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Power Quality Improvement of Renewable Energy-fuel Cell Integrated Power System

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Abstract

In this paper multiple RES modules are integrated to grid in parallelfor sharing ofpower to the heavy load connected to the grid system.The RES modules include PVA, PMG WF, FC connected to the grid through synchronized inverters and circuits.All the inverters are controlled by closed loop feedback synchronization controllers which operate in synchronization with the grid voltage. Different control schemes with different circuits are adopted for each RES source and multiple conditions are considered for analyzing the test system. The design and analysis of the above-mentioned modules with the grid interconnection is achieved in MATLAB Simulink environment with graphical representation generated by powergui toolbox.

Keywords: Renewable energy source, Photo voltaic array, Permanent magnet generator,powerGUI.

1. Introduction

Many countries throughout the world are opting for green energy so as to avoid fossil fuel consumption as they generate great amounts of environment damaging waste and gases. In India especially integration of green energy RESs [1] is very vital as the power demand is very high as compared to other countries and is increasing day by day. Higher power demand needs higher power production, which is presently done by conventional power production techniques like thermal plants (coal plants), nuclear plants, and hydro power plants. These ways of producing electricity leads to generation of very large bio hazard waste and air pollution. The hydro power plant is however a green energy source but has very high capital investment and takes years to install the plant. To overcome the fossil fuel consumption for power production, high initial capital investments and long installation time, renewable energy sources need to be integrated into the grid. RESs cannot be used in standalone condition in some of the grid systems where the power demand is unpredictable. A constant power demand grid can have standalone RES where the power for the loads is completely compensated by the RESs.For our analysis we are considering a high-power demand grid which includes three RESs PVA, PMG WF and FC [2]. In the mentioned sources the PVA and PMG WF are natural sources power generators and FC is natural gas power generator which operates on gas provided as per demand. These sources are integrated with grid in parallel which share power to the load. The PVA and PMG WF sources [1] are main RESs whereas the FC is a backup power source utilized during critical power demand conditions. The multi-RES grid system with conventional source is shown in Fig. 1.

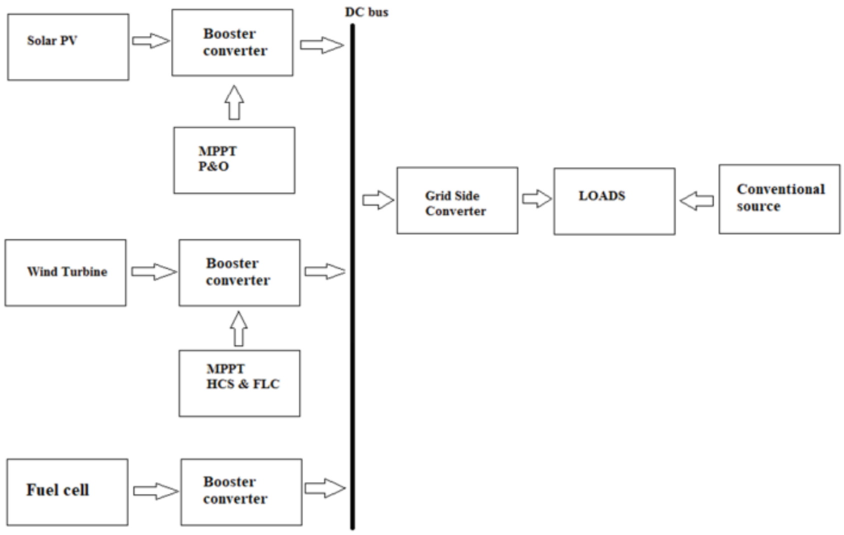

Fig. 1: Multi RES grid system.

As seen in the above block diagram representation three RESs PVA, PMG WF and FC are connected to common DC bus with individual DC-DC circuits[2] controlled by MPPT techniques. The common DC link is fed to GSC which generally a three phase inverter is feeding the loads. The loads are receiving power from both RES and also the conventional source. Therefore, the GSChas to be operated in synchronization with the grid.

This paper is included with proposed test system in section I followed by working principles of RES in section II. Section III comprises of controller for the circuits and MPPT techniques adopted in the system. In section IV simulation results with graphical representation with time domain are given with different operating conditions. The final section V includes conclusion and references for the paper.

2. Renewable Energy Source

2.1 PVA modelling

The most acceptable RES is PVA (solar panels) [2] which generate electricity using sun irradiation as the natural source. It is also a static device which needs to be placed at one place with no dynamic parts making it easy for controlandmaintain the plant. The solar panel is a source with p-typeand$n$-type materials connected back-to-back with silicon doping for generation of electronsandholes. When the IR drops on the panel surface electrons from the n-type material is releasedandpass through the circuit (as current conduction) reaching the p-type side neutralizing with holes that the released in the p-type material. The continuous release of electrons creates potential difference across the load. However, the power generated by the solar panels is in DC type&also variable with respect to the IR. Therefore a DC-DC boost converter [6] is connected to the solar panel in order to maintain the output DC voltage at constant value. The PVA connected with DC-DC booster converter can be seen in Fig. 2.

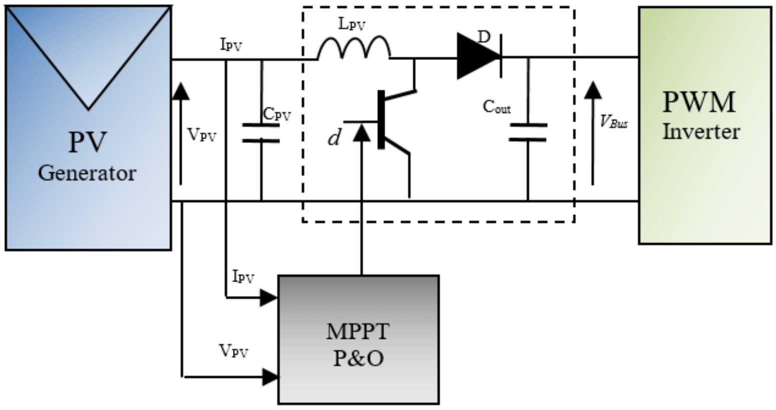

Fig. 2: PVA DC-DC booster converter module.

As seen in the above diagram the booster converter comprises of IGBT controlled by P&O MPPT technique [11]. The output voltage is controlled by booster inductor L_{pv} charge stored which depends on 'ON' time of the IGBT switch. The ON time&OFF time of the switch is controlled by the MPPT controller with feedback from PVA voltage V_{pv} andcurrent I_{pv}. The MPPT technique adopted is discussed in section III.

2.2 PMG WFmodeling

PMG WF[3] is considered to be the next best option in RESs after solar plants as WF generates more power as compared to any other RES. But the capital investment for the installation of wind turbines [4] and generators is very highandalso need to be placed very far from the human interference. These issues make the WF source as the second best option for RES after PVA. There are different types WFs with different turbine generator sets. For standalone operation of WF PMG machine need to be used which does not need any external excitation for generation of power. The PMG generates power in AC which is unstable (variable voltage, frequency andphase) needs to be stabilized. Therefore, a two-stage conversionandcontrol schematic is adopted for stabilized AC voltage generation [5]. The PMG WF topology proposed is given in Fig. 3.

2.3 FC modelling

As similar to PVA topology the FC [7] also generates power in DC format. The FC generates power from fusion reaction of hydrogen&oxygen gases. During the fusion reaction one oxygen atom is separated&two hydrogen one oxygen atoms [8] are combined producing water (H2O) as discharge material. The single oxygen atom is released into air, therefore there is no damage to the environment with no hazardous gases generation. The fusion reaction is given as

Anode Reaction – $H_2 \rightarrow 2H^+ + 2e^-$

Cathode reaction: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

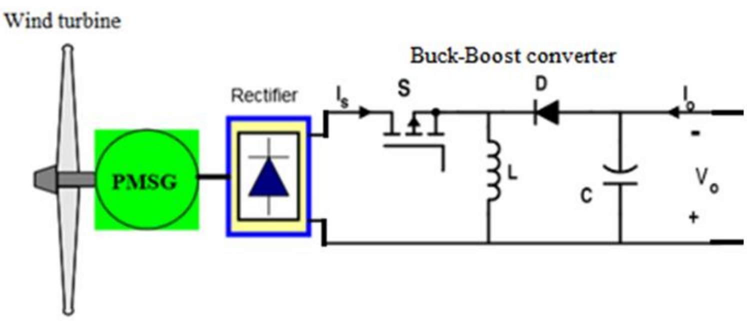

Fig. 3: PMG WF with buck boost converter

The above reaction happens for mutiple molecules generating many electrons which combine creating current for the loads [9]. The FC is connected to booster converter for votlage boosting as the loads operate at higher voltages. The FC booster converter topology is shown in Fig. 4.

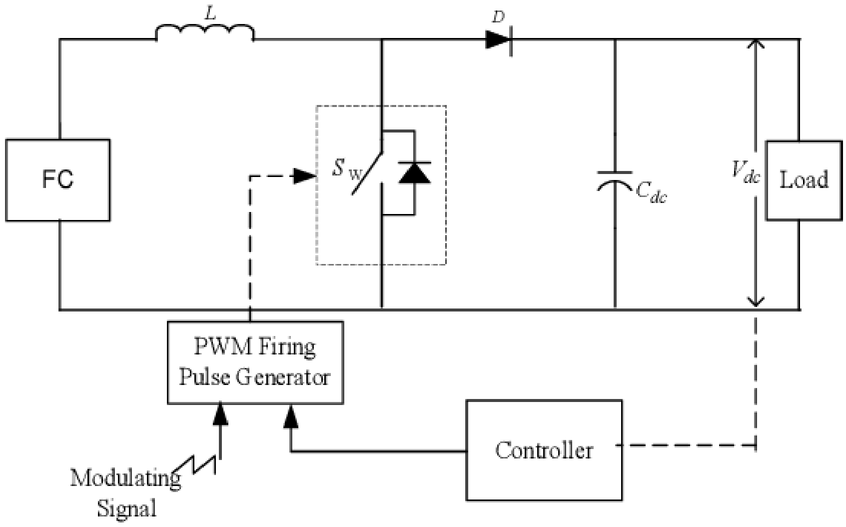

Fig. 4: FC module with booster converter

The above circuit is similar to PVA module [1], but the booster switch is not controlled by MPPT but by a voltage oriented controller. The voltage feedback controller is explained in detail in next section.

3. ControllerDesign

3.1 PVA MPPT technique

As mentioned in previous section the booster converter connected to PVA is controlled by P&O (Perturb&Observe) MPPT technique [10]. This is a traditional technique used in most of the PVA modules for maximum power transfer to the load or grid with maintaining the DC voltage. The MPPT takes feedback from the PVA currentandvoltage I_{pv} andV_{pv} giving output as D to control booster converter. The below is the MPPT technique proposed in the paper for the booster converter. As seen in Fig. 5, $V(t)$and$I(t)$are the present measurement [11] of PV panel voltageandcurrent. From these measurements power from the PV is calculated which is given as

$$P(t) = V(t) * I(t) \tag{1}$$

The change in Dn depends on change in power&voltage of the PV panel. The change in D is given as

$$If\ P(t) > P(t-1) \begin{cases} 1, & \begin{aligned} If\ V(t) > V(t-1)\ is\ 1, D(t) = D(t-1) + \Delta D \\ If\ V(t) > V(t-1)\ is\ 0, D(t) = D(t-1) - \Delta D \end{aligned} \\ 0, & \begin{aligned} If\ V(t) > V(t-1)\ is\ 1, D(t) = D(t-1) - \Delta D \\ If\ V(t) > V(t-1)\ is\ 0, D(t) = D(t-1) + \Delta D \end{aligned} \end{cases} \tag{2}$$

Here, $(t-1)$ is the past measurementandΔD is the change in D updated to previous DD (t-1) as per change in power&voltage of the PVA.

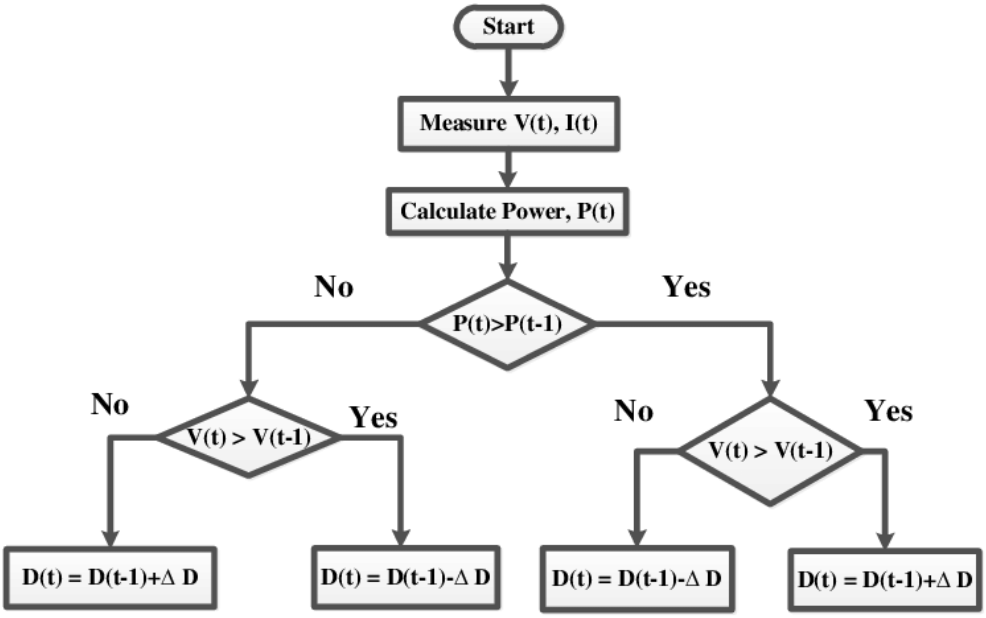

Fig. 5: P&O MPPT technique algorithm.

3.2 WF FUZZY MPPT technique

As similar to PVA MPPT the WF MPPT [12] also has two inputs power generated (Pg) by the machine&speed of the rotor (wm). The two input variables are analyzed by multiple membership functions with specific rule base. The fuzzy MPPT [13] [14] of the WF can is shown below.

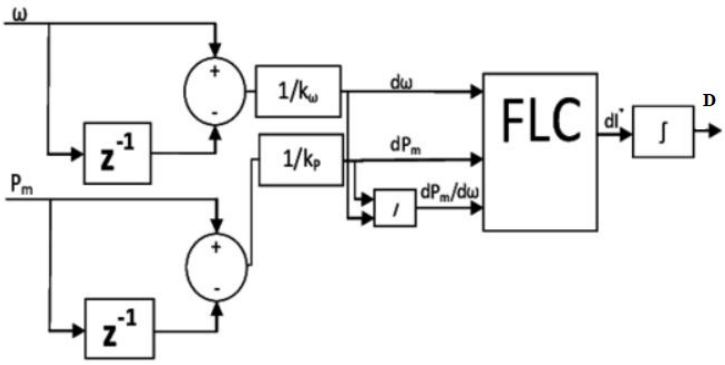

Fig. 6: Fuzzy MPPT of WF.

As the measurements taken from the machine the change in speed&power of the generator are calculated which is given as

$$dw = \frac{w(t)-w(t-1)}{kw} \tag{3}$$

$$dPm = \frac{Pm(t)-Pm(t-1)}{kp} \tag{4}$$

The two variables are set with 7 membership functions each&the output variable D also has 7 membership functions. The output is generated by 7x7 = 49 rule base given in Table 1 as below.

Table1. Fuzzy rules.

e/d	**NB**	**NM**	**NS**	**EZ**	**PS**	**PM**	**PB**
PB	**Z**	PS	PM	PB	PB	PB	PB
PM	NS	**Z**	PS	PM	PB	PB	PB
PS	NM	NS	**Z**	PS	PM	PB	PB
EZ	NB	NM	NS	**Z**	PS	PM	PB
NS	NB	NB	NM	NS	**Z**	PS	PM
NM	NB	NB	NB	NM	NS	**Z**	PS
NB	NB	NB	NB	NB	NM	NS	**Z**

The output D is compared HF triangular waveform generating pulse for the buck-boost converter MOSFET.

3.3 FCvoltage controller

The FC controller adopts voltage feedback-oriented control [15] which takes output voltage as feedback compared to reference value fed to PI controller which generates D for the booster converter [16] connected to FC. The below is the voltage oriented controller for the FC converter.

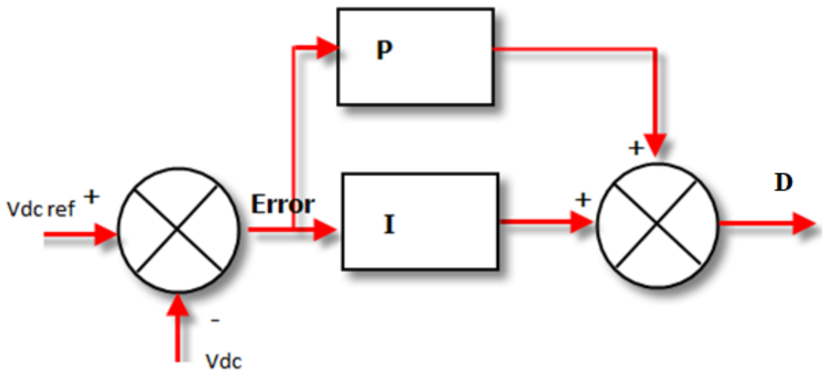

Fig. 7: Voltage feedback oriented control for FC converter

4. Simulation Results

All the above modules are connected to a common point referred as PCC (point of common coupling) where all the RESs, conventional source&loads connected in parallel for power sharing. The sources&circuits are designed in MATLAB Simulink environment with different operating conditions&the graphs are recorded with respect to time. The total simulation time is taken for 1sec.

Case 1: Test system connected with only PVA&WF

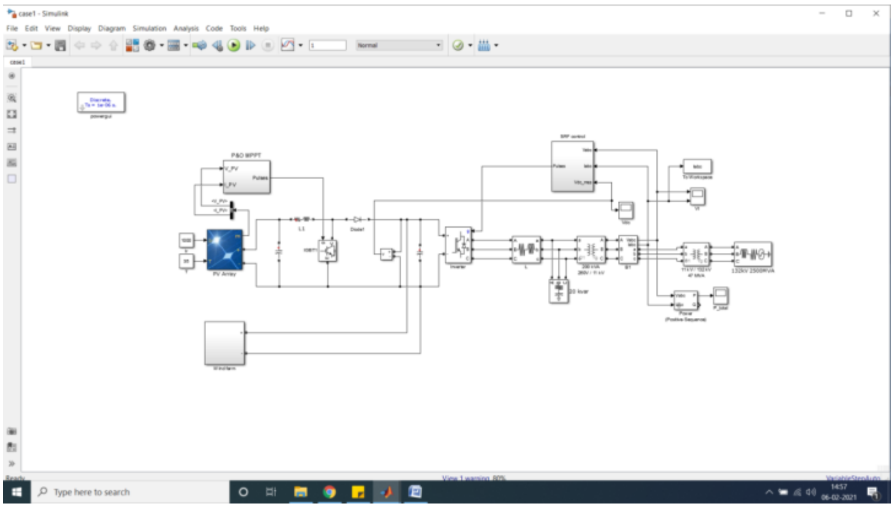

Fig. 8: Proposed system with only PVA and WF

The design with only PVA and WF RESs connected to the grid for power sharing is the model presented in Fig. 8.The DC voltage at the input of the inverter maintained at 500V is illustrated in Fig. 9.

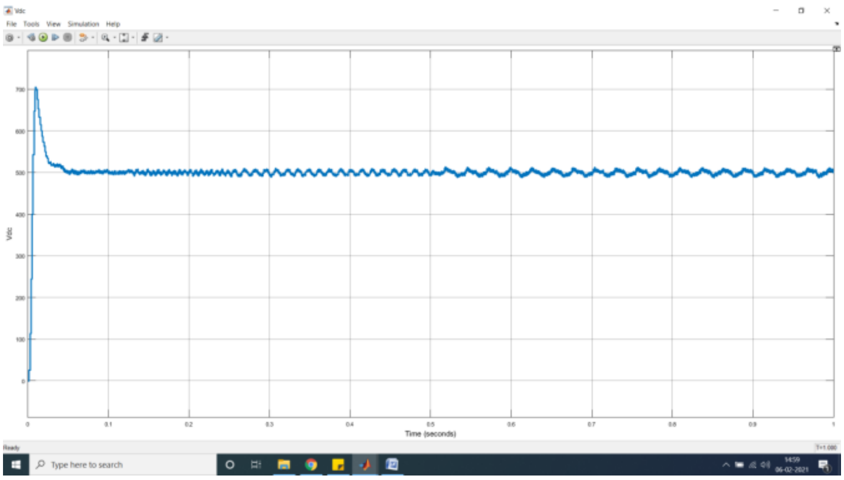

Fig. 9: DC link voltage with only PVA and WF.

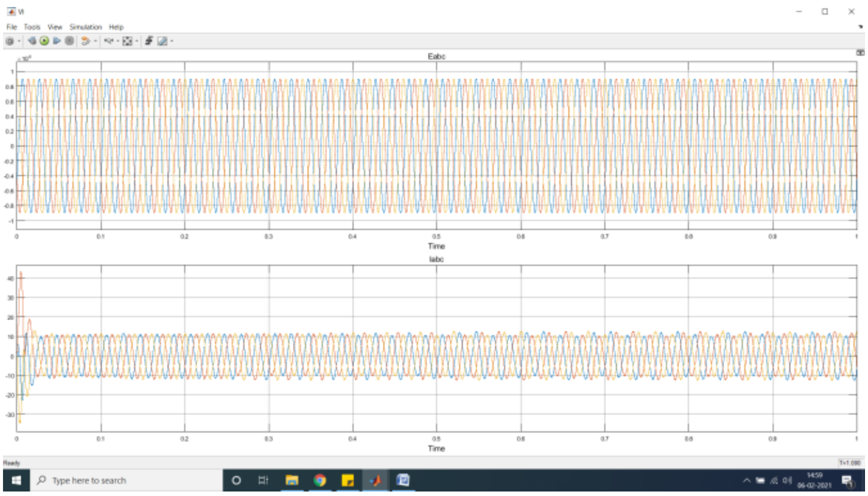

Fig. 10: Three phase voltages and currents of the inverter with only PVA and WF

Fig. 10 discloses the three phase inverter voltages and currents for case 1 topology. The total power shared in case 1 is 150kW. Where, PVA generating 100kW and WF generating 50kW as demonstrated inFig. 11

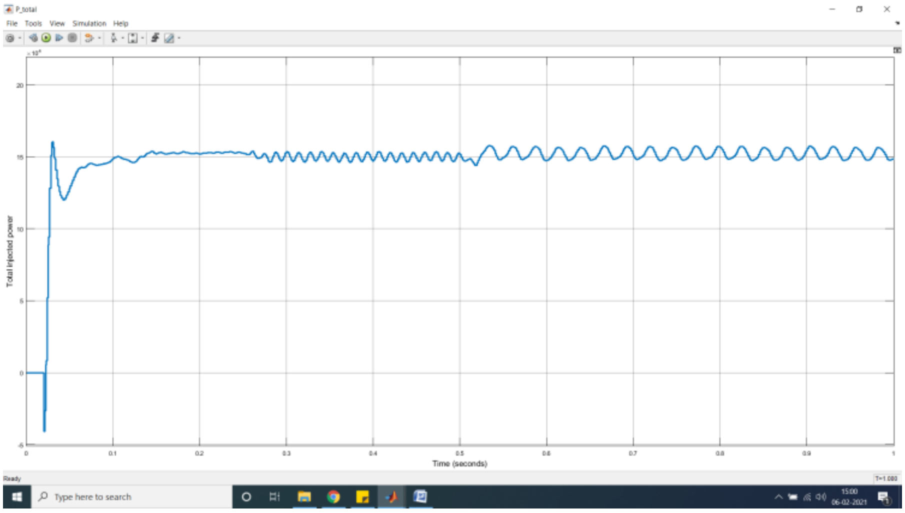

Fig. 11: Total power output of the inverter with only PVA and WF

Case 2: Test system connected with only PVA and FC

Fig. 12 demonstrate the test system connected with only PVA and FC and its corresponding DC link voltage is disclosed in Fig. 13. The 3-phase inverter voltages and currents with PVA and FC is illustrated in Fig. 14 and its total output power of the inverter is depicted in Fig. 15

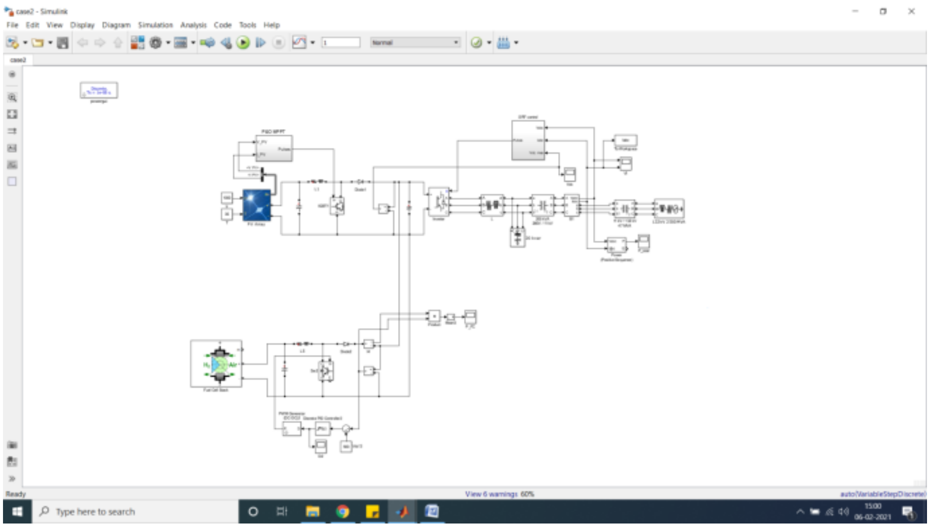

Fig. 12: Proposed system with only PVA and FC

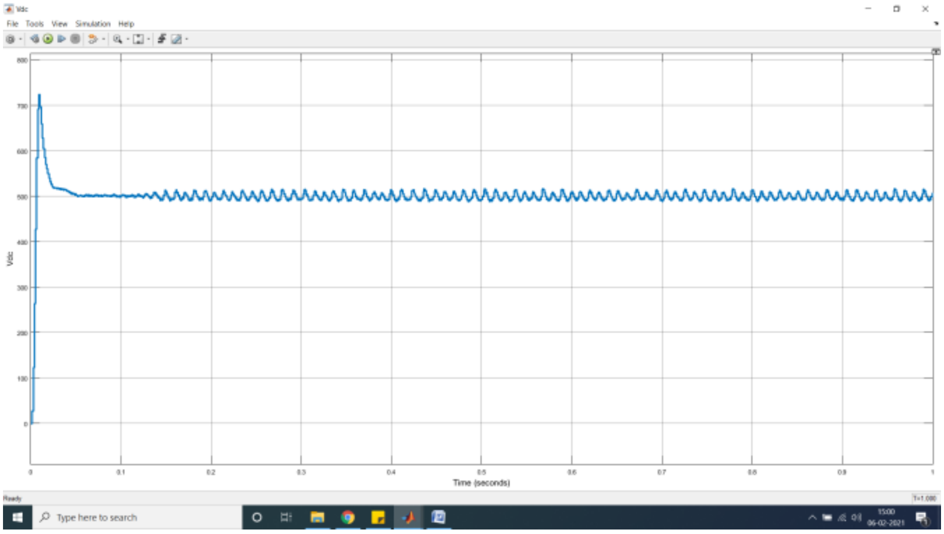

Fig. 13: DC link voltage with only PVA and FC

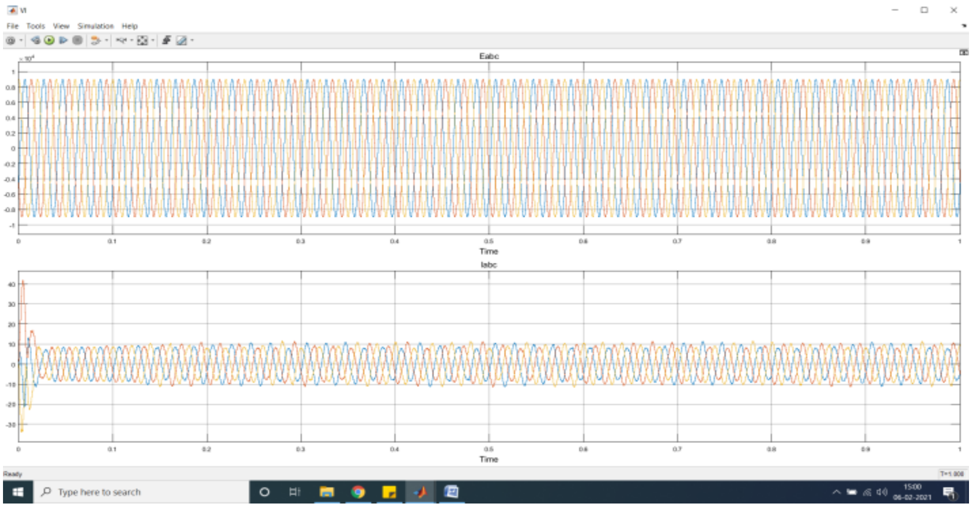

Fig. 14: Three phase voltages and currents of the inverter with only PVA and FC

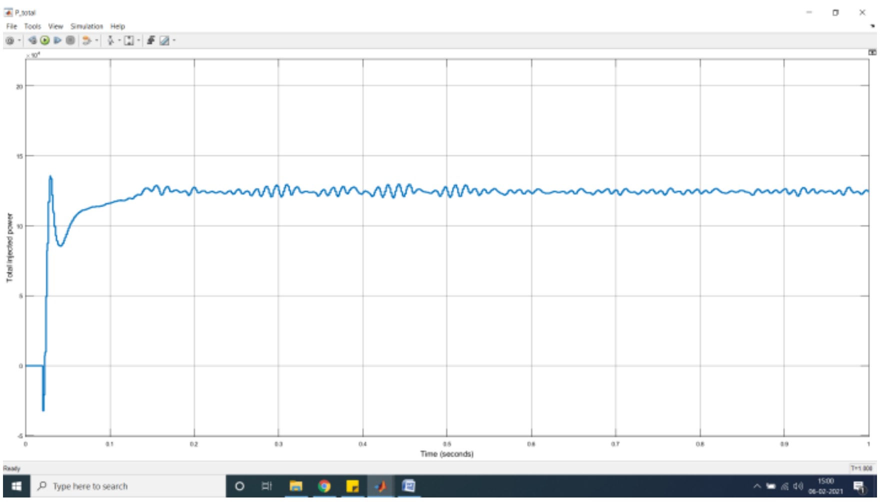

Fig. 15: Total power output of the inverter with only PVA and FC

Case 3: Proposed test system with PVA, WF and FC

Fig. 16 demonstrate the test system connected with PVA, WF and FC and its corresponding DC link voltage is disclosed in Fig. 17. The 3-phase inverter voltages and currents with PVA, WF and FC is illustrated in Fig. 18 and its total output power of the inverter is depicted in Fig. 19

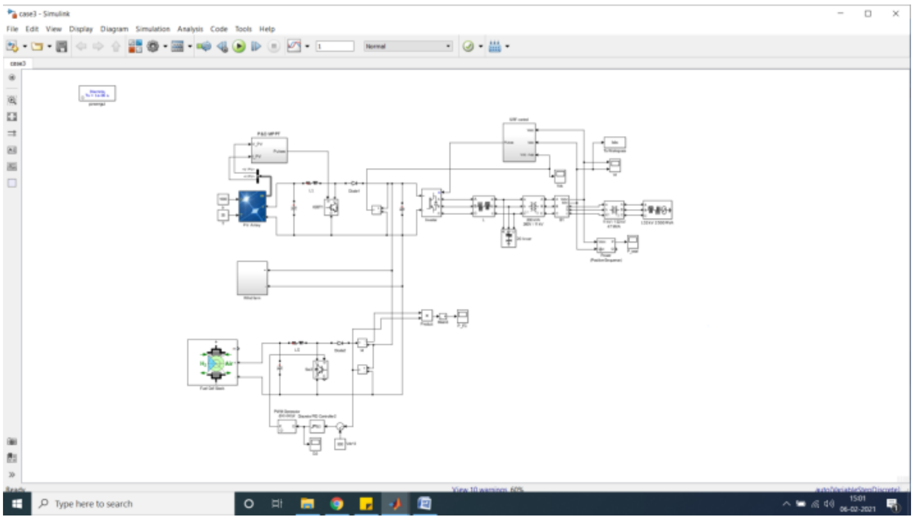

Fig. 16: Proposed system with PVA, WF and FC

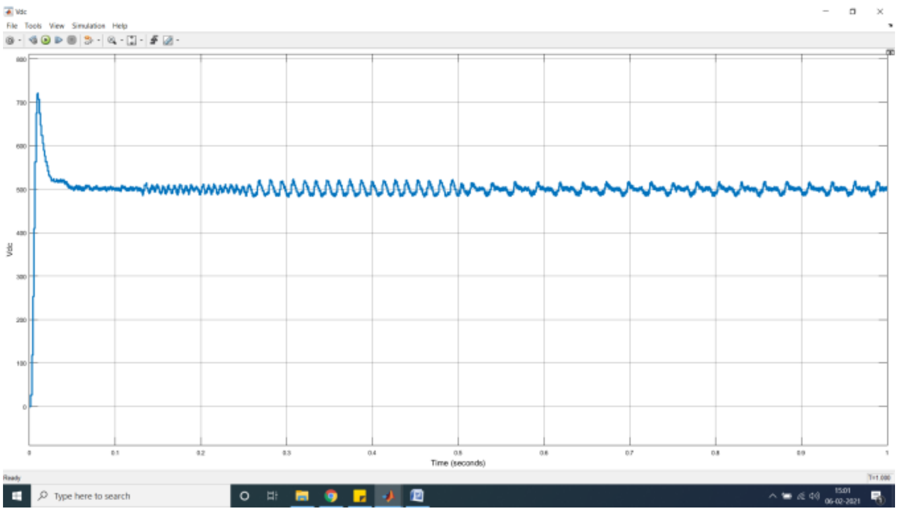

Fig. 17: DC link voltage with PVA, WF and FC

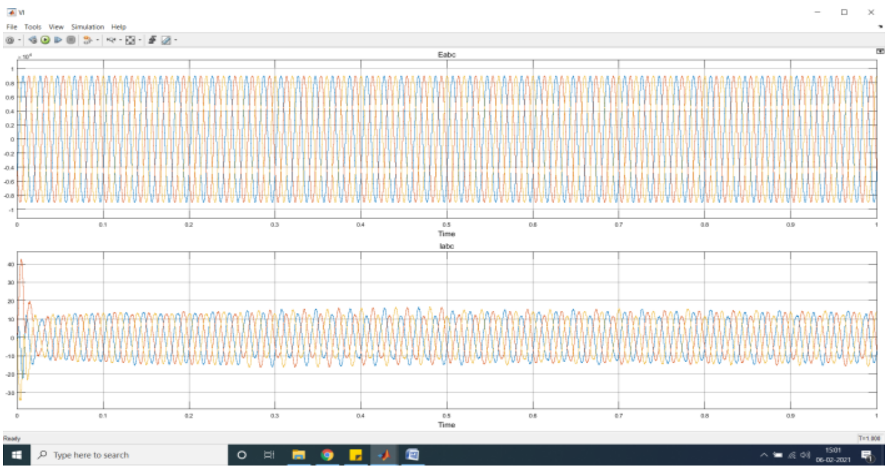

Fig. 18: Three phase voltage and currents of inverter with PVA, WF and FC

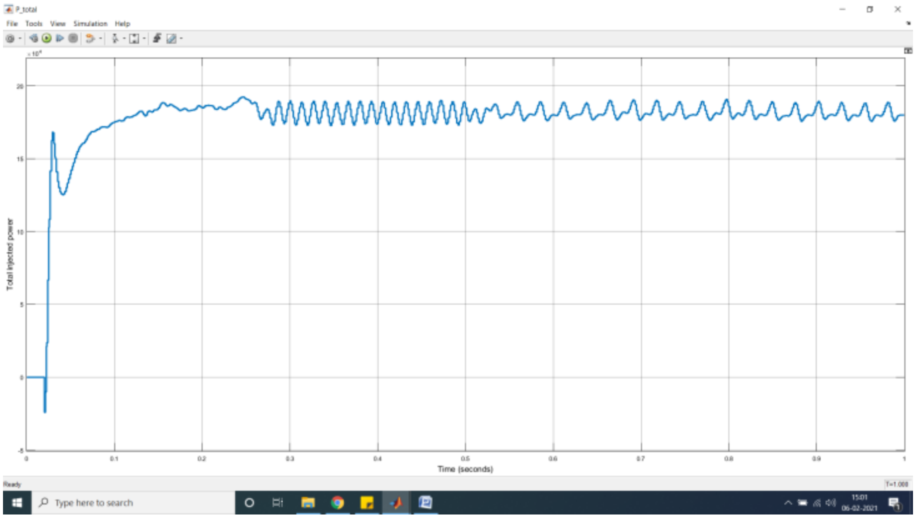

Fig. 19: Total power output of inverter with PVA, WF and FC

5. Conclusion

With the above results generated by the proposed topology denote that the power sharing from different combinations of RESs is changing with respect to the combination of sources. The power shared by only PVA and WF is 150kW where 100kW is generated by PVA and 50kW is generated by WF. In second case with only PVA and FC the power is reduced to 130kW as the FC power is less 30kW. The final case is combination of all sources (PVA, WF and FC) so the total power is 180kW. In any case the DC link voltage is maintained at 500V with ripple maintained below 5%. The system can be stabilized further with adaptive controllers for the circuits making the system work more efficient with reduced ripple and harmonics.

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