THD ANALYSIS AND FREQUENCY RESPONSE STUDY OF PQ-CONTROLLED L-FILTER GRID INTEGRATED WIND/PV HYBRID ENERGY SYSTEM UNDER DYNAMIC CONDITIONS

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Abstract: *Now a day due to depletion of fossil fuels, renewable energy sources are plying major role in contributing to meet load demand to certain extent. Due to technology advancement and the mass production of the equipments like wind turbine generators, photovoltaic cell and power electronic devices, etc. the wind and photovoltaic generating systems are becoming cost effective to install and operate. Due to varying output of the wind energy and the photovoltaic (PV) energy systems, the hybrid energy system is preferred to deliver continuous power.*

This paper is to model and simulate dc-connected grid-interfaced hybrid PV/Wind power system interfaced through power electronic models using MATLAB/SIMULINK. Using simulated model, performance study is done for different dynamic conditions.

Key-words: *Wind model, PV model, Voltage source inverter (VSI), PQ controller and DC shunted system.*

1. Introduction

The energy demand is increasing day by day due to increase in industrialization and standard of living. Renewable energy sources (RES) are abundant sources which are from direct sun energy or derived form of energy sources like wind, tidal, wave, etc., and these will play a major role to meet energy demand. Hybrid energy system (HES) consists of more than two energy sources. In RES hybrid systems there are two kinds; first topology is wind power with fuel cell and other topology is wind power with PV [1] & [2]. PV/wind energy systems are combined into hybrid system due to their complementary power output. Therefore hybrid PV/wind energy system has more capability to generate uninterrupted power output. In case of hybrid isolated energy systems, battery banks are necessary to feed the load, the best way to utilize these renewable energy sources (RES) is in the grid connected mode of operation. Due to grid integration of RES, the harmonics are produces because of nonlinearity of power electronic converters. The overall harmonics produced here will disturb the grid quality of supply too. So here the simulation model has been developed to study HES wind/PV system to do dynamic system performance studies and the corresponding power quality indices like THD study.

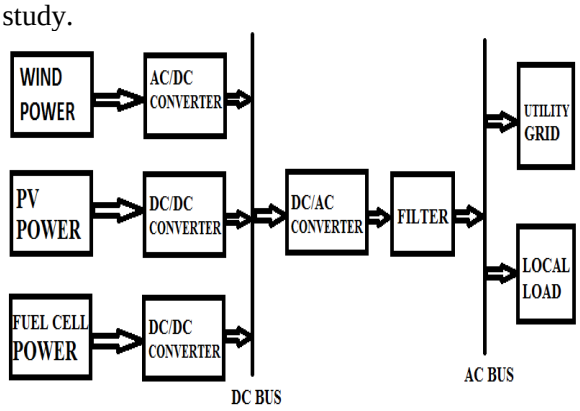


Fig. 1 Block diagram of DC-shunted HES

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The above block diagram of HES consists of wind power, PV power and fuel cell power systems interfaced to the grid. Here the DC bus has been created to connect all RES regulated output by the help of power converters. The DC bus is connected to VSI with filter to feed power to local loads as well as the grid [12] & [14].

2. Dc-shunted topology of grid-interfaced pv/wind hes

The DC output from PV system and the AC output from wind system is fed to grid by the help of suitable converters. The DC connected topology is discussed below [4].

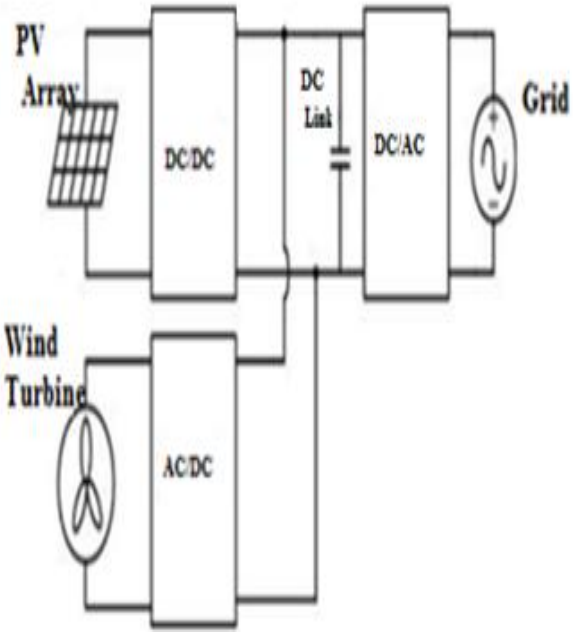


Fig. 2 Schematic diagram of DC topology

In Fig. 2 the regulated DC output of PV system from controlled DC/DC converter and the uncontrolled rectified output of wind energy system connected to one more controlled converter are connected to a common DC link. Input of DC/AC converter is fed from DC link and AC output of converter is fed to grid using PQ controller [15] & [16].

The modeling aspect of the above system is discussed as follow:

2.1 Boost converter design

Boost converter gives regulated DC voltage from variable DC input which is obtained by wind and PV arrays.

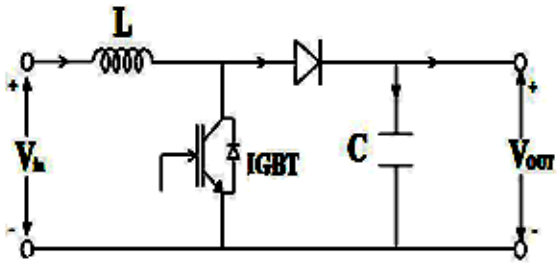


Fig. 3 Block diagram of DC/DC boost converter

The Fig. 3 shows the boost converter topology, it is connected between RES and DC link. The regulated DC output is obtained by controlling the gate pulse of IGBT switch which is controlled by PWM output tuned by PI controller with respect to reference voltage.

Components are calculated by using the following equations: [6]

$$D = 1 - \frac{V_{in}}{V_{out}} \quad (1)$$

$$R = \frac{{V_{out}}^2}{P_{in}} \quad (2)$$

$$L = \frac{D(1-D)^2 R}{2 * f_s} \quad (3)$$

$$C \geq \frac{V_{out} * D}{R * f_s * \Delta V_{out}} \quad (4)$$

Where, D is Duty cycle, $V_{in\ is}$ Input voltage from RES, V_{out} boost converter output voltage, $P_{in\ is}$ Input power from RES, R is Load resistance and f_s is Switching frequency.

2.2 Voltage source inverter (VSI)

The VSI converts rectified DC power into 3Φ AC power source.

Typically those are controlled by two ways. One is active power (P) and reactive power (Q) control scheme under grid interfaced condition and other one is active power (P) and voltage (V) control under isolated load condition [3] [7] [8] & [11]. Here the PQ control scheme is implemented using SIMULINK.

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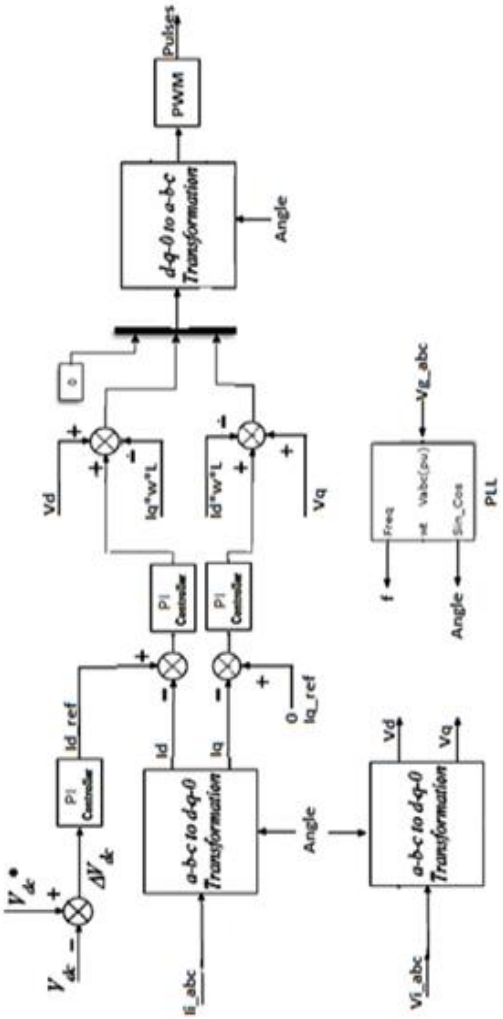


Fig. 4 Simulated PQ control strategy [17]

Fig. 4 grid connected inverter control scheme. The voltage of DC link is measured and compared with DC link reference voltage to control active power flow. This error is taken as current reference to compare actual current. Inverter control performed in d-q frame rotating [17]. The voltage equations are as follow.

$$V_d = V_{sd} - R_f i_d - L_f \frac{di_d}{dt} + \omega L_f i_q \quad (5)$$

$$0 = V_{sq} - R_f i_q - L_f \frac{di_q}{dt} - \omega L_f i_d \quad (6)$$

q-axis current is set by q-axis voltage controller to control the reactive power flow. Decouple of d-q axes are done by the parameters $\omega L f i_q$ and $-\omega L f i_d$.

2.3 Simulated model

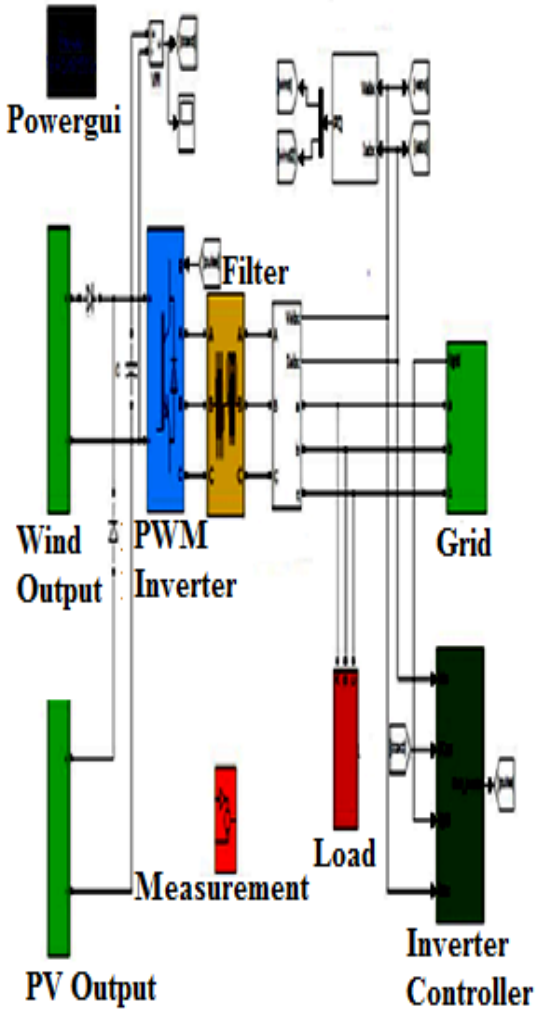


Fig. 5 Simulated diagram of DC-shunted topology of grid-interfaced hybrid PV/wind HES

Fig. 5 shows the final modeled simulation diagram. System is modeled by interconnecting PV and wind system model, DC/DC boost converter, DC link, VSI, Local load and the utility grid as shown [9] & [10].

3. Results and Discussions

By using the simulated model, performance study has been done by giving following input parameters: Solar irradiation 800 W/m^2, temperature 25^{0}C, wind seed 12 m/s and load parameters active power 100 kW, reactive power 60 kVAR are given to simulated model with 415V, 50 Hz as grid parameter. To do dynamic performance study, the particular parameters are changed during the particular dynamic period as given in each case.

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3.1 Variation of load

In this case the 50 KW load is increased during 1s.

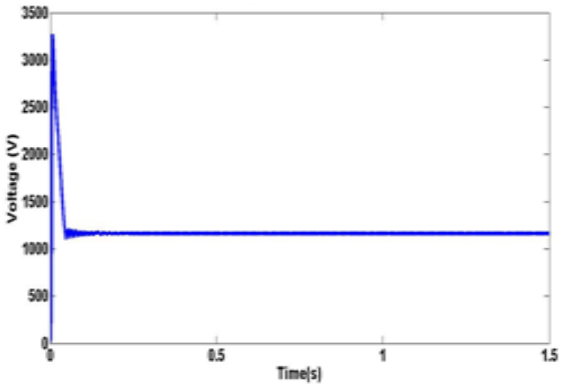


Fig. 6(a) DC Link Voltage.

In Fig. 6(a) constant DC link voltage is obtained during simulation with the help of boost regulators tuned by PI controllers.

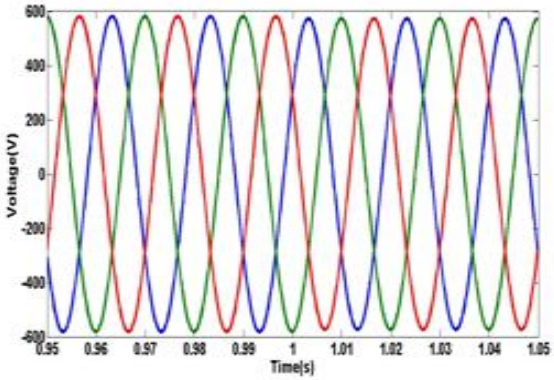


Fig. 6(b) AC Voltage.

In Fig. 6(b) constant voltages are obtained throughout simulation controlled by the controller.

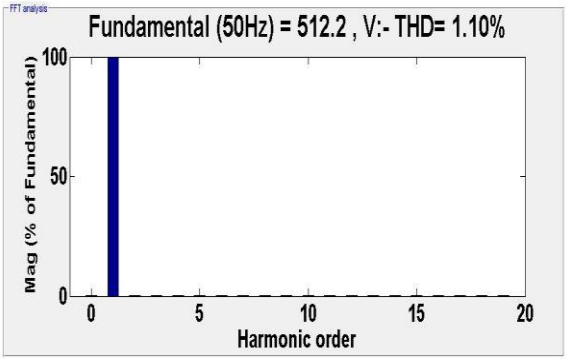


Fig. 6(c) AC Voltage THD.

In fig. 6(c) shows voltage THD index of AC voltage waveform which shows 1.10% and it is within limit as mentioned in grid standards (IEEE-1547).

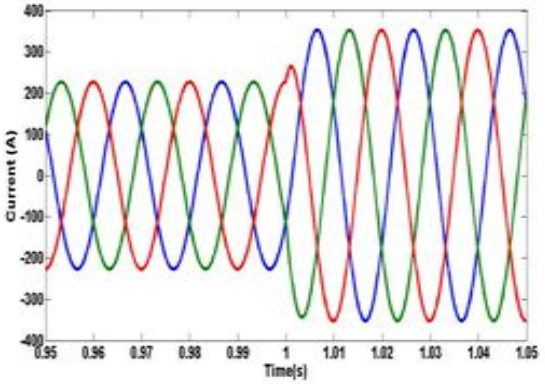


Fig. 6(d) Load Current.

Fig. 6(d) shows variation of AC current at load terminal due to increase in load at 1s. The current has been increased at 1s and the increased load current is fed from grid which is shown in fig. 6(f).

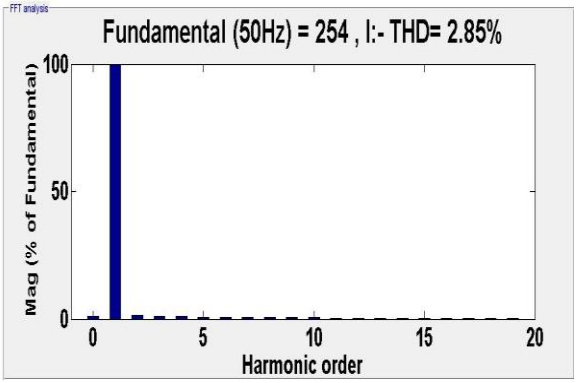


Fig. 6(e) Load Current THD.

In fig. 6(e) shows current THD index of AC load current which shows 2.85% and it is within the limit as mentioned in grid standards (IEEE-1547).

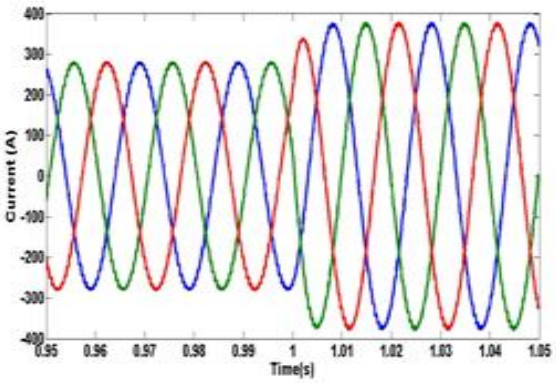


Fig. 6(f) Grid Current.

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Fig. 6(f) shows variation of AC current at grid terminal to feed increase in load demand at 1s.

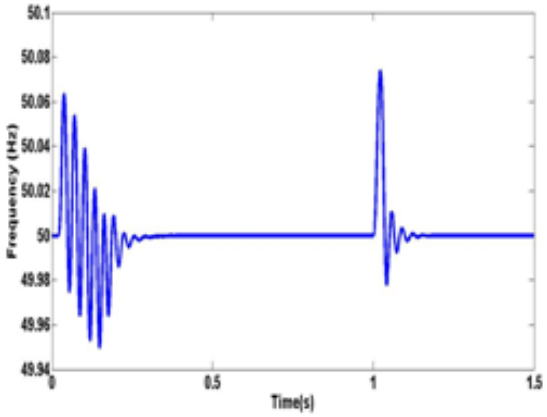


Fig. 6(g) Frequency Variation.

In Fig. 6(g) the system frequency variation throughout the simulation time is within the limits of grid connection requirement which is specified in the standard IEEE-1547.

3.2 Generation variation

In this case wind speed is varied from 12 m/s to 14 m/s at 0.7s, there is change in temperature from 25^0C to 30^0C at 0.9s, there is change in solar irradiation from 800 W/m^2 to 1000 W/m^2 at 1.25s.

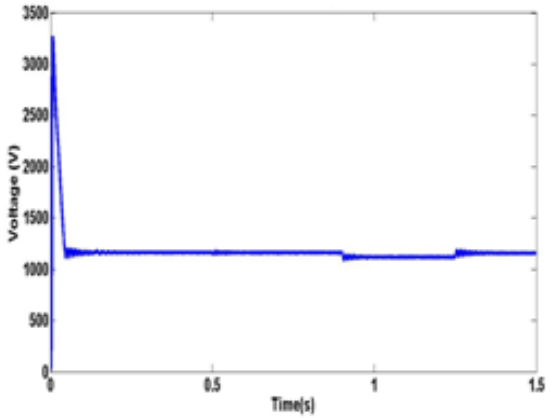


Fig. 7(a) DC Link Voltage.

Fig. 7(a) shows DC link voltage which is obtained during simulation with the help of boost regulators tuned by PI controllers. The dynamic disturbances like change in wind speed, irradiation or change in temperature on DC link voltage is not much predominant and the deviation of voltage level is less (within grid standards) as shown.

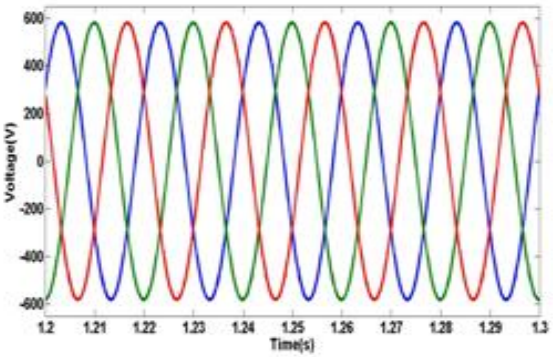


Fig. 7(b) AC Voltage.

In Fig. 7(b) constant voltages are obtained throughout simulation controlled by the controller.

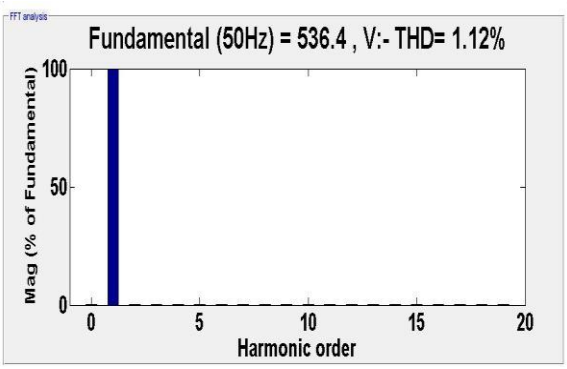


Fig. 7(c) AC Voltage THD.

In fig. 7(c) shows voltage THD index of AC voltage waveform which shows 1.12% and it is within limit as mentioned in grid standards (IEEE-1547).

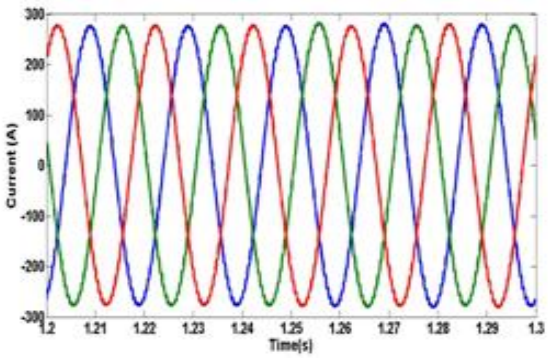


Fig. 7(d) Grid Current.

Fig. 7(d) shows variation of AC current at grid terminal due to increase in generation at 1.25s. The current has been decreased at 1.25s due to increase in generation.

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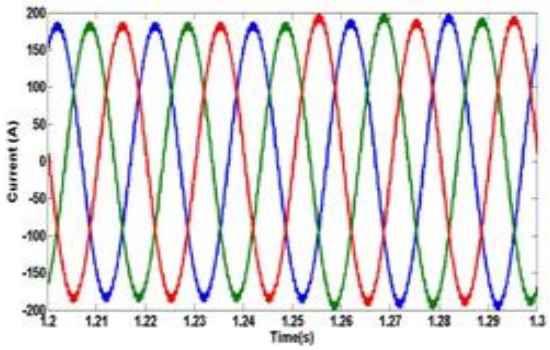


Fig. 7(e) PV and Wind Current.

Fig. 7(e) shows variation of AC current at inverter terminal due to increase in irradiation from1000 W/m^2 to 1800 W/m^2 at 1.25s. The current has been increased at 1.25s due to increase in generation.

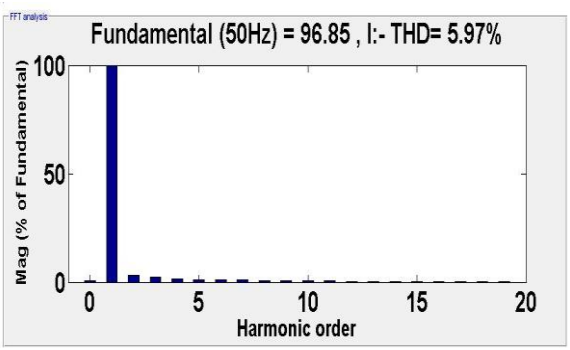


Fig. 7(f) PV and Wind Current THD.

In fig. 7(f) shows current THD index of AC current waveform at inverter output, which shows 5.97% and it is near to the limit as mentioned in grid standards (IEEE-1547).

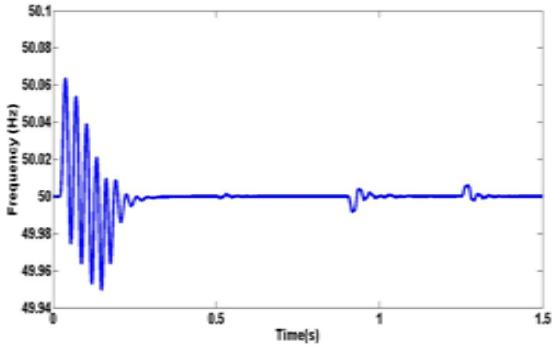


Fig. 7(g) Frequency Variation.

In Fig. 7(g) the system frequency variation throughout the simulation time is within the limits of grid connection requirement which is specified in the standard IEEE-1547.

3.3Single- line fault

In this case the LG fault is created at load during 0.5s to 0.55s.

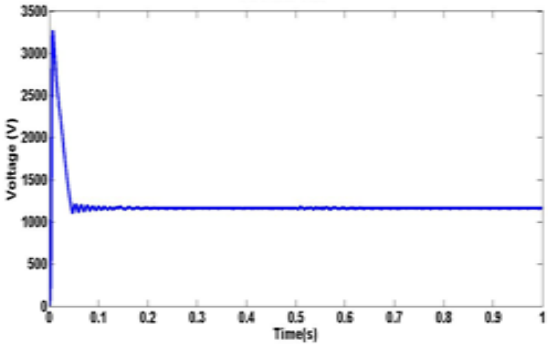


Fig. 8(a) DC Link Voltage.

Fig. 8(a) shows DC link voltage which is obtained during simulation with the help of boost regulators tuned by PI controllers. The dynamic disturbance deviation of voltage level is less (within grid standards) as shown.

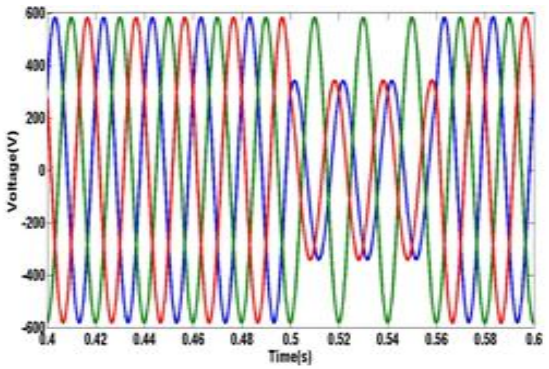


Fig. 8(b) AC Voltage.

In Fig. 8(b) inverter voltage due to LG fault at load side during 0.5s.

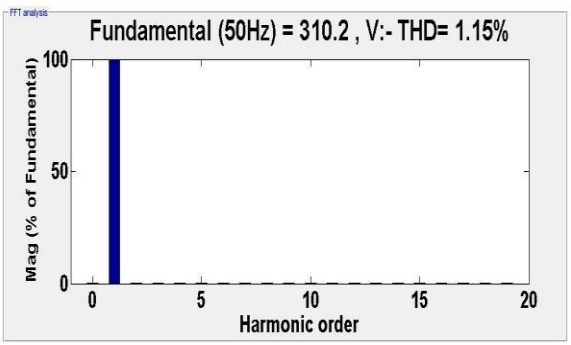


Fig. 8(c) AC Voltage THD.

In fig. 8(c) shows voltage THD index of AC voltage waveform which shows 1.15% and it is within limit as mentioned in grid standards (IEEE-1547).

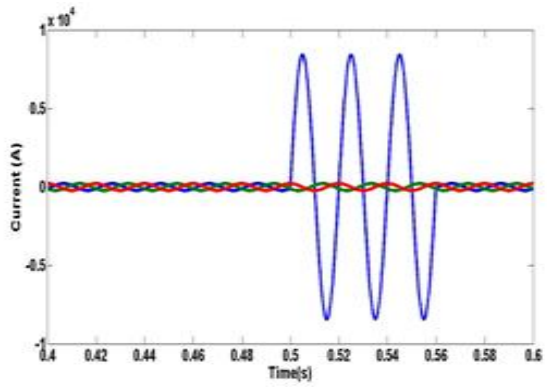


Fig. 8(d) Load Current.

Fig. 8(d) shows AC current at load terminal during LG fault at 0.5s.

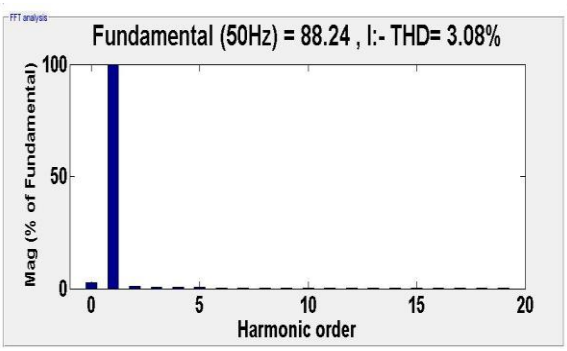


Fig. 8(e) Load Current THD.

In fig. 8(e) shows current THD index of AC current waveform at load, which shows 5.97% and it is within limit as mentioned in grid standards (IEEE-1547).

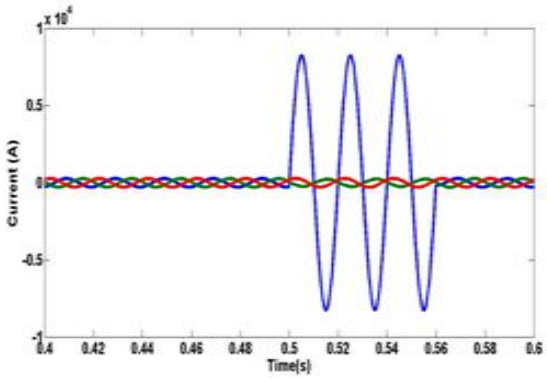


Fig. 8(f) Grid Current.

Fig. 8(f) shows AC current at grid terminal during LG fault at 0.5s.

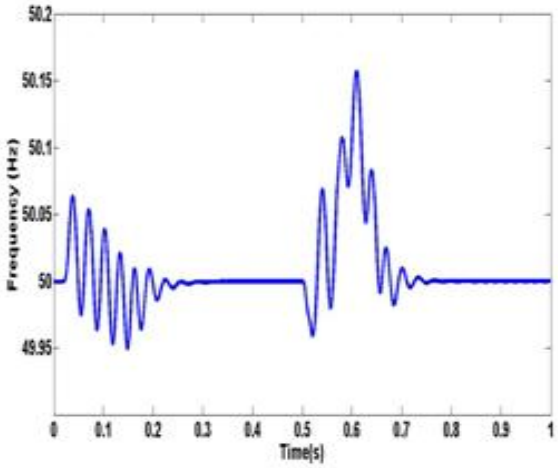


Fig. 8(g) Frequency Variation.

In Fig. 8(g) the system frequency variation throughout the simulation time is within the limits of grid connection requirement which is specified in the standard IEEE-1547.

CONCLUSIONS

Here the modeling of PV/wind HES has made using MATLAB/Simulink. The PQ control is used to control VSI.

The grid connected HES topology is better than stand alone HES, because grid connected HES system requires no battery system and it can supply local load, the remaining power can be fed to the grid. So grid connected HES are eco-friendly systems and there will not be any power interruptions, like in standalone systems.

The DC shunted HES gives us the saving of one VSI and gives good performances which meets IEEE-1547 standards like DC link voltage deviation within 10%of rated voltage, frequency deviation (49.3-50.5) Hz for >30kW rated systems and THD limit 5%. The modeled topology is more economic than AC shunted HES.

Further the PID controller tuning can be done by fuzzy or artificial neural network (ANN) technique to get good performance.

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