Unbalanced Fault Control for a Grid Connected Hybrid Renewable System

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Abstract— One of the most popular issues in the future power generation is the renewable energy and the development of grid energy system. Different types of renewable energies are harnessed and integrated into the Grid system formed a hybrid grid energy system, which can enhance the stability and flexibility of the entire energy system. This paper presents the modeling and control of Wind-PV grid connected system under unbalanced fault condition. Control operation of hybrid system under normal as well as unbalanced fault conditions is analyzed. Multiple input DC-DC converters are designed to integrate the renewable energy sources into the main DC bus. This study considers both wind energy and solar irradiance changes in combination with the load power variations. It is shown that the major constraints like harmonic is to be absorbed by the DC link capacitor and the control effectiveness depends on the voltage and current capabilities of the semiconductor in the inverter circuit. Finally wind-PV hybrid energy system is integrated with the IEEE 14 bus test system in MATLAB SIMULINK environment. Simulation and test results for the proposed system performances under unbalanced fault condition are presented in order to supply continues power to the load.

Key words: PV Power Generation, Wind Power Generation, Distributed Power Generation Systems, Control Strategies, Permanent Magnet Synchronous Generator, Grid Fault

I. INTRODUCTION

Renewable energy resources, which are becoming integrated into electric power systems around the world, connect to existing transmission grids at a range of voltage levels. The massive installation of wind power systems in the last years has been launched by the arrival of variable speed wind turbines (WT), which are able to produce electrical power for a wide range of carrying wind conditions [1]. One of the most commonly used renewable energy source is the solar energy in grid system. PV system is growing 15% per year during last two decades and it's developing even faster recent years, the speed is up to 30% per year. But unfortunately PV system has two major problems due to changes continuously with the wind weather conditions. The Voltage-Current (V-I) characteristic is nonlinear and varies with irradiation and temperature. Therefore a flexible control system is needed to regulate the operation of grid [2].Wind power plant plays an important role around electrical power. There are two types of generators are used to generate power. One is variable speed drive system another one is fixed drive system. Among these generator types used for wind turbines, the technical development has moved from fixed-speed to variable-speed concepts. In [3] wind farms with fixed speed induction generators are controlled by means of STATCOM under Asymmetrical grid fault condition. In power system network Grid codes in many countries require low-voltage ride-through (LVRT) capability to maintain system stability and reliability during grid fault conditions [4]. Unbalanced grid fault ride through control for a large variable speed wind turbines with fully rated direct-in–line voltage source converters [5], [8]. A power management control strategy of a standalone wind-PV-fuel cell hybrid energy system has proposed in [6], [7]. This distributed generation system is synchronized with the grid system to supply power [9].

Total installed power from renewable-energy sources is constantly growing in the new electric power system scenario. Among them, photovoltaic and wind turbine are gaining increasing attention in the last few years [10]. When connected to the grid, renewable-energy sources behave as distributed generation (DG) systems. Conventionally, a distributed generation system would be required to disconnect from the grid when voltage dips occur and to reconnect to the grid when faults are cleared [11].

This paper presents a modeling and control strategy for a sustainable grid primarily powered by wind and PV energy sources. A multiple-input dc-dc converter is used to integrate the renewable energy sources to the main dc bus. Potential suitable applications range from a communication area or a residential area. A direct-driven permanent magnet synchronous wind generator is used with a variable speed control method whose strategy is to capture the maximum wind energy below the rated wind speed. This study considers both wind energy and solar irradiance changes in combination with load power variations. Wind turbine power input is converted into DC by means of rectifier. Multiple inputs DC-DC converter is used to control the combined output of PV and wind power system. The inverter unit is used to convert the DC generated power from renewable energy sources to feed the load with the required AC power. Finally this PV-Wind renewable hybrid system is integrated into IEEE 14 bus system to supply power to grid.

II. PROPOSED SYSTEM ARCHITECTURE

Fig. 1 shows the overall hybrid system architecture of the proposed grid based wind and PV energy sources. The main sources of wind-PV power generation are based on the varying wind conditions and solar irradiation conditions. To combine power produced from these energy sources, the multi input converter, such as MI cuk converter is used. This MI dc-dc converter is more effective for maximum power point tracking in PV modules. MICs were chosen because they provide a cost-effective and flexible method to interface various renewable energy sources. In addition, a dc power distribution system is chosen because dc power systems may achieve higher availability and energy efficiency in a simpler way than equivalent ac power systems.

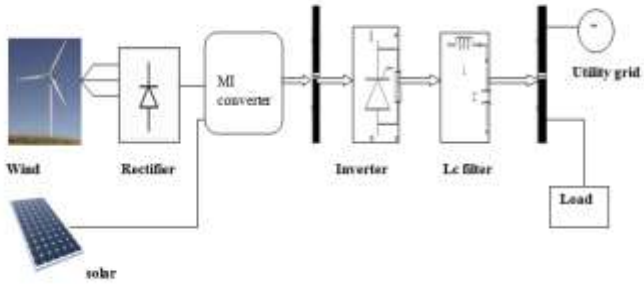

Fig. 1: Overall system Architecture

The voltage level of 415v is considered to be the main DC bus in this system because it is more suitable for bidirectional power flow between the intended power system and the utility grid. Finally DC bus power is converted into AC by means of Inverter, after filter circuit it is fed to the grid system .For that purpose this DG hybrid unit is integrated into the IEEE 14 bus system. Depending on the applications, various voltage levels of local AC loads are also connected with the hybrid system.

III. MODELING COMPONENTS OF PROPOSED TEST SYSTEM

The proposed hybrid system consists of the following renewable sources.

1) 20KW wind turbine
2) 10KW PV array system

A. *Wind Energy Source*

There are different types of wind turbine generator and one of the commonly used WTG in PMSG.

Amount of mechanical power produced by the wind turbine is given by

$$P_m = \frac{1}{2} C_p(\lambda,\beta)\rho A v_w^3 \qquad (1)$$

Where ρ = Air density (Kg/m3)

A = Swept area (m^2)

C_P = Power coefficient of the wind turbine

V = wind speed (m/s)

Therefore, if the air density, swept area and wind speed are constant the output power of the turbine will be a function of power coefficient of the turbine. In addition, the wind turbine is normally characterized by its CP-λ curve; where the tip speed ratio, λ, is given by:

$$\lambda = \frac{\omega R}{V} \qquad (2)$$

The expression "Cp (λ, β)" is calculated using below equation.

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda$$

Coefficients C1 through C6 are: C1 =0.5176,C2 =116,C3 =0.4,C4 =5,C5 =21, and C6 =0.0068. β is equal to 0, but, if necessary, this value can be changed. Parameters and Specifications of The Wind Turbine Model is shown in Table 1

Parameter name	Value	Unit
Rated power	20	KW
Rated wind speed	12	m/s
Rated rotor speed	27.54	Rad/s
Blade radius	3.7	M
Blade pitch angle	0	Degree
Air density	1.225	Kgm3

Table 1: Parameters and Specifications Of The Wind Turbine Model

B. *Direct-Driven PMSG*

The wind generator considered here is a gearless direct-driven PSMG. This PMSG does not require frequent mechanical maintenance because it does not use gears between wind blades and the generator. Another advantage of the direct-driven PMSG is that a permanent magnet eliminates the dc excitation circuit that may complicate the control hardware [23].

Table II shows the specifications of the direct-driven PMSG model used in the simulation study. For the simulation study, the internal model of a PMSG in MATLAB Simulink/Simpowersystems is used with the specifications provided in Table I.

C. *PV System Model*

A solar cell is the most fundamental component of photovoltaic (PV) system, which converts the solar energy into electrical energy. A solar cell essentially consists of a pn junction formed by semiconductor material. When sunlight falls on a solar cell an electron-hole pair is generated by the energy from the light (photons). The electric field created at the junction causes the electron-hole pair to separate with the electrons drifting towards the n-region and the holes towards the p-region. Hence electrical voltage is generated at the output. The photocurrent (Iph) will then flow through the load connected to the output terminals of the cell.

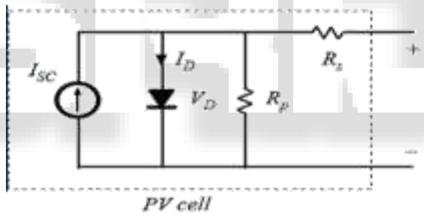

Fig. 2: Equivalent circuit of PV cell

The ideal equivalent circuit of a solar cell consists of a current source in parallel with a diode. Figure 2 shows in Equivalent circuit of PV cell. Short circuit current equation of solar cell is given by

$$I_{sc} = I_D + \frac{V_D}{R_P} + I_{PV} \qquad (4)$$

Where I_{SC} = Short circuit current (A)

I_D =Diode current (A)

V_D =Voltage across diode (V)

R_p =Equivalent shunt resistance (Ω)

I_{PV} =Photo current (A)

Diode characteristics equation is given by

$$I_D = I_o\left(e^{V_D/V_T} - 1\right) \qquad (5)$$

Where I_o =Diode reverse saturation current (A)

V_T =Voltage at ref temperature

The power output of a solar cell is given by

$$P_{PV} = V_{PV} * I_{PV} \qquad (6)$$

$$P_{PV} = V_{PV} * I_{PV} \qquad (7)$$

Where: I_{PV} = Output current of solar cell (A).

V_{PV} = Solar cell operating voltage (V).
P_{PV} =Output power of solar cell (W).

The power-voltage (P-V) characteristic of a photovoltaic module operating at a standard irradiance of 1000 W/m2 and temperature of 25°C is shown in Fig.3

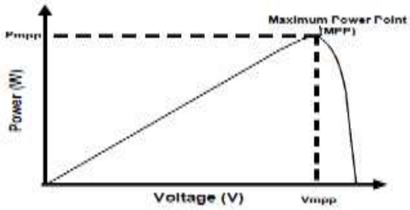

Fig. 3: Power-Voltage Characteristics of PV module

The PV system is also controlled so that it operates at its MPP. An incremental conductance method [27] is selected for this purpose. It uses the PV modules output current and voltage information based on polarity changes in the derivative of power with respect to their voltage, which is zero at the MPP, positive at the left of the MPP, and negative at the right of the MPP.

D. MI DC-DC CONVERTER

The proposed hybrid Wind-PV system uses the multiple inputs DC-DC CUK to control the dc output power. These MI CSI converters provide nearly continuous input current waveforms due to their CSI input legs. Hence, these converters provide more operational flexibility than an MI buck boost converter because they allow the integration of input sources that require a relatively constant current. An MI Ćuk converter is similar to an MI SEPIC converter [15], [19] except for the output voltage inversion. However, since there are more past works focusing exclusively on the MI SEPIC [19], the analysis here focuses on the MI Ćuk converter shown in Fig. 4

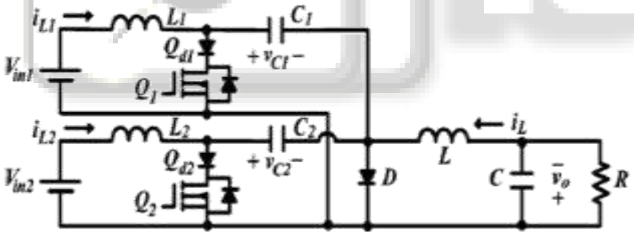

Fig. 4: MI Cuk DC-DC converter

IV. SIMULATION RESULTS AND DISCUSSION

Fig 5 shows overall simulation block diagram of proposed IEEE 14 bus test system with DG unit. This system is analyzed under normal as well as unbalanced grid fault conditions. This Wind-PV hybrid system is integrated with IEEE 14 bus system to supply the power to grid. Fig 6 shows single line diagram IEEE 14 bus test system. It consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 Mvar. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are considered to be 0.95p.u. to 1.05p.u. and -45_ to +45_ respectively.

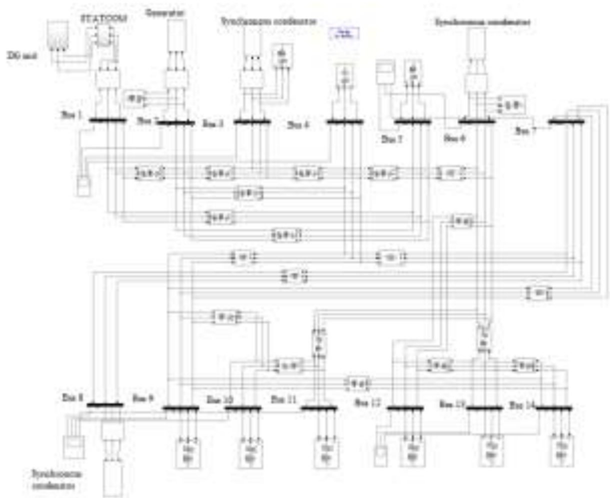

Fig. 5: Simulation model of proposed IEEE 14 test system

Fig 6 shows 20 KW wind turbine output wave form and Fig 7 shows PV and VI curves of 10 KW photovoltaic system. Fig 6 shows the output power waveform of test system with DG unit under normal mode of operation. Under this condition system produce uniform power output to grid. Both the wind and PV system power output varies with the changes in wind speed and irradiation levels of whether conditions. By use of converter circuit this hybrid unit output is regulated and then, it is integrated into the test system.

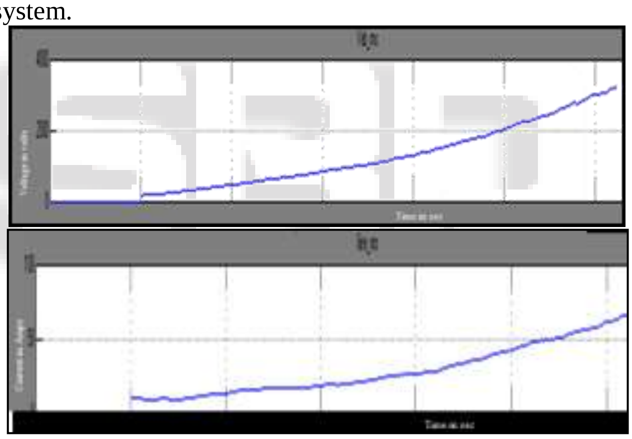

Fig. 6: Wind turbine output

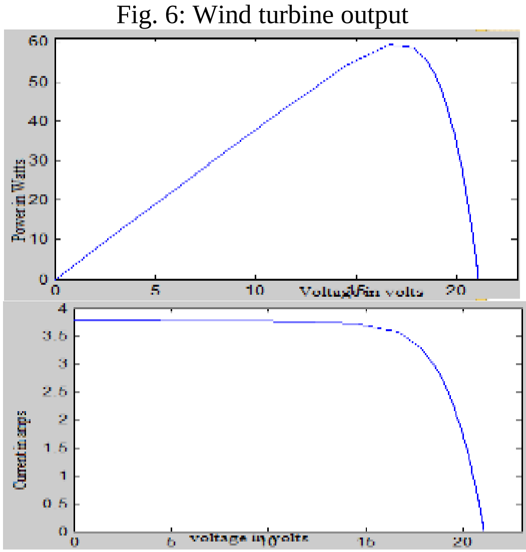

Fig. 7: PV and VI curves of Solar system

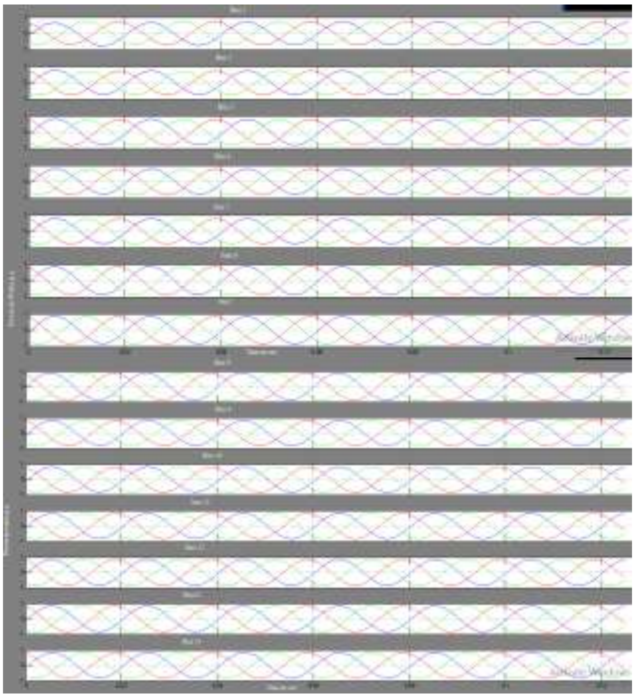

Fig. 8: Output waveform under normal operation both source and grid side

Fault analysis is done for both supply and load sides. Under unbalanced fault conditions ie, L-G, L-L, L-L-G faults the proposed system is not affected by use of MI-DC-DC converter. This converter mitigates these unbalanced source side faults. IEEE 14 buses are producing same power under source side fault. But due to these fault grid side all the bus outputs are affected. To clear these faults to improve power output STATCOM equivalent circuit is designed and injected in grid side test system. Under L-L-G and L-L fault the bus output waveforms are displayed in Fig

Fig. 9: Bus outputs under unbalanced fault condition in grid side

After the fault clearance the test system with DG unit produce uniform uninterrupted supply to grid. By use of STATCOM equivalent circuit these unbalanced faults are cleared in all the 14 buses. These output waveforms are shown in Fig 10.

Fig. 10: Output Waveforms

V. Conclusion

The paper presents a wind, photovoltaic and fuel cell hybrid energy system, designed to generate a continuous power irrespective of the intermittent power outputs from the wind and photovoltaic energy sources. The wind and photovoltaic systems are controlled to operate at their point of maximum power under all operating conditions. The simulation results shows that the following results. The MI dc-dc converters are very effective in tracking the maximum power of the wind and photovoltaic sources. With both wind and photovoltaic systems operating at their rated capacity, the system can generate power as high as 20KW The system is capable of providing a minimum power of 10 kW to the load even under worst climatic conditions, when the wind and photovoltaic energies are completely absent. These hybrid renewable sources are integrated with the IEEE 14 bus system. Simulation results are shown that, the unbalanced faults are analyzed both source and grid side of the system. Performances of the IEEE 14 buses are controlled under unbalanced faults in grid side and simulation results are displayed.

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