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Performance Analysis of Integrated PV Wind and Fuel Cell Hybrid System Connected to Grid

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Abstract—*This paper deals with performance of integrated Photovoltaic (PV), Wind and Fuel cell hybrid system connected to grid. PV system connected to grid via DC-DC boost converter and three phase three level voltage source converter (VSC). Fuel cell also connected to grid via DC-DC boost converter and three phase three level voltage source converter. Doubly fed induction generator (DFIG) is used as wind turbine connected to grid in the hybrid system via transformer. In this paper simulation with Total Harmonic Distortion (THD) measurement of hybrid system has been developed using MATLAB Simulink. THD of the hybrid system shows hybrid system quality. Performance of the Hybrid system is decided by the measured THD of the hybrid system. In the proposed system there are four cases have been carried out viz. case1: PV system connected to grid, case2: PV system and Fuel cell connected to grid, case3: PV system and Wind energy system connected to grid, case4: PV system, Fuel cell and Wind energy system connected to grid.*

1. Introduction

The continually increasing energy consumption, rising public awareness of environment protection, the increasing cost and the exhaustible nature of fossil fuel have created fine interest in green energy sources (i.e., Renewable and Fuel cell based). Wind and Solar are two of the most hopeful renewable power generation system [1]. Fuel cells (FCs) also show great potential to be green energy sources of future because of many merits they have such as high efficiency, zero or low emission of pollutant gases, flexible modular structure, and reusability of exhaust heat, on-site installation and rapid progress in FC technology [1]. PV, Wind with Fuel cell integration to grid is best suitable for future energy requirement and power quality improvement of the system. Integration of PV, Wind with Fuel cell as storage device replacing the conventional battery and supercapacitor [2]. A hybrid energy system generally contains of two or more renewable energy sources used together to provide improved system efficiency as well as greater balance in energy supply [4]. The ideal power system has balance load and sinusoidal load supply with unity power factor and zero total harmonic distortion. But practically it is not possible because of linear and nonlinear load. PV and Wind energy system are primary energy sources whereas Fuel cell is used as secondary or back up energy source [5]. Reliability of the hybrid system has increased when we used PV, Wind and Fuel cell with Grid.

In the proposed system a hybrid PV, Wind and Fuel cell are connected to grid. The objective of this proposed system has to find out THD of the hybrid system. In the proposed system performance analysis with THD measurement by the MATLAB Simulink for four different cases has been done. The four cases considered are:

Case1: PV system connected to grid.
Case2: PV system and Fuel cell connected to grid.
Case3: PV system and Wind energy system connected to grid.
Case4: PV system, Fuel cell and Wind energy system connected to grid.

The systematic diagram of proposed system is shown in Figure 1.

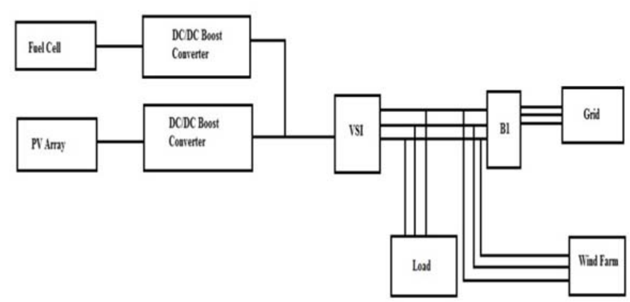

Figure 1. Systematic block diagram of proposed system

2. PV System

Solar photovoltaic generation system are becoming increasing significant as renewabe energy source since it offers many benefits such as incurring no fuel cost, not being polluting, requiring little maintenance and emitting no noise among others [2]. The construction block of PV arrays is the solar cell which is mainly a p-n semiconductor junction. When sun light falls on a solar cell an electron hole pair is created by the energy from the light (photons). The electric field generated at the junction causes the electron hole pair to seperate with the electron traveling towards the n region and holes towards the p region. Hence electric voltage is generated at the output. The photocurrent will then flow through the load connected to the output terminals of cell.

The ideal equivalent circuit of a solar cell consists of a current source in parallel with a diode. The output terminals of the circuit are connected to the load. Ideally the voltage current equation of the solar cell is given by equation (1)[5] as:

$$I_{PV} = I_{ph} - I_0(e^{\frac{qV_{PV}}{KT}} - 1) \quad (1)$$

Where
$I_{ph} = Photo\ current$(A)
$I_0 = Diode\ reverse\ saturation\ current(A)$
q=Electron charge (1.6$\times 10^{-19}C$*)*
K=Boltzmann constant (1.38$\times 10^{-23}J/K$*)*
T= Cell Temperature (K)

The power output of a solar cell is given by equation (2) [5] as
$P_{PV} = V_{PV} \times I_{PV}$ (2)

Where
$I_{PV} = Output\ current\ of\ solar\ cell(A)$
$V_{PV} = Solar\ cell\ operating\ voltage(V)$
$P_{PV} = Output\ power\ of\ solar\ cell(W)$

Maximum power for a single PV array in watts is given by equation (3) [3] as:
$PV_{array} = N_{parralel} \times N_{series} \times P_{maxpower}$ (3)
Where $N_{parralel}$ is number of parallel strings which is 66, N_{series} is number of series connected modules per string which is 5 and $P_{maxpower}$ is maximum power which is 305.2 watts in the proposed model of PV array. SunPower SPR-305E-WHT-D module of PV array system is used in this proposed system.

3. Wind Energy System

In this configuration, wind generation is based on constant speed topologies. The Doubly fed induction generator is used in this proposed scheme because of its simplicity. The available power of wind energy system is presented in equation (4).

$$Wind\ power(P_r) = \frac{1}{2}\rho AV^3 \quad (4)$$

Where ρ (kg/m^3) is the air density and A (m^2) is the area swept out by turbine blade, V is the wind speed in meter/second [9]. As it is not possible to extract all kinetic energy of wind due to losses in the system. Therefore it extract only fraction of wind power and it is given in equation (5).

$$Mechanical\ power\ of\ wind = \frac{1}{2}\rho AV^3 C_p \quad (5)$$

Where C_p is the power coefficient of wind turbine and it depends on operating condition and type of wind turbine [9].

The power generated by wind turbine at different wind speed is given in equation (6) as:

$$\left.\begin{aligned} P &= 0, (v < v_i\ or\ v > v_o) \\ P &= P_r \frac{(v-v_i)}{(v_r-v_i)}, (v_i \le v \le v_r) \\ P &= P_r, (\ v_r \le v \le v_0) \end{aligned}\right\} \quad (6)$$

Where v_i, $v_o$and v_r are cut in, cut out and rated wind speed for wind turbine system respectively and P_r is the rated power of the wind turbine [10]. There is no power generated at wind speeds below cut-in speed or above cut-out speed. Power is only generated between cut in and cut out speed.

4. Fuel cell system

The Fuel cell is an electrochemical device that produces electricity by chemical reaction that does not alter the electrodes and electrolyte materials [6]. Fuel cell is a static device that changes the chemical energy of fuel directly into electric energy. Byproducts of fuel cell are water and heat only if the fuel is pure hydrogen. As there is no moving parts in fuel cell so it is additional benefit of fuel cell as compared to the diesel generator.

In the proposed scheme Proton Exchange Membrane Fuel cell (PEMFC) is used. In the proposed system, air is used as the oxidant and hydrogen tank as fuel [6]. The net reaction in a typical FC is given by equation (7) as

$2H_2$+O_2=H_2O (7)

The output of the fuel cell is given by equation (8) as

$$V_{cell} = E - \Delta V_{act} - \Delta V_{ohm} - \Delta V_{trans} \quad (8)$$

Where E is the open circuit voltage, ΔV_{act} is the voltage drop due to activation of the anode and cathode, ΔV_{ohm} is the ohmic voltage drop resulting from the resistance of the electrodes and resistance of the electrolyte, ΔV_{trans} is the voltage drop resulting from the reduction of the concentration of reactants gases [6].

5. System Performance and THD

The simulation result with THD of voltage and current at bus B1 for four cases has been analyzed. Figure 2 and Figure 3 show THD of voltage and current respectively for case1. Figure 4 and Figure 5 show THD of voltage and current respectively for case2. Figure 6 and figure 7 show THD of voltage and current for case3 respectively. Figure 8 and Figure 9 show THD of voltage and current respectively for case4.

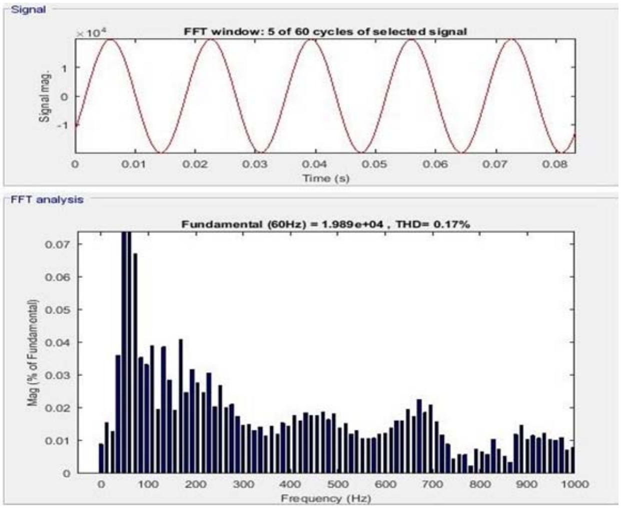

Figure 2. THD of voltage for case1

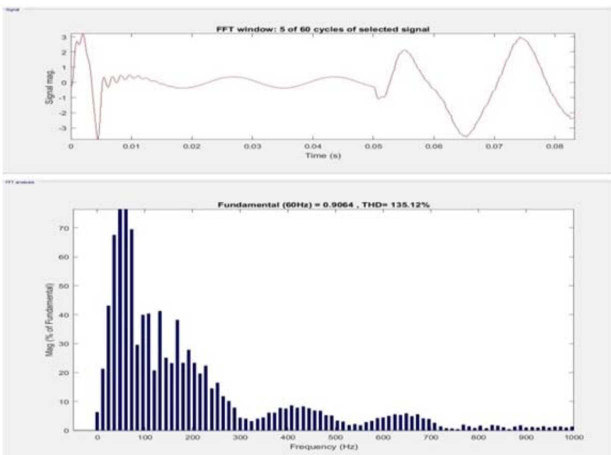

Figure 3. THD of current for case1

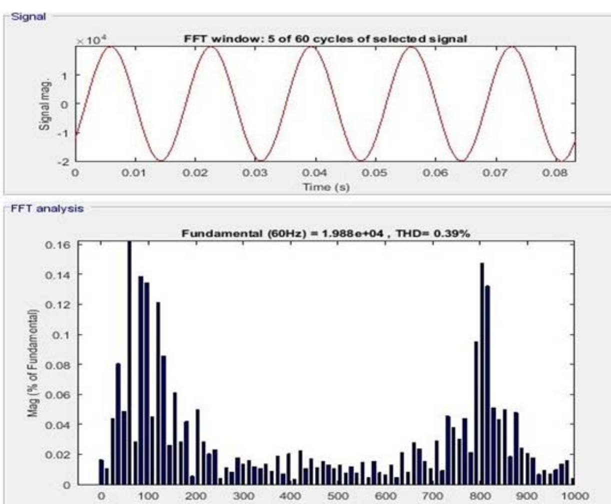

Figure 4. THD of voltage for case2

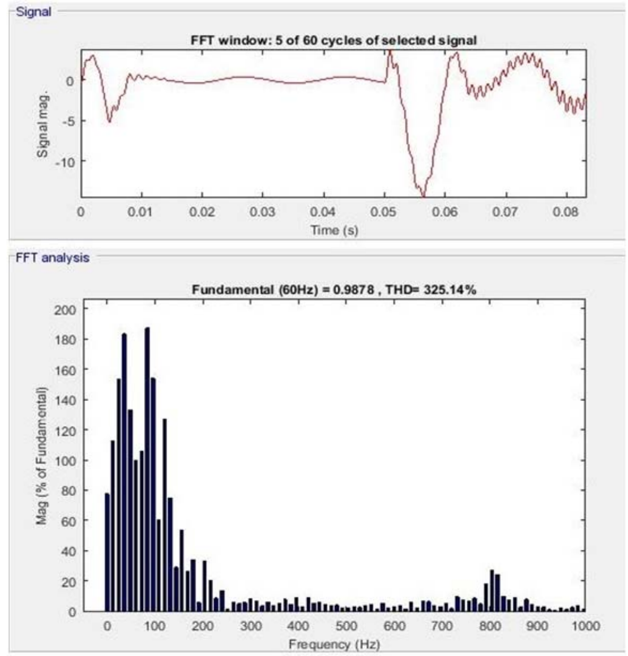

Figure 5. THD of current for case2

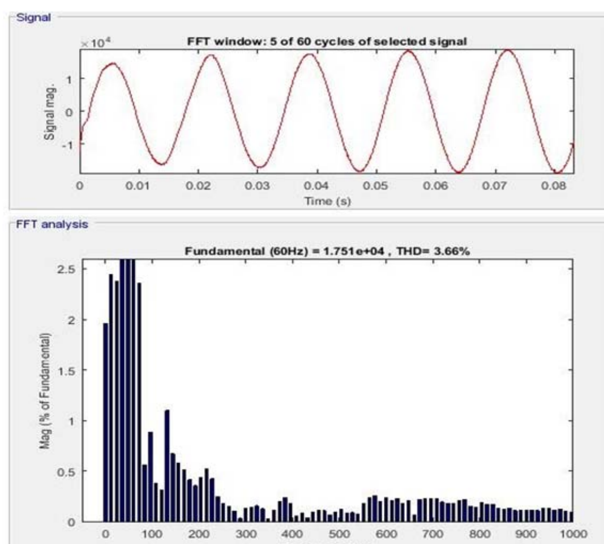

Figure 6. THD of voltage for case3

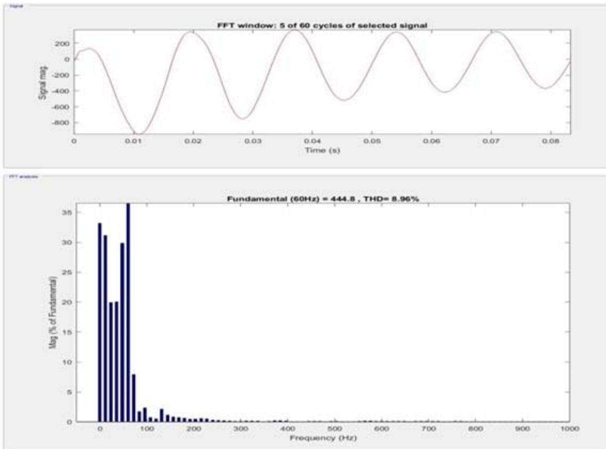

Figure 7. THD of current for case3

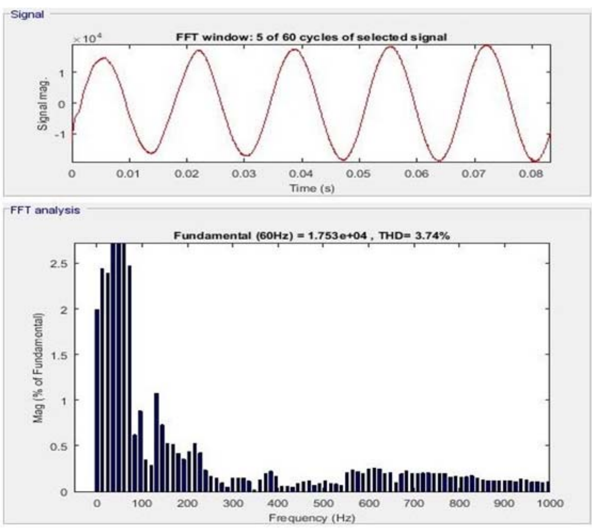

Figure 8. THD of voltage for case4

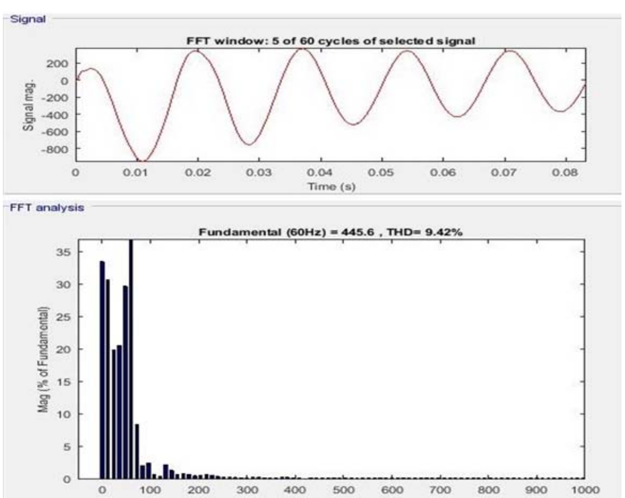

Figure 9. THD of current for case4

Table 1. THD at bus B1 for different cases

	Case1	Case2	Case3	Case4
% THD of voltage	0.17	0.39	3.66	3.74
%THD of current	135.12	325.14	8.96	9.42

The THD for different cases has been analyzed at 60Hz fundamental frequency and for 1000Hz maximum frequency by FFT analysis for 5 cycles. THD for different cases has shown in Table1. The THD of voltage and current at bus B1 for case4 i.e., hybrid PV, Wind and Fuel cell system with grid is 3.74% and 9.42% respectively.

6. Specification

Table 2. System Parameters

S. No.	Parameters	Rating
1.	Wind turbine generator(DFIG)	9MW
2.	PV system (SunPower SPR-305E-WHT-D)	100KW
3.	Boost converter	500V
4.	Fuel cell (PEMFC)	6KW,45V
5.	Grid	120KV,2500MW
6.	Rated frequency	60Hz
7.	Load	2MW,30MW,2MVar,10KVar

7. Conclusion

The Hybrid system containing Wind (DFIG) Energy system, PV array system (SunPower SPR-305E-WHT-D), and Fuel cell (PEMFC) energy system with grid has been successfully implemented and simulated using MATLAB simulation at 60 Hz fundamental frequency and for 1000 Hz maximum frequency with 5 cycles. THD has been calculated for voltage and current separately at bus B1 for four cases i.e., for case1, case2, case3 and case4. The THD has obtained by FFT analysis for voltage and current for proposed system for case4 is 3.74% and 9.42% respectively. The THD result shows that the reliability, power quality and performance of hybrid PV, Wind, Fuel cell system with system has been improved.

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