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# Integration and Modelling of Renewable Energy Sources for DC Microgrid Application

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*Abstract*—This Paper presents a dynamic modeling of a DC Microgrid which has a Solar and Wind as a Distributed Energy Sources (DES). A Multi Port DC –DC converter is used to integrate the renewable sources to the DC bus. A Permanent Magnet Synchronous Generator (PMSG) based Wind energy conversion system (WECS) is used with a Maximum power point tracking so that it can extract high wind energy below the rated speed of the wind. Both the Photovoltaic (PV) and WECS is integrated to a common bus with an Energy Storage system to support the DC bus based on the load requirement.

***Keywords—DC Microgrid, PMSG, Photovoltaic, Maximum power point tracking, Perturb and Observe***

## Introduction

DC Distributed energy system (DES) has the advantage to interact with Renewable Energy source due to simplicity and efficiency. Distributed energy resources include PV and fuel cell, which generates DC voltage and wind turbine and internal combustion engine which produces AC voltage. All of these resources have to be interfaced with a DC bus and feed power to the load, therefore dc-dc or ac-dc converters are used. The Bus can balance the voltage between the energy storage system and the DC load. Power Electronics Converter is used to interface the load and the Renewable Source. A common DC Bus is shared between the loads and to store the energy.

The conventional electrical system in place today sees our electrical devices powered by AC mains. But as renewable technologies such as solar photovoltaic and wind power become more prevalent at a household level, DC Microgrid could be a cheaper and more efficient alternative.

DC-DC converters are essential in DC Distribution Systems since they connect not only Dc sources but also DC energy storage Elements. This Paper focus on developing a DC bus for a Distributed PV and Wind Applications.

In this system the energy sources are Solar and Wind for a Distributed Energy system, and energy storage elements such as Batteries. In this system a Multi port DC converter is used such that it can interface PV and Wind with their respective MPPT to the DC bus and also to the battery. By using such kind of converters the efficiency of the DES is increased and it is cost effective. The converter consists of a Bi – Directional port for the batteries so that it can charge and discharge randomly.

## Proposed Architecture of DC Microgrid

Fig. 1 shows the overall architecture of the proposed Microgrid with wind and PV sources [1]. The main sources, of wind and solar radiation are converted into electrical energy by wind generator and the array of PV modules. To combine these input sources a Multiport DC Converter is used. Multiport DC Converter is used because it has effective MPP tracking in PV System and effective control of input current in grid connection system. They provide a cost effective and flexible method to interface many such Renewable sources since they have multiple ports [2].
In addition, DC system is used because it is present in abundant and efficiency is higher than the AC system. An Energy Storage System (ESS) is also connected to main DC bus in order to support the local loads for the uninterrupted power supply [3]. Depending upon applications the local loads requires different voltage levels which is obtained by the using DC – DC converters. The Converter either buck or boost the voltage obtained from the DC bus and it is given as an input to the load [4].

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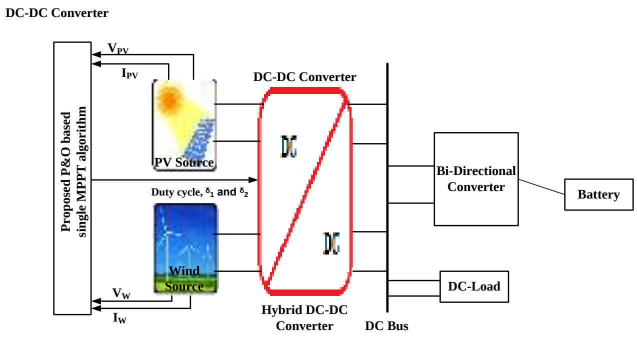


Fig.1. Proposed architecture of DC Microgrid System

Modelling of Proposed Microgrid

The modeling of different Source blocks is as follows:

## Solar Cell Modelling

Solar cell is made up of semiconductor material with doping of p-n junction, to absorb the irradiance and temperature of the solar energy with non linear characteristics and converts into the DC current [5]. Most commonly, single diode model is considered because of its simple and accurate. The cells are connected in series and/or parallel to achieve the corresponding voltage and current. If the cells are connected in series then it obtains the large output voltage whereas, if the connection is in parallel it produces large output current. The equivalent circuit diagram of the single diode PV panel consists of a current source, a diode, series and parallel resistances is shown in Fig. 2. The relation between the voltage, current and power of the PV panel is shown as the P-V and I-V characteristics in Fig. 3.

The modeling of the solar cell is defined by voltage – current relationship of PV system as follows [6].

$$I = I_{pv} - I_S\left(exp\left[\frac{q(V+R_s I)}{N_s kTa}\right]-1\right)-\frac{V+R_S I}{R_P} \qquad (1)$$

$$I_{pv} = (I_{pv,n} + K_I \Delta T)\frac{G}{G_n} \qquad (2)$$

$$I_S = \frac{I_{SC,n} + K_I \Delta T}{exp(V_{OC,n} + K_V \Delta T)/a(N_S kT/q)-1} \qquad (3)$$

Where, $I_{pv}$ is the PV current, $I_{pv,n}$ is nominal PV current, $I_s$ is the saturation current , $q$ is the electron charge ($1.60217\times10^{-19}$ C), $k$ is the Boltzmann constant ($1.38065\times10^{-23}$ J/K), $a$ is the diode ideality constant, $R_s$ and $R_p$ is the series and parallel resistance of cell, $N_s$ is the number of cells connected in series, $T$ is the absolute temperature, $T_n$ is the nominal temperature, $G$ is the irradiance and $G_n$ is nominal irradiance from solar energy. $\Delta T=T-T_n$ is the deviation from operating temperature. $I_{SC,n}$ and $V_{OC,n}$ are the short circuit current and open circuit voltage based on nominal condition ($T_n$=25 ˚C and $G_n$=1000 W/m$^2$). $K_I$ is the ratio of short circuit current variation with temperature in standard condition; $K_V$ is the ratio of open circuit voltage with respect to temperature.

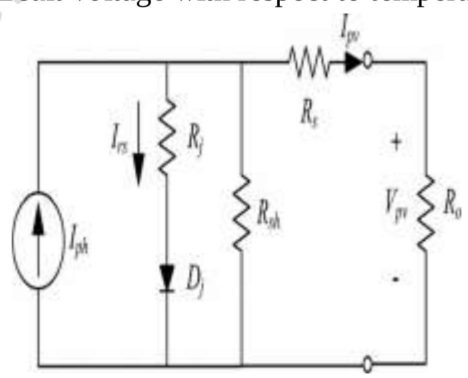


Fig. 2 SOLAR PANEL EQUIVALENT CIRCUIT

## Wind Energy Conversion Modelling

The configuration of gearless wind generation system is shown in Fig. 3. The direct driven PMSG is preferred mostly because it eliminates the use of gear box thus reducing the complexity and overall size of the system [7] – [10]. The speed of the wind generator is controlled using the pitch actuator. The variable pitch angle is fed into the wind turbine in order to obtain optimal torque for stabilised power generation.

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### A. Wind Turbine

The torque obtained from the wind turbine is expressed as [12],

$$T_m = \frac{1}{2}\rho\pi\frac{C_p(\lambda,\beta)}{\lambda}R^3v^2 \quad (1)$$

where, $\rho$ is the air density $(kg/m^3)$, $C_p$ is power coefficient and the parameters of $C_p$ are $\lambda$ and $\beta$ which represents the tip speed ratio and pitch angle respectively. The wind speed is represented as $v$ $(m/s)$ and $R$ represents the radius of the blade $(m)$.

The power coefficient $(C_p)$ of the wind turbine is expressed as,

$$C_p(\lambda,\beta)=c_1 * \frac{c_2}{\lambda_i} \quad c_3\beta \quad c_4 \quad *exp \quad {}^{c_5}/_{\lambda_i} \quad +c_6\lambda \quad (2)$$

where,

$$\lambda_i = \frac{1}{\lambda+0.08\beta} \quad \frac{0.035}{1+\beta^3}$$

And $c_1$ to $c_6$ are the parameter coefficients with $c_1$= 0.5176, $c_2$=116, $c_3$=0.4, $c_4$=5, $c_5$=21, and $c_6$=0.0065 which is used in this paper.

The power coefficient of wind turbine with respect to tip speed ratio is shown in Fig. 3.

### B. Pitch Actuator

The pitch angle control is generally used to limit the turbine mechanical torque of wind turbine in large wind turbine. The blades are adjusted in such a way that the torque from the wind turbine is always at optimal range [10]. The electric pitch angle is preferred over hydraulic pitch controller for its simplicity and efficiency [11]. The angle of the blades is adjusted in order to maintain the turbine torque. The pitch actuator system consists of integrator and time constant $\tau_c$. The pitch actuator of wind turbine is expressed as [12],

$$\frac{d\beta}{dt} = \frac{1}{\tau_c}\beta + \frac{1}{\tau_c}\beta_{ref} \quad (3)$$

which is subjected to,

$$\left(\frac{d\beta}{dt}\right)_{min} \le \frac{d\beta}{dt} \le \left(\frac{d\beta}{dt}\right)_{max}$$

where, $\beta_{min}$ and $\beta_{max}$ are the minimum and maximum pitch angle, respectively.

The configuration of pitch control system is shown in Fig. 4. The time constant of the pitch actuator determines the response time of the pitch controller. The response time of the pitch controller is usually between 0.2s to 0.25s. Blade angle for typical WECS lies between -2 to 30 degrees. Thus the variable range in the pitch angle has an adverse effect on the performance of the controller [16].

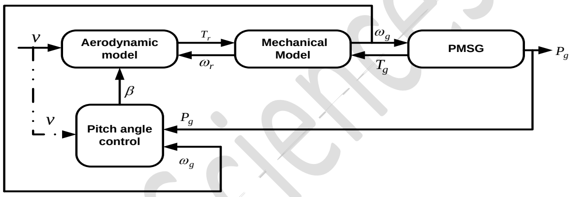


Fig. 2. Typical configuration of gearless wind generation system

### PMSG Generator

The mechanical torque $(T_m)$ and electrical torque $(T_e)$ of three phase PMSG generator used in this study are expressed as [17],

$$T_m = \frac{P_m}{\omega_r} \quad (4)$$

$$T_e = \frac{Pe}{\omega_r n_p}*2 \quad (5)$$

where, $P_m, P_e$ are mechanical and electrical power obtained respectively. $\omega_r$ is the mechanical rotational speed and $n_p$ is the number of pole pair used in PMSG. In general, the dynamic motion of PMSG generator is given as,

$$T_e = J_{eq}\frac{d\omega_r}{dt} + D\omega_r + T_m \quad (6)$$

Here, $D$ represents the rotational damping and $J_{eq}$ represents the equivalent inertia of wind turbine and generator.

The machine model of PMSG in d-q reference frame are described as,

$$v_q = Ri_q + p\lambda_q + \omega_s\lambda_d$$
$$v_d = Ri_d + p\lambda_d \quad \omega_s\lambda_q \quad (7)$$

where, $v_d, i_d$ represents the stator voltage and current in the d axis and $v_q, i_q$ in q axis respectively. R denotes the stator resistance of PMSG. $\lambda_q, \lambda_d$ are the stator flux linkage of *d*, *q* axis respectively given as,

$$\lambda_q = L_q i_q$$
$$\lambda_d = L_d i_d + L_{md} I_{fd} \quad (8)$$

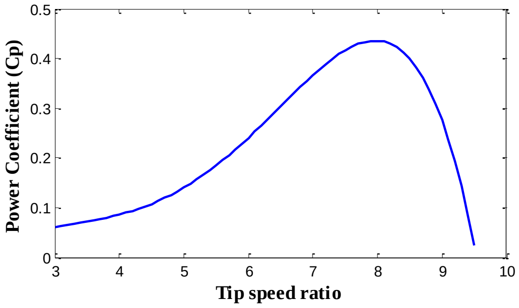

Fig. 3. Cp vs λ curve of wind turbine

where, $L_{md}, I_{fd}$ are the mutual inductance and magnetizing current in *d* axis. $\omega_s$ is the stator frequency, which is represented as,

$$\omega_s = n_p \omega_r \quad (9)$$

The PMSG generator does not require any drive train and they are used for variable speed variable pitch application [18].

## DC-DC CONVERTER MODELLING

Fig. 4. shows the proposed integrated three-port dc–dc converter topology. A three-phase DAB converter is applied to realize the bidirectional power flow function and the Y-Y connected high-frequency transformers can provide galvanic isolation and voltage-level matching between low voltage energy sources and high-voltage dc bus [13]. The leakage inductances Ls1 − Ls3 of the transformer are used as energy storage elements to transfer the power between two sides, and the power flow is mainly controlled by a phase-shift angle ϕ. The middle points of three legs in the LVS are connected to one energy source port through three dc inductors Ldc1 − Ldc3, and duty cycle D is another control variable to adjust the power distribution between the two ports of the LVS. In the application of a PV system on dc distribution bus, the converter is applied to interface with PV panels, BU, and dc bus or load. The BU is connected to the LVS dc link. The voltage of the battery changes slowly with different SOCs, so the primary-side dc-link voltage can be treated as almost constant. The PV panels are connected to the current source port. The output voltage and current of PV change in a large range due to different solar irradiation and ambient temperature. Three-phase dc inductors and primary-side switches are used to boost the PV voltage and MPPT can be realized by the duty cycle control. With the help of dc inductors, the ZVS is guaranteed in all the operation modes, even though the battery's voltage changes with different SOCs. Compared to the single phase topology, the three-phase interleaved topology can reduce the current and voltage ripples to reduce the inductor and capacitor's size.

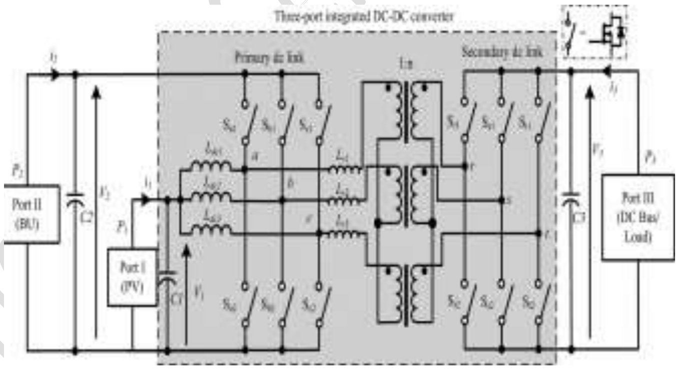

Fig. 4. Proposed three-port integrated bidirectional dc–dc converter.

### MPPT technique

The MPPT techniques are implemented to extract the optimum power from the PV system by tracking the maximum power point. From Fig. 3, it is observed that the MPPT techniques can able to track the operating point and to generate the appropriate duty cycle for firing the converter. In order to attain MPP, three techniques have been implemented and described below.

### Perturbation & Observation Method

P&O method for tracking the maximum point is a simple and easy method to implement in the real time. This method is implemented by measuring the output power variation (*ΔP*) which follows each perturbation from PV system. If *ΔP* is positive, the operating power will reach MPP,

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through perturbation in positive direction at each stage. If *ΔP* is negative, then the point is moved away from the MPP and perturbation changes in reverse direction, then the process is repeated to select the optimum point from PV system [44]. If the size of perturbation step is large then the oscillation will be more and if it is small then oscillation around MPP becomes less. The duty cycle of the P&O method is described by the voltage and power relationship from PV system. The main drawbacks of this system are the tradeoff between response and oscillations around the maximum power point during steady state and the low tracking efficiency under rapidly changing irradiance conditions. The algorithm of P&O method is illustrated in Fig.5.

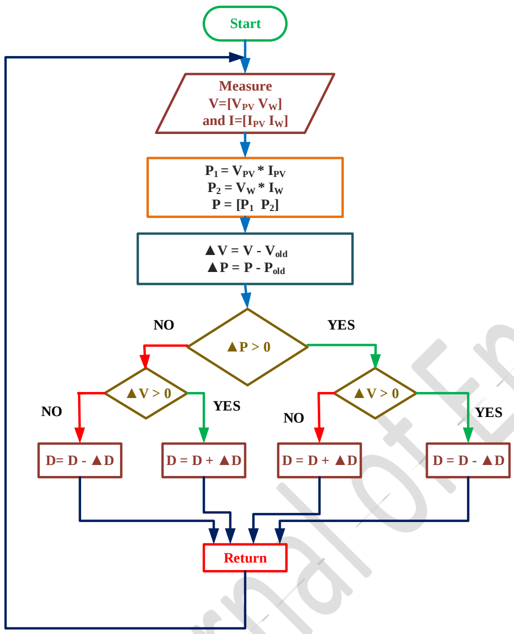
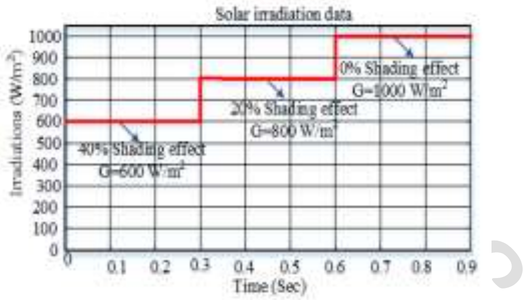


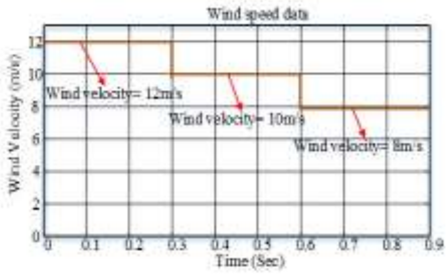

Fig. 5. Flow chart of modified P&O MPPT for hybrid system

Simulation Result

The performance analysis of proposed architecture is validated in the MATLAB/Simulink software. The availability of both solar and wind energy sources are alternative to each other in order to verify the feasibility of battery management system. For the period 0 to 0.3 sec, the availability of wind source is12 m/s and the PV irradiation is 600 W/m$^2$. Similarly, for period of 0.3 to 0.6 sec and 0.6 to 0.9 sec are wind velocity 10m/s with PV irradiation of 800 W/m$^2$ and wind velocity 8 m/s with 1000 W/m$^2$ respectively as shown in Fig. 6.




(a)




(b)

Fig. 6 (a) Considered solar irradiation data, (b) Considered wind speed data

The proposed hybrid system with 560 W PV and 500 W wind system with the developed HL converter parameter specifications are listed in Table. 4.

TABLE 1. Specifications of Proposed System

| Description | Ratings |
|---|---|
| PV rating | 24 V, 23.4 A, 560 W |
| Wind rating | 24 V, 21 A, 500 W |
| Boost converter-PV | $L_1$=3e$^{-3}$ H |
| Boost converter-Wind | $L_2$=3e$^{-3}$ H |
| DC link capacitor | $C_2$=5e$^{-3}$ F |
| Load resistance | R=96 Ω |

The performance of single P&O based MPPT topology is shown in Fig. 7. The DC link voltage, current and power obtained using single P&O

based MPPT technique employed for hybrid system is shown in Fig. 7.

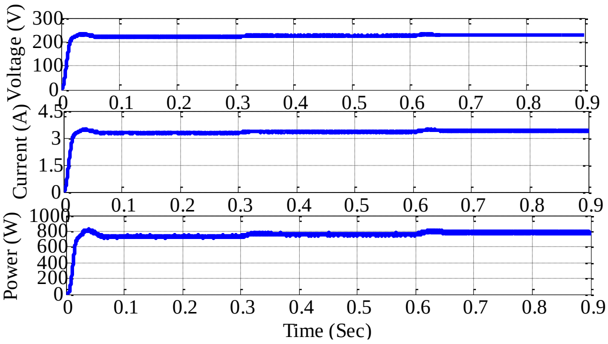



Fig.7. Hybrid system DC link output Voltage, Current and Power with single P&O MPPT

## Conclusion

In this paper, a hybrid PV and wind system was designed with the proposed single P&O based MPPT controllers for DC Microgrid application. The various multi input DC-DC converters and MPPT techniques available in the literature for the hybrid renewable energy sources are discussed. A hybrid renewable energy system is designed by considering the 560 W PV system and 500 W wind system. The performance of the proposed structure and single MPPT is analyzed in standalone system three different regions by considering the different renewable energy source data with respective time. The simulation and hardware prototype model results are presented to validate the developed system output. The proposed architecture based single MPPT effectively tracks the maximum power from both sources concurrently, which reduces the hybrid system implementation complexity.

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