Hybrid Renewable Resource Power Generation using Back to Back Voltage Source Converter with Output Regulation

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Abstract - There is a massive and rapid development in the industry and prevailing population inflation due to which the energy demand spikes. The increase in demand dilates the gap between the energy supplied and usage which makes the power quality important to consider, otherwise it causes voltage, current or frequency deviations which has unfavourable consequences in customer’s equipment or result in failure. To overcome this the concept of complementary usage of wind and solar cogeneration system is introduced along with the topology with Neutral Point Clamped inverter which has 3-level output converter that decreases the harmonics and the switching rate, it also features the regulation of the VSC through fuzzy based control scheme in the rotating reference frame of wind-solar cogeneration system with no extra DC/DC conversion stages.

Keywords - Renewable energy, Wind – Photovoltaic cogeneration, Voltage source converter, Fuzzy logic

1. Introduction
The dilating gap between the power generated and the demand is increasing day by day. Meanwhile, the price hike in generating power using conventional power resources has been noticed. It is also observed since the last decade, the cost of solar and wind energy has been falling down. It may be due to the provision of incentives which increased the global installed capacity of wind generators and photovoltaic generators has approached 592GW and 509 GW respectively in 2018 as compared to 159GW and 23GW respectively in 2008 [1].

Though the wind and solar energy is abundant in nature they are intermittent and unregulated in nature. To subdue this tribulation power electronic devices are utilized but these devices are solely available for one form of renewable energy sources. In order to obtain continuous and high operational efficiency the wind and solar cogeneration system is considered. Therefore, the power electronic converters are made to support this wind-solar cogeneration. The existing system though own many advantages such as complementary usage of power resources, optimization of utilising land resources, dynamic support to utility grid etc., the quality of power distributed from the system is less scrutinized. It must be noted that the high-power wind generators interfaced with fragile AC grids which would bear from stability and quality issues in power while photovoltaic generator provides limited power and non-linear current possessing both constant voltage and constant current which relies on the operating point. The existing system uses ASMC algorithm for controlling single-phase VSC in order to mitigate the harmonic current but the ASMC control deals with stability, higher order sliding surface and other issues though chattering and high activity of control action is eliminated. Besides the problem of circulating and leakage current is dominant which thereby decreases the power quality. Therefore, a new topology is needed for achieving greater operational efficiency and greater power quality in wind-solar cogeneration system.

The proposed system focuses on maximizing the benefits acquired from the wind-solar cogeneration system which focuses on obtaining the following objectives, they are realizing wind-solar co-generation system using back to back VSCs with no additional dc/dc conversion stages, independent operation of MPPT, developing small-signal state-space model, regulation of VSC using fuzzy logic control and implementation of Neutral Point Converter (NPC) to eliminate leakage and circulating current in the system.

2. Modelling and Control of Proposed wind-PV Cogeneration system
The proposed system is implemented using the PIC1F877A which is employed to control the driver circuit which drives the Voltage source rectifier and the neutral point converter. From the Figure 2 it can be observed that the machine side voltage source converter (VSC) is interfaced with the wind-turbine generator which consists of six cells. The PV generator is straightly coupled with the dc-link of the MVSC through dc-link cable. The following section provides complete modelling and control this system.

![Block diagram of the proposed wind-solar cogeneration system](image-url)
Figure 1 shows the block diagram model and Circuit diagram of the proposed system. The interconnection of wind along with PV creates cogeneration. Due to the presence of cogeneration load sharing is made feasible and maintaining the grid system under stable condition, thus, flows from higher to lower potential which causes the blades to rotate. The blades thus rotate the drive shaft which in turn rotates the generator. The three factors which determine the amount of energy that can be acquired from the wind are speed of the wind, density of the atmosphere and sweeping area.

Fig 2: Circuit diagram of the proposed system

Wind generation

For an FSWT which is fully-scaled wind turbine, the permanent magnet synchronous motor is chosen for its minimal maintenance and operational cost. The FSWT model is given as below in Equation (1),

\[ P_m = \frac{1}{2} C_p(\beta, \lambda) \rho \pi R^2 v_{\text{wind}}^3 \]

\[ \lambda = \frac{\omega_r}{v_{\text{wind}}} \]

Where, mechanical power of the turbine blades is represented as \( P_m \); rotor coefficient which is an erratic function of the blade pitch angle (\( \beta \)) and the tip-speed ratio (\( \lambda \)) is represented as \( C_p \); air density is represented as \( \rho \); radius of the wind turbine blade is represented as \( R \); Wind speed as \( v_{\text{wind}} \), and \( \omega_r \) is the mechanical speed of the rotor.

In our system, \( \beta \) is assumed to be zero in the normal conditions in order to optimize the wind power generation. The model of PMSG is as follows in Equation (2),

\[ \dot{x}_s = R_s x_s + L_s \frac{dx_s}{dt} + j P \omega_r (\psi + L_s i_s) \]

\[ j \frac{d}{dt} \omega_r + \beta \omega_r = \frac{3}{2} P \psi I_{sq} - T_m \]

The vectors representation where a complex vector as \( x^* = Xd + jXq \) such that \( Xd \) and \( Xq \) are the straight (\( d \) -) and quadrature (\( q \) -) components of \( x^* \) in the rotating reference frame; \( R_s \)- stator-winding resistance \( L_s \)-inductance; \( j \) – imaginary number; flux linkage of the rotor magnets is represented as \( \psi \); \( P \) - number of poles pairs; \( T_m \)- mechanical torque; \( j \) - motor inertia, \( \beta \) - viscous friction. It is known that the wind is caused due to the irregular heating of atmosphere by the sun. The wind

Voltage Source Rectifier (VSR) Control system

As shown in Figure 3, the proposed VSR control system contains the VDC regulator, PLL measurement unit and reference voltage generation. The feedback of dc-link voltage is possessed by the VDC regulator is measured. Then, the measured value is compared with the reference value. Now, the reference quantity of current in d-axis is generated by the PI controller i.e., the \( V_{abc} \) and \( I_{abc} \) of wind is converted into d and q components by using the measurement of \( I_d \) and PLL. The \( \dot{\theta} \) is found from the PLL block to convert abc to dq component. This dq value and \( \dot{\theta} \) reference are fed to the current regulator which generates the \( V_d \) & \( V_q \) reference value. The reference abc voltage generation block fed by the reference d-q axis voltage component. The required signal which switches to the VSC is generated by the PWM generator. The comparison of reference voltage signal with the carrier signal with specified frequency is done by the PWM generator. The MPPT used for maximum power extraction from the wind is P&O based. Thus, the wind MPPT generates the reference speed of the generator thus acquiring maximum power from the wind.

Voltage Source Inverter (VSI) control scheme

The input is the load voltage which is converted into D-Q component by Park’s transformation. The d-axis, q-axis and zero sequence quantities are computed by transformation block abc-to-dq0 in a 2-axis rotating reference frame. The following Equation (3) is the computed transformation,
Where, rotation speed (rad/s) is represented as $w$ of the rotating frame.

The positive sequence component $V_1$ of three phase voltage or currents can be measured using this block. The rectangular co-ordinates of the positive sequence component are represented by the $V_d$ and $V_q$ (or $I_d$ and $I_q$).

\[ V_d = \frac{2}{3} (V_x \sin(\omega t) + V_y \sin(\omega t - 2\pi/3) + V_z \sin(\omega t + 2\pi/3)) \]
\[ V_q = \frac{2}{3} (V_x \cos(\omega t) + V_y \cos(\omega t - 2\pi/3) + V_z \cos(\omega t + 2\pi/3)) \]
\[ V_0 = \frac{1}{3} (V_x + V_y + V_z) \]  \hfill (3)

**Photovoltaic energy**

The electrical energy trapped by PV panels at any time depends on the intrinsic properties of the panel and the incoming solar radiation. The solar cells are fundamentally a semi-conductor diode which is exposed to light. The cell parameters compromise SCC - short-circuit current, VOC - open circuit voltage, efficiency, RS - series resistance and $R_{sh}$ - shunt resistance could be altered through variations in light intensity and temperature. Thus, a quite good modelling of PV panels is considered in which the diode-based PV cell modelling gains attraction due to the graphical interface of simulation software like MATLAB/ Simulink which facilitates better simulation of these models as shown in Figure 5. In this system, the single diode-based PV modelling is preferred.

As shown in Figure 4, the converted d-q component is compared accordance with the reference value through the PI controller.

**Fig. 4: VSI control scheme**

From this it is noted that the current that has been generated from the PV array is directly proportional to the solar isolation. Figure 6 and Figure 7 as shown Simulink PV single diode model, calculation of induction motor model as in Equation (4),

\[ I_{pv} = I_m - I_{sh} \]  \hfill (4)

Where $I_{sh}$ is the current through shunt resistor as in Equation (5) and Equation (6),

\[ I_m = I_g - I_d \]  \hfill (5)

\[ I_{sh} = \left( \frac{V + I_{pv} R_s}{R_p} \right) \]  \hfill (6)

**Fig. 5: Single diode-based PV modelling**

Where $I_g$ is the generated PV current proportional to solar isolation given by Equation (7) and Equation (8),

\[ I_g = (I_{g,n} + K_I \Delta T) \frac{G}{G_n} \]  \hfill (7)

Where $I_d$ is the diode current given by,

\[ I_d = I_0 \left( \exp \left( \frac{(V + I_{pv} R_s)}{V_T} \right) - 1 \right) \]  \hfill (8)

Here, $I_0$ = reverse saturation current of the diode that is provided by Equation (9) and Equation (10),

\[ I_0 = \frac{I_{sc,n} + K_I \Delta T}{\exp \left( \frac{(V_{oc,n} + K_I \Delta T)}{a V_T} \right) - 1} \]  \hfill (9)

Where $V_T$ is temperature equivalent voltage given by

\[ V_T = \frac{N_s k T}{q} \]  \hfill (10)

Final expression for PV cell output current is given by
Fuzzy logic can be defined as fundamental control system which depends on the grades of input state and the output relies on the input and rate of change of the states. In other words, it can be defined as the system which assigns a specific output supporting on the probability of the state of the input. It runs on the concept of deciding the output state regarding the assumptions. It runs on the basis of sets. Each of those sets represents a linguistic variable interpreting the possible state of the output as shown in Figure 8 and Figure 9. A group of the set are each possible input state and the grades of change relying upon which the prediction of output is done. It fundamentally adopts the concept of If-else-the, i.e. If B and C then A.

Neutral Point Clamped Converter- NPC
A neutral point clamped is a three-level voltage source inverter. The new topology of using NPC in the wind solar cogeneration system has been adopted for high power application as it can achieve better harmonic mitigation than traditional two-level VSI. It is noticed that the NPC multi-level inverter is capable of producing only twenty-two percentage and thirty-two percentage THD voltage, meanwhile the two-level inverters for this similar test produces hundred and fifteen percentage THD voltage. NPC is used mainly to reach a quality output voltage or output current with subtle ripple content. It is also noted that two-level inverters have high switching frequency along with other pulse width modulation techniques which incurs heavy losses. The usage of NPC lowers the switching rate which in turn lowers the loss and amends the operational efficiency. The usage of NPC also reduces the circulating and leakage current in the system as shown in Figure 11.
Thus, the proposed system of wind-solar cogeneration system connected to the utility grid through no extra dc/dc conversion stages possess NPC, fuzzy logic controller, VSC and others.

3. Research Background
The paper [2] presents the idea of inquisitive stability study of varying speed straightly driven perpetually excited two mega-watt wind generator. It proposes a system which has two b-t-b vector controller full scale three level NPC VSC. Though the paper proposes a system the availability of wind is irregular therefore the power quality as well as generation is not constant. The paper [3] presents the topology of standalone micro-grid based on a single VSC. It uses different renewable sources such as wind and solar. It also uses BESS (Battery Energy Storage System) and diesel energy generator set for achieving the reliability of the system. But it lags to provide information on power quality issues that rises due to wind availability. The paper [4] provides information on modelling of PV generators and its types for feeding its power-to-power electronic converters. This paper doesn’t provide enough information on simulation and designing of the power electronic converters best opted for the solar generation. The paper [5] focuses of Adaptable Sliding Mode control (ASMC) for hybrid generation due to wind, solar and hydro. It uses ASMC controller for VSC controlling. The ASMC just overcomes the high activity of control action and chattering other than that the stability and higher order sliding surface remains. The paper [6] focuses on harnessing strategy for Watt-flow management for a hybrid generation i.e., wind and solar energy with a many input t/f coupled two directional dc-dc converters is proposed. The paper’s objective is to convince the load demand, watt-flow management from numerous sources, and superfluous power injection into the grid and recharge the battery whenever required from the grid [7]. The paper provides good information on power quality but has lesser control over mitigating power quality issues such as the little higher switching rate due to which efficiency is lowered, the presence of leakage and circulating current is not considered. It also gives the simulation output using MATLAB/Simulink [8].

4. Simulation Results
The simulation of the proposed wind-solar co-generation system is proceeded with the MATLAB/Simulink. The following are the output voltage of different devices and generator. These generators include solar and wind, the power electronic devices include the Neutral Point clamped VSC’s output and the grid voltage and current wave forms. Each of these waveforms are noted and tabulated and the output is clearly compared with the existing system’s simulation results as shown in Figure 12 and Figure 13.

![Fig. 12: Output voltage for PV](image)

![Fig. 13: Output power for PV](image)

The above output graph shows the $V_{out}$ of Photovoltaic array under solar radiance and the $P_{out}$ trapped by the photovoltaic array.

![Fig. 14: Common DC-link voltage](image)

![Fig. 15: Grid output Voltage and current](image)
The Figure 14 and Figure 15 shows the common dc-link voltage and grid voltage and current output got from Simulink respectively. From these figures it can be noted that the ripple free output is achieved by the proposed system. The common dc-link voltage is nearly around 250V approximately.

The other readings are tabulated in the following.

### Table 1: Output Parameters Obtained from Simulation

| Parameters      | Values     |
|-----------------|------------|
| Wind Voltage    | 2 kV       |
| Wind Power      | 50 kW      |
| Solar Voltage   | 275 V      |
| Solar Power     | 100 kW     |
| Total Grid Power| 148 kW     |
| NPC Voltage     | 280 V      |
| DC Link Voltage | 280 V      |

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