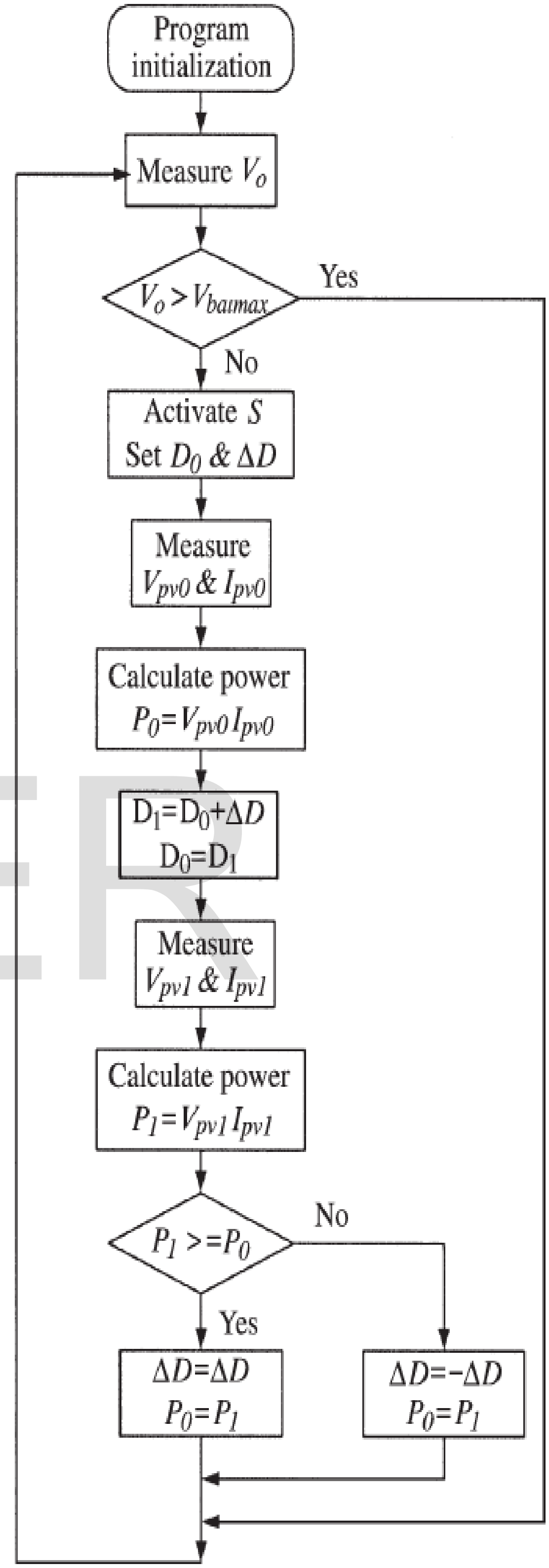

Fig. 7. MPPT flowchart for the PV power generation branch.

The above proposed system has the following features: 1) The proposed system utilizes the battery tank and inverter to couple the wind power and PV power branches. Here, the PV power can directly be used for dc field excitation of the doubly excited PM generator, thus reducing the power loss. 2) The MPPT can simultaneously be achieved by independently controlling the wind power generation branch and the PV power generation branch of the hybrid generation system. 3) The wind–PV hybrid generation system allow the wind power and the PV power to complement one another between day and night. 4) It can eliminate the complicated mechanical transmission and the relevant costs since the rotor is directly coupled with the wind blades. 5) It has simple structure and uncomplicated control. 6) It has lower cost than two individual wind and PV power systems.

3PV-WIND INTEGRATION FOR GRID CONNECTED SYSTEM

Here, both the pv and wind sources are associated with their own power converters even though these converters are not properly utilized because of highly intermittent nature of the two sources. Another issue with the conventional system is that part of the power simply circulates in the machine during its sub-synchronous operation. Further, there is no large PV integration with power capacity above its dedicated inverter rating. This paper does not consider prominent features such as efficiency, reduction in circulating power, cost, etc.

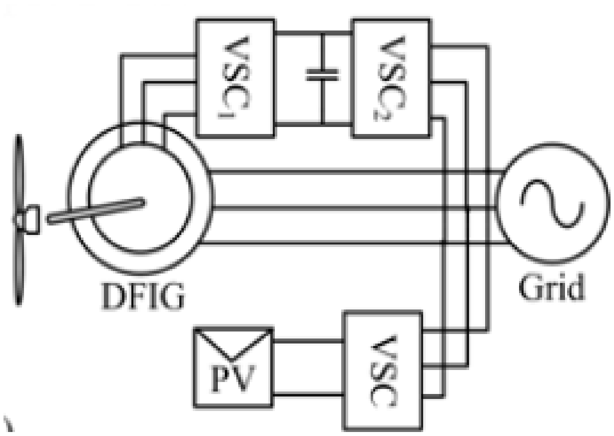

Fig. 8. Block diagram of the conventional PV-wind hybrid system

Therefore, a cost-effective, efficient, and compact integration of the solar PV and doubly fed induction generator (PV-DFIG)-based wind turbine system is proposed as shown in Fig. 9. In the proposed scheme, the grid- and rotor side power converters associated with DFIG are also used to inject PV generated power into the grid.

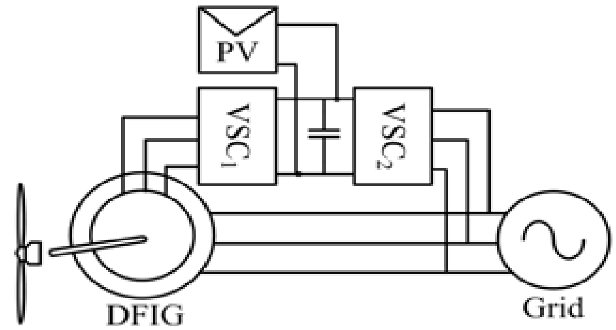

Fig. 9. Block diagram of the proposed PV-wind hybrid system

3.1 System Description

The schematic of the proposed system is shown in Fig. 10. A wind DFIG system of 1MWcapacity is considered in this study along with a PV generation of comparable rating. The stator circuit of the DFIG is coupled to the grid through the circuit breaker, *S*2. The rotor-side converter (VSC1) is rated for 250 kVA, while the grid-side converter (VSC2) is rated at 340 kVA. A 380 kW capacity PV source is considered which is significantly higher than the grid-side converter rating (VSC2). Later, it is demonstrated that a PV source with much larger rating, compared to the inverter capacity used in a conventional grid-tied PV system, can be integrated with the wind-DFIG system without an additional dedicated inverter.

Though the rotor-side converter (VSC1) can support system operation over a wide speed range, pitch control is provided to ensure optimal energy extraction and protection against excessive wind turbulence and overloading. The PV source is protected with an anti- blocking diode and dc circuit breaker *S*1. In addition to this, a modified algorithm is incorporated to control the PV power using dc-bus voltage control (rather than only MPPT control). This protects VSC2 from overloading. Idle condition of PV VSI is nearly eliminated. A bare minimum power delivery from the hybrid system is maintained throughout the day and across the seasons. This is not true for systems fed either by solar PV or wind turbine sources alone. The proposed hybrid system has scope for integration of energy storage for enhancing power quality and reliability in terms of continuity and availability of the power supply. The overall power injection from this hybrid system to the grid is averaged by the intermittent but complementary sources of PV and wind.

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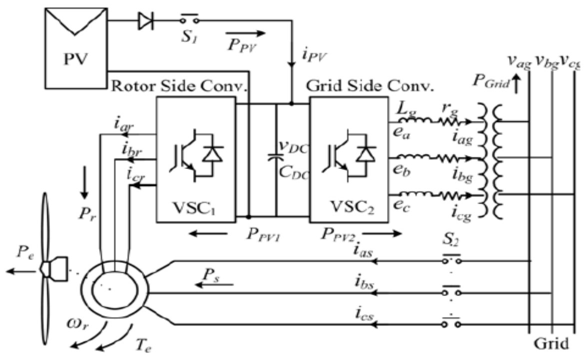

Fig. 10. Proposed solar PV-wind DFIG system.

3.2 Power Control of PV-Wind System

Maximum power is extracted from the PV source by realizing maximum power point tracking (MPPT) in conjunction with the dc bus voltage control [6]. The wind turbine system is controlled with the maximum power extraction algorithm in conjunction with pitch control to avoid overloading in case of high wind velocity. In the proposed system, the control scheme presented for grid-side converter has been incorporated with a special (modified) PV power control algorithm and not just a conventional MPPT control.

An additional control loop has been incorporated in the proposed system to tackle high solar radiation and high wind velocity existing at the same time by automatically adjusting VSC2 loading. During most of the time, the PV and the wind systems operate at MPP. However, during a harsh sunny day and heavy wind conditions occurring simultaneously, the PV operating point shifts from MPP so as to avoid overloading of VSC2. Fig. 11 shows the proposed modified algorithm for the control of PV power. This algorithm incorporates MPPT for optimum power and also precise power control depending upon the operating mode (DFIG sub- or super-synchronous speed), environmental conditions, and VSC2 loading.

Thus, a modified PV power control algorithm incorporated in the control scheme can tackle any of the environmental conditions in case of both high radiation and wind velocity level occrring simultaneously. The pitch control for the wind turbine along with the maximum power extraction algorithm allows to extract maximum wind power.

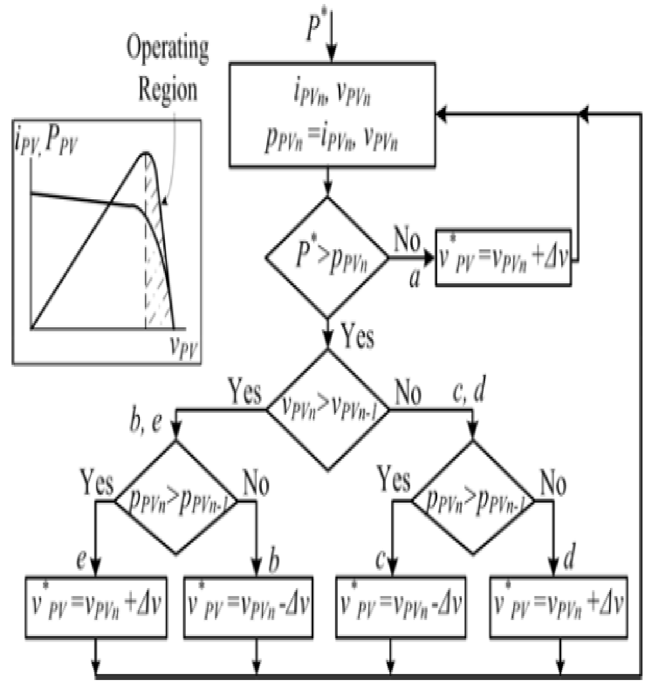

Fig. 11. PV power control algorithm for the proposed hybrid PV-wind system.

A) Pitch Control for Wind Turbine

When controlling a wind turbine with pitch control, blade angle is changed with a positive angle. Above rated wind speed, the blades are pitched out of the wind and when the wind speed reduces again, the blades are pitched back into the wind. This result in a lot of trimming of the pitch angle compared to active stall. The angle the blades have to be pitched is about 10-20 degrees. Since pitch control limits power by pitching the blade out of the wind, fast power fluctuations in the wind above rated wind speed will also result in a fast electrical power fluctuation above rated power, unless the blades can be pitched fast enough to overcome the fluctuation.

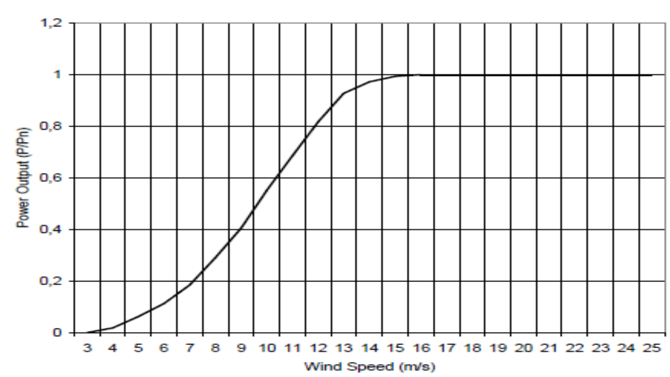

Fig. 12. Power curve for a pitch controlled wind turbine

Therefore, this proposed system possesses the advantages as follows: 1) As the PV installation uses rotor circuit converters since it has no dedicated inverter, power conversion efficiency is improved. 2) Overall cost is reduced. 3) Interfacing of a higher rating PV source compared to the dedicated inverter in the conventional interface is possible. 4) Power converters are optimally utilized. 5) During low speed operation and high solar radiation, the circulating power flow in the DFIG system is reduced thus reducing the losses of the overall system. 5) Variation in the grid-injected power over a day is minimized and idle condition of PV VSI is nearly eliminated. 6) Maximum power point tracking (MPPT) of the PV installation is realized in conjunction with the dc bus voltage control to extract optimum power from the PV source. The wind turbine system is controlled with the maximum power extraction algorithm in conjunction with pitch control to avoid overloading in case of high wind velocity. 7) In case of both high radiation and wind velocity level occurring simultaneously, any of the environmental conditions can be overcome by the modified PV power control algorithm incorporated in the control scheme.

4 CONCLUSION

A comparison of PV-wind integration for the standalone off-grid system, which uses a doubly excited permanent-magnet (PM) brushless machine, and grid connected system, where a novel integration in which the rotor-side and grid-side converters are used to inject PV power into the grid since there is no dedicated inverter for the PV source, is used. The various control schemes of both PV and wind sources to harness maximum PV and wind energy has been discussed. The various advantages of the proposed system with the conventional ones for off-grid and grid connected system are also presented.Both the schemes provide an economical and efficient integration of PV source and DFIG-based wind energy source.

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