HYBRID MICRO-GRID WITH RENEWABLES AND ENERGY STORAGE ADDRESSING POWER QUALITY

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ABSTRACT

This paper proposes a hybrid AC/DC microgrid to reduce the number of converter stations for converting DC power to AC power or vice versa, thereby reducing the THD of voltage and current waveforms at the utility grid. The hybrid grid has AC and DC grid connected together by bidirectional converter station whose operation depends on the availability and load demand on AC and DC side. The AC grid would serve as the utility grid. In the proposed system all the DC energy sources, such as PV array and battery, are connected to the DC grid and AC energy sources, such as Wind power plant, are connected to AC grid. A miniature model of the proposed hybrid grid is modelled in MATLAB/SIMULINK. The simulation show the structure of various SIMULINK components included in the model and the result is the THD of the utility grid.

Index Terms—Converter station; Hybrid grid; DC load; AC load; Battery; Microgrid; PV Array; Power System; Wind Power Plant; THD; Utility Grid

INTRODUCTION

The early history of power systems is characterised by centralised power generating stations, feeding load centres that were quite far away. These power generating station were mainly constituted by thermal power generating stations and hydroelectric power stations. By the late 1900s nuclear technology had become considerably advanced and there were a number of nuclear power stations around the world feeding distant load centres. However in the past 30 years renewable energy has come from being a mute spectator to taking a respectable percentage of total power generated. This continuing technology advancement in the renewable energy sector has paved the way for remodelling the conventional grid structure to a smarter grid with better reliability and security. Microgrid and distributed generation system is the trend in power systems. When power can be fully delivered by local renewable energy sources, long distance power transmission is no longer necessary [1].

Microgrid is a grid located close to load centres with many decentralised micro sources, like PV Array and Wind turbines, and local loads connected to it. It has the ability to operate in islanding mode whenever there is a fault or the power quality is below standards in the utility grid. AC microgrid [14] has been proposed earlier to integrate the renewable power sources to the conventional utility grid. However DC power micro sources such as PV Array or fuel cells has to be converted into AC power vi a DC/DC boosters and DC/AC inverters.

DC microgrid was proposed [3]-[5], [7]-[8] due to the development of renewable DC sources and their advantage of DC loads in residential, commercial, industrial areas. This, however, creates the need for converting AC sources into DC before connec ting to the DC grid and DC/AC inverters are required to accomplish this. Therefore, it is safe to say that multiple reverse conversions occur in an individual AC or DC grid which leads to further loss to the system and would make the home and office appliances more complicated.

The smart grid concept is currently prevailing in the power sector. Its main aim is to provide reliable, good quality power in a sustainable and green way. Microgrid and distributed generation play a hand in hand role in achieving this. A hybrid microgrid is proposed in this paper which has both AC and DC grids to reduce the multiple reverse conversions that occurs in an individual AC or DC grid. The DC grid is introduced between the DC micro sources and DC/AC inverter station. The new grid system would facilitate the connection of various renewable DC and AC sources

This paper focuses on the modelling of PV array, Wind power plant and shows a comparative value of THD in utility grid with a AC grid and hybrid grid.

PROPOSED BLOCK DIAGRAM

Fig. 1. shows the block diagram of the proposed hybrid grid. DC sources are connected to the DC grid whereas AC sources are connected to the AC grid. AC grid is in turn connected to the utility. The simulation diagram, which will be shown later, represents the power system to reasonable extent. But when implementing this concept practically, further components like filters, compensators need to be added at appropriate places. This paper focuses on the reduction in THD by the use of hybrid model.

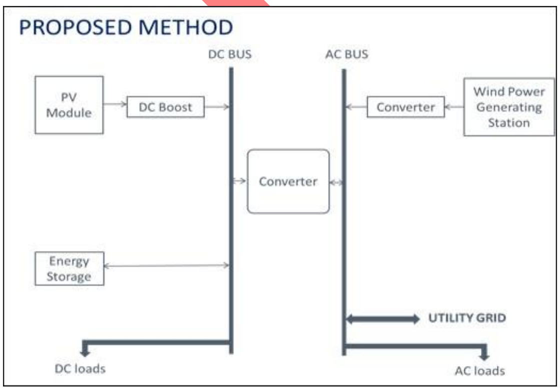

Fig. 1.Block diagram of the Hybrid microgrid (*block diagram)*

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The block diagram shows single bidirectional converter connecting the DC grid (bus). However another bidirectional converter station may be used to provide an added security measure in case the main converter is shut down for maintenance or there are other issues. AC and DC loads have not been included in simulation model though it could be added at the AC and DC bus respectively. Battery has been included to act as the energy storage device. Other DC sources like fuel cells can be included at the DC bus. Similarly, other AC sources like diesel generator or a micro tidal power plant can included at the AC bus

SIMULATION DIAGRAM

Since this paper focuses on the effect on THD at the utility grid due to DC/AC converters, all the other converters used in the simulation are based on average models, meaning that they do not contribute to harmonics, except for the converters that invert DC power from DC sources to AC.

A. PV Array model

PV Array Simulink model is based on the equivalent circuit of PV cell. Fig. 2 shows the MATLAB/Simulink model of PV Array. The values for various parameters involved in the design are got from the data sheet of the manufacturer. Table I. shows the various parameters involved in the modelling of PV Array.

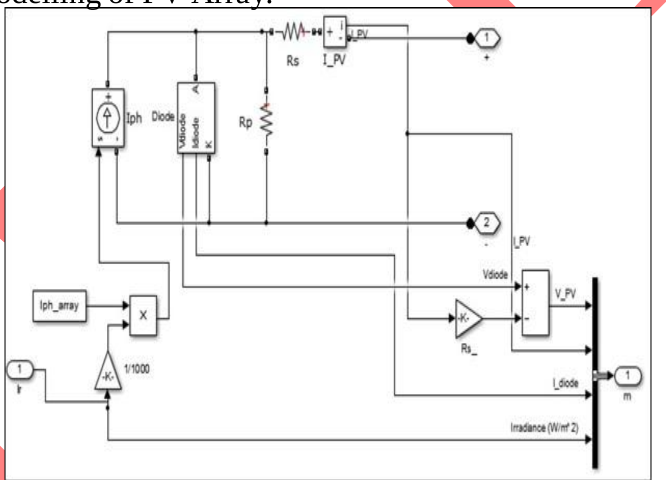

Fig. 2.Simulink model of PV Array

Table I PARAMETERS FOR PV ARRAY.

Symbol	Description	SI Unit
Iph	Photo current	*A*
Ir	Irradiation	W/m^2

Rp	Parallel resistance	Ω
Rs	Series Resistance	Ω
Isat	Diode Saturation	*A*
Qd	Diode quality factor	-
T	Surface temperature of PV	*K*
K	Boltzmann Constant	*J/K*
Q	Electron charge	*C*

MPPT control algorithm has been implemented. The control algorithm used in this simulation is Perturb and Observe (P&O) algorithm. In this method the MPPT adjusts the PV Array voltage by a small amount and the power is measured. If the power increases, adjustments are continued in that direction until power no longer increases. Fig. 3. shows the flow chart for MPPT P&O algorithm.

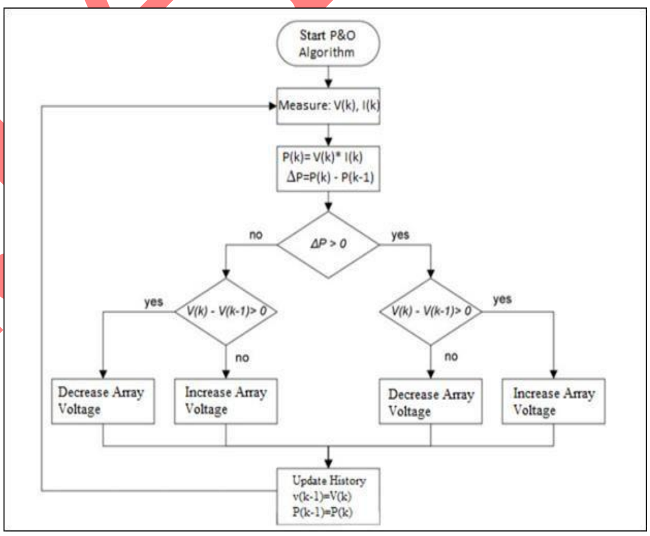

Fig. 3.P&O Algorithm Flowchart

The MPPT P&O algorithm has been implemented by programing the above flowchart through a MATLAB code embedded within the Simulink model. The inputs to the controller include PV Array voltage and current, initial value of duty cycle, upper limit and lower limit of duty cycle, change in value of duty cycle, and an enable signal. The output of the controller is the duty cycle (D) which is given as the input to the boost converter. Fig. 4. shows the simulink diagram of boost converter.

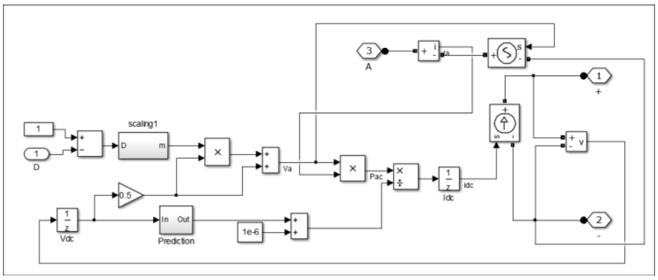

Fig. 4. Simulink model of boost converter

The boost converter is average model type meaning that switching action is absent. This model uses controlled current and voltage sources, whose input is reference signals, instead of power electronic devices to generate boosted voltage across output terminal. The output of boost converter is the input to the DC/AC inverter.

B. Wind Power Plant Model

Wind power plant is modelled as a variable speed wind turbine. Wind turbine generator (WTG) is modelled as a doubly fed induction generator (DFIG). The primary advantage of doubly fed induction generator when used in wind turbine is that they allow amplitude and frequency of their output voltages to be maintained constant, no matter the speed of the wind flowing over the wind turbine. Fig. 5. shows the structure of a DFIG based wind power plant.

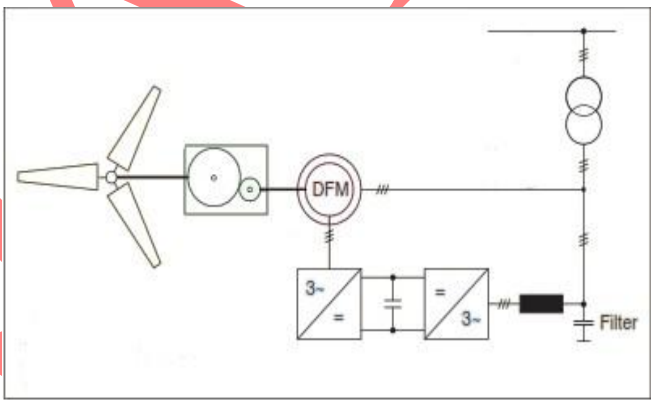

Fig. 5.Structure of DFIG based wind power plant

A wound rotor induction machine can used as a doubly fed induction motor Here, the machine operates as synchronous machine whose synchronous speed(speed at which the rotor shaft rotates) can be varied by adjusting the frequency of the ac current fed into the rotor windings. To achieve this, a control is needed at the back to back converter stations. Each converter performs a different task. The grid side converter is used to maintain the voltage level at the DC link. The rotor side converter is used to adjust the amplitude and frequency of rotor current thereby controlling the frequency and voltage of the output i.e. grid. Fig. 6. and Fig. 7. shows the general block diagram of the rotor side and grid side converter control.

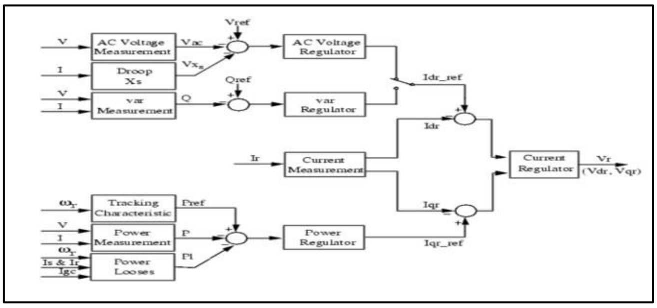

Fig. 6.Rotor side converter control system

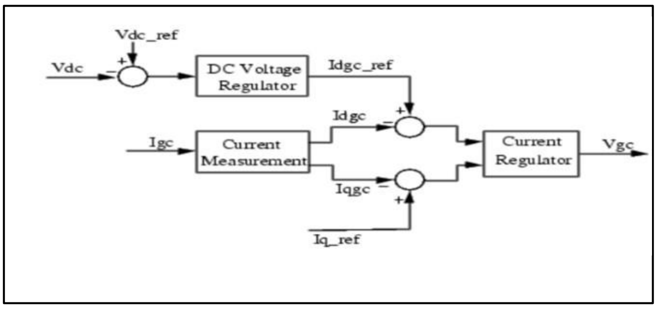

Fig. 7. Grid side converter control system

The back to back converter is also average model type. The final model consisting of PV Array, Wind power plant and battery connected to the utility grid is shown in Fig. 8.

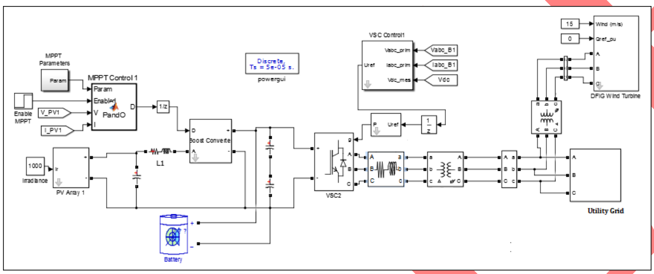

Fig. 8.Model of PV Array, Battery, Wind power plant connected to utility grid.

In order to study the effect on THD due to multiple DC/AC converters, another PV Array is introduced. In one model, each PV Array uses separate DC/AC inverters. This model is called the two converter model or simply, conventional grid model. In another model the two PV Arrays use only one DC/AC inverter station because the two PV sources are connected to a common DC grid whereas in the former model, due to the absence of a DC grid the two PV sources uses separate converters to convert DC to AC. This model is called the one converter model or simply the hybrid grid model. Fig. 9. and Fig. 10. shows the conventional grid model and hybrid grid model respectively.

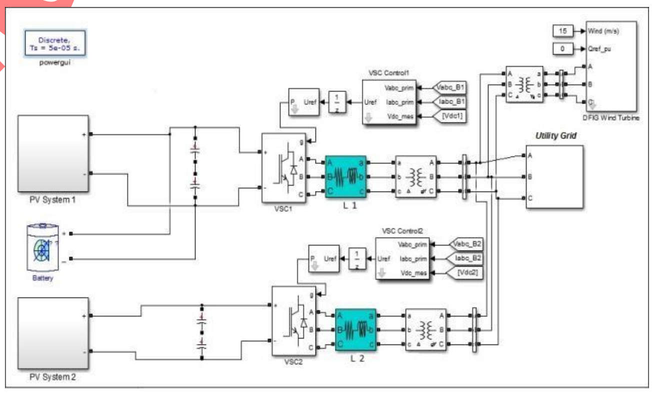

Fig. 9. Conventional grid model or Two converter model

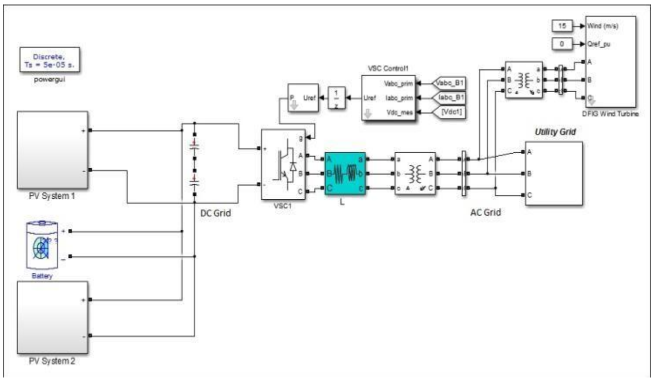

Fig. 10. Hybrid Grid model or One converter model

SIMULATION RESULTS

To get a better understanding on the effect of harmonics, the simulation shown if Fig. 8. is first done with converter harmonics absent. Fig. 11. shows the PV system outputs.

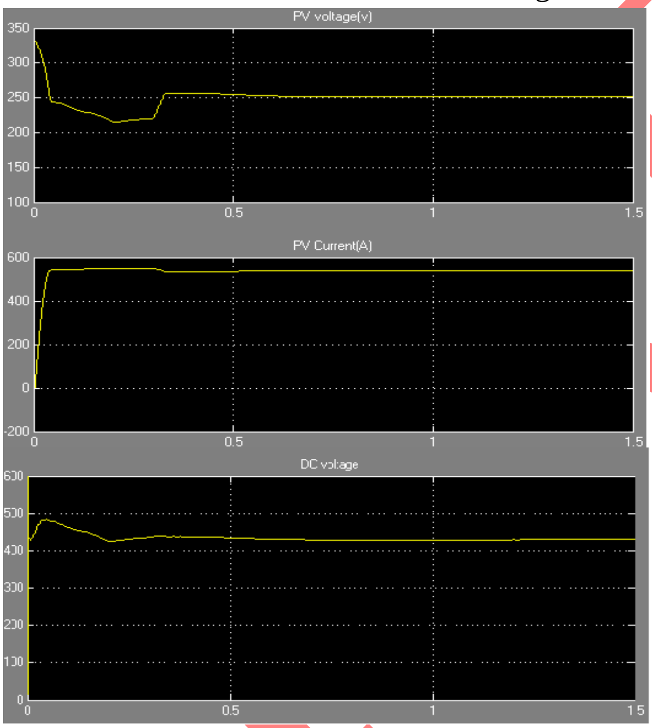

Fig. 11.PV Array voltage, current and DC boost voltage, with DC/AC converter harmonics absent

THD of voltage and current waveforms at utility grid was found using FFT analysis.to be 0.01% and 0.05%. Fig. 12. shows the utility grid phase A voltage and current waveform.

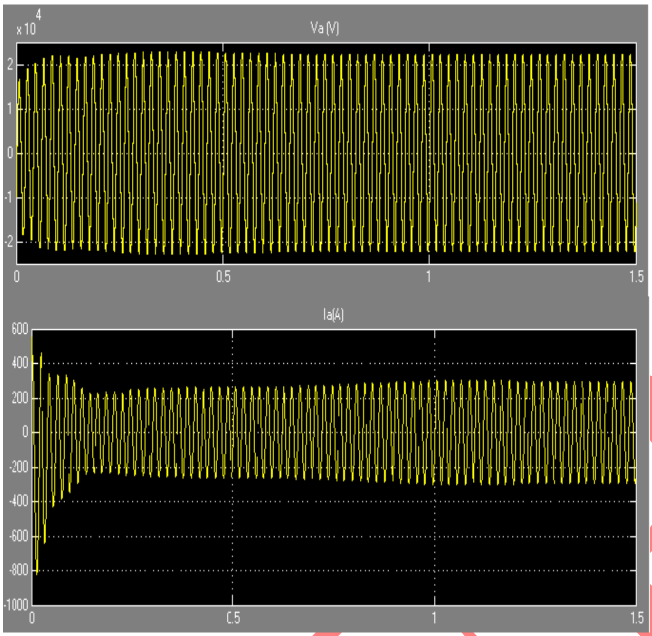

Fig. 12. Utility grid phase A voltage and current with harmonics absent.

Fig. 13. shows the output voltage, current, speed in per unit and P (MW), Q (Mvar), DC link voltage (V) of Wind power plant. 3 phase MVA base is 10. Nominal voltage is 575V. Nominal speed is set at 1.2 pu.

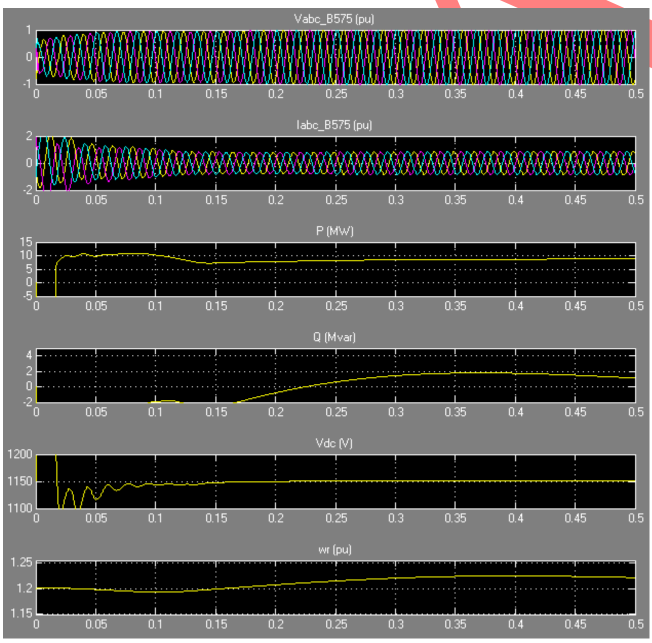

Fig. 13. Wind Power plant output voltage, output current, P, Q, DC link voltage and pu rotor speed, with DC/AC converter harmonics absent.

Now the DC/AC converter harmonics are included. The output waveforms, on both sides of the converter become distorted. Fig.14. shows the PV system waveforms with harmonics included.

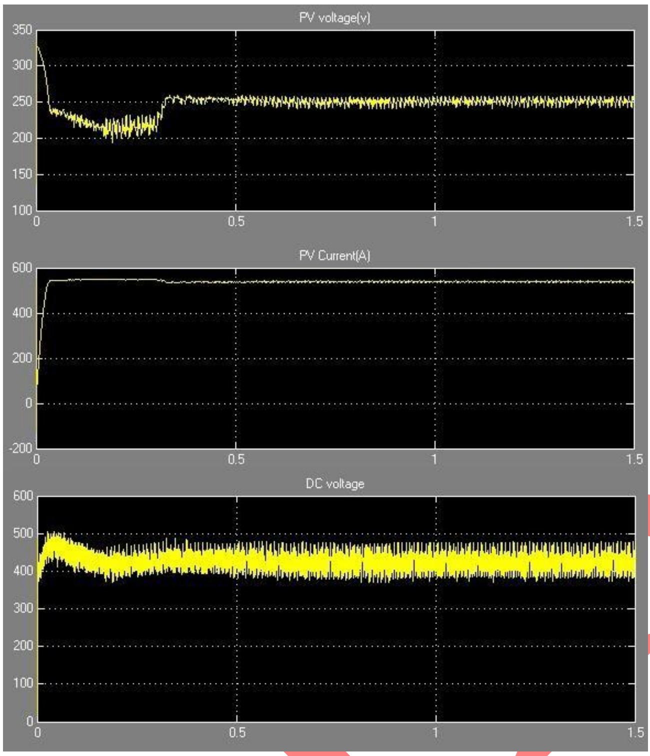

Fig. 14. PV Array voltage, current and DC boost voltage, with DC/AC converter harmonics present

THD of voltage and current waveforms at utility grid was found using FFT analysis.to be 0.50% and 0.19%. Fig. 15. shows the utility grid phase A voltage and current waveform.

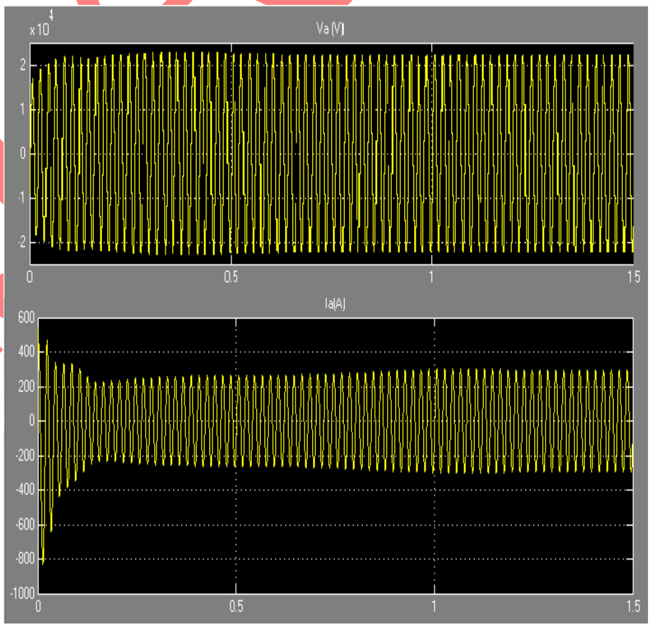

Fig. 15. Utility grid phase A voltage and current, with DC/AC converter harmonics present

Fig. 16. shows the various Wind power plant output. The base values and nominal values are maintained as before.

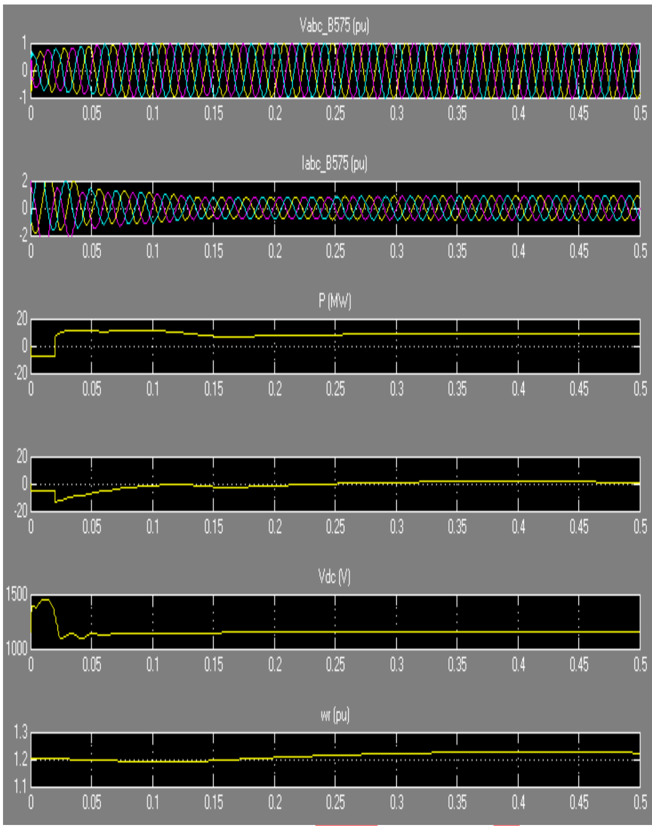

Fig. 16. Wind Power plant output voltage, output current, P, Q, DC link voltage and pu rotor speed, with DC/AC converter harmonics present.

For the above two simulation, the THD at the grid were calculated for filter (block highlighted by blue colour) whose value is
R=.001Ω
and
L=125e-6
H.

Now the simulation is performed on the conventional grid model (or two converter model) and hybrid grid model (or one converter model) for various values of the RL filter. The value is varied and the two model are run each time. Table II shows the tabulated results.

Table II THD comparison

L(uH		**Hybrid**	**Conventional**
No	V	4.4	9.0
	I	27.7	41.4
25	V	4.1	8.2
	I	14.9	28.5
50	V	3.0	6.1
	I	11.1	23.0
75	V	2.0	4.8
	I	12.7	18.8
10	V	1.2	4.1
	I	9.1	18.6
20	V	1.3	2.4
	I	6.1	10.5
50	V	0.5	1.2
	I	3.6	5.9
75	V	0.4	0.5
	I	2.3	3.8

CONCLUSION

A hybrid AC DC microgrid is proposed in this paper. The simulation was carried out on the two models, namely conventional model and hybrid model, for various RL filter values and it was found that the THD of voltage and current at the utility grid for the conventional model is nearly double that of the hybrid model. Therefore, if more DC micro sources ar e added in the conventional model the THD would increase by times the number of DC sources. By decreasing the THD it is possible to reduce the filter size.

Although the proposed hybrid grid model can reduce the number DC/AC or AC/DC conversions in theory, it is not fully ready to be implemented practically. Filters and compensating equipment needs to be added at appropriate places. Furthermore, there are practical constraints for implementing the hybrid model with the current infrastructure. It is difficult for the all the residents to adjust to the renewed system as it requires financial assistance. It may be implemented on isolated industries which use both PV Arrays and Wind power plant. The trend is changing and even schools and residential customers have started installing PV system on their terrace and roofs for small loads. Where excess power is available by such an arrangement it is possible to link it to the common grid and earn revenue. Its implementation depends on the encouragement by government agencies and acceptance by end users.

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