Analysis of Hybrid AC-DC Microgrid: Z-Inverse Technique

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Abstract- This paper deals with the control scheme of the hybrid grid which lags in some important areas like smooth and fast power transfer in the grid and stable system operation under various conditions. For reliable operation of hybrid grid, the converter plays a crucial role which necessities an efficient control strategy at converter. Z inverse technique has been proposed at the converter in this paper. Also in this paper an energy storage system (ESS) has been introduced. The performance of the new control strategy had been demonstrated by modeling it in MATLAB and the satisfactory results are obtained.

Keywords – Microgrid, hybrid grid, PWM, Co-ordination control, Z-Source inverter.

I. INTRODUCTION

In the past few years the power transmission sector had been rapidly changing form 3phase AC to DC system and now a days this is from large scale AC-DC system stepping further grids are also being divided into many parts the newly emerging grid is the hybrid micro grid which has its own source of generation distribution and load parts, mostly independent of the main grid (national grids, regional grids). This micro hybrid grid has sources and loads are of both AC and DC simultaneously which AC load demands are fulfilled by the AC sources and the DC load demand are fulfilled by the DC sources, resulting to many advantages of reliable, compatibility and etc., So these grids are now being trending in many sectors. Moreover presence of renewable energy as the source of power leads to much more interest in this sector and a step forward of implementing this in real time. This type of grids can be setup near the load centers. Having micro sources close to the load has the advantage of reducing transmission losses as well as preventing network congestions. When power can be fully supplied by local renewable power sources, long distance high voltage transmission can be avoided. Recently more renewable power conversion systems are connected in low voltage ac distribution systems as distributed generators or ac micro grids due to environmental issues caused by conventional fossil fueled power plants. On other hand, more and more dc loads such as light-emitting diode (LED) lights and electric vehicles (EVs) are connected to ac power systems to save energy and reduce carbon emission.

Microgrid can be framed as an electrical system which includes electricity generation, energy storage, loads that normally operate along with the main utility grid and can disconnect and operate autonomously as well. The Microgrid consists of micro sources with power electronic interfaces[3]-[4]. These micro sources usually are micro turbines, PV panels, and fuel cells, bio mass, bio gas are placed at customer sites. They are low cost, low voltage with reduced carbon emissions level. Power electronics interface provide the control and flexibility required by the Microgrid.[2]

Depending on locally available energy sources, *Hybrid Microgrid* systems can be developed often in combination with a storage element to match the available energy with the load. Many combinations are possible depending on local conditions, such as Wind-Diesel, Wind- Bio, Wind- Battery[5], Hydro-Bio, Wind-Solar, Hydro-Solar etc. Storage Systems includes Fuel Cells, Battery, Super Capacitor, Pump Storage, Fly Wheel etc.,

II. ESTABLITION OF SYSTEM COMPONENTS

2.1 Proposed Model

For the purpose of study and analysis the generalized hybrid grid has been considered as shown in figure 1 and it is modeled in MATLAB/SIMULINK platform. For the proposed model, the sources and loads both of AC and are connected to the corresponding dc and ac networks through the transformers and four-quadrant operating three phase converters. While designing the proposed model a 40KW PV arrays are connected to dc bus through a dc/dc boost converter to simulate dc sources. A capacitor C_{pv} is placed to suppress high frequency ripples of the PV output voltage. A 50kW Wind Turbine Generator (WTG) has been connected to an ac bus to simulate ac sources. A 65 Ah battery is connected as energy storage to dc bus through a bidirectional dc/dc converter. Loads of both AC and DC type were modelled in between which an auxiliary battery is placed for charging or discharging. The rated voltages for dc and ac buses are 400V and 400V (rms) respectively. A three phase bidirectional dc/ac main converter with R-L-C filter connects the dc bus to the ac bus through an isolation transformer.[1]

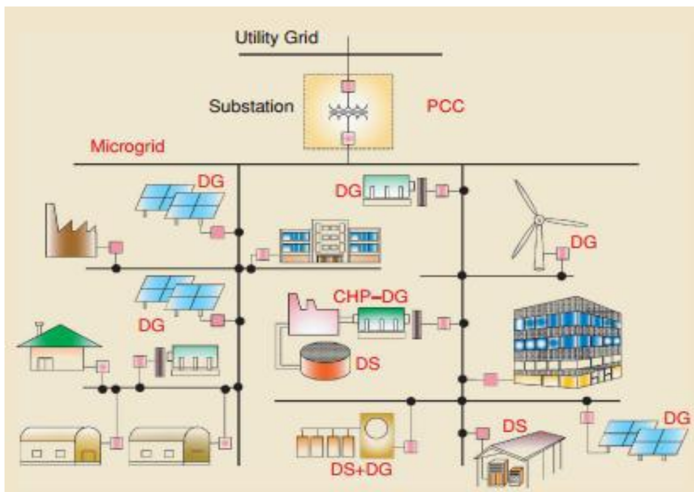


Figure 1. Generalized Microgrid structure for system studies

The mode of operation of the entire grid is classified based on the direction of power flow as either Grid connected (ON-grid) mode or OFF-grid mode.

A.Grid connected mode

In steady state operation of the system i.e., load is supplied from the source and in the case of power imbalance condition, the overloaded load bus will take power from nearby DC energy source (ESS). In case of excess load demand, the load bus will draw power from the main grid whatever is inadequate. The reverse is happened in case of excess generation by the local sources in the proposed hybrid grid. This mode of operation is termed as the grid connected mode. This mode is helpful in the emergency condition where the load suddenly increases and the existing system (hybrid grid) cannot satisfy the load demand.[6]

B.Off- grid mode

When the total load of the hybrid grid is less than the source then the demand is meet by the hybrid grid itself without the combination of any other source, then the entire hybrid grid acts independently i.e. without the help of any external source. This mode of hybrid grid system is said to be off-grid mode.

2.2 Modeling of System Components

In this hybrid grid different components are used which are playing the role of energy sources generating power and supplying to the load, the different sources are pv panel, wind turbine generator, batteries.

A.Photovoltaic modeling

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. The equivalent circuit model of a pv cell is shown in the below figure2.

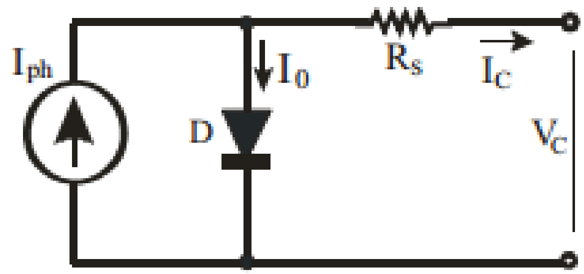


Figure2 Equivalent model of pv cell

$$I_{pv} = n_p I_{ph} - n_p I_{sat} * \left[\exp\left(\left(\frac{q}{AkT}\right)\left(\frac{V_{pv}}{n_s} + I_{pv}R_s\right)\right) - 1\right] \quad (1)$$

The output current of the photovoltaic panel is given in the equation

$$I_{ph} = (I_{sso} + k_i(T - T_r)).\ S/100 \quad (2)$$

$$I_{sat} = I_{rr}\left(\frac{T}{T_r}\right)^3 exp\left(\left(\frac{qE_{gap}}{kA}\right)\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (3)$$

With the help of these current equations modeling of pv panels is done.

B. Modeling of wind turbine generator

The wind turbine generator is the only AC source in this hybrid grid. This wind turbine generates power irrespective of the time it only depends upon the speed of the wind. So this power can be available throughout the day and to get it synchronized with the existing hybrid system the turbine model has to be modeled.[9] Wind generating system is connected with turbine , induction generator, interfacing transformer and AC-DC-AC converter.

The static characteristics of wind turbine can be described with the relationship in the wind as in

$$P_{wind}=0.5\rho\pi R^3 V^3_{wind} \quad (4)$$

It is not possible to extract all kinetic energy of wind and is called power co-efficient. This power co-efficient can be expressed as a function of tip speed ratio and pitch angle.

The mathematical power can be written as

$$P_{mech}=c_{pp\ wind} \quad (5)$$

By using turbine rotational speed, $W_{turbine}$ mechanical torque is shown in figure3.

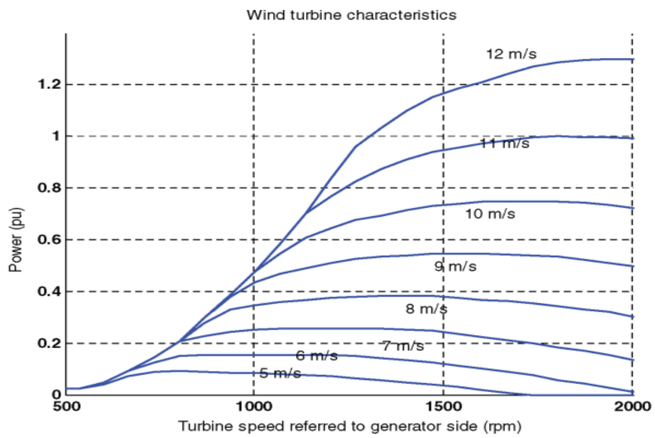


Figure 3. Power speed characteristic of turbine

In this hybrid grid the energy storage system is been used. Depending on the load the battery changes its function. two important parameters to represent state of a battery are terminal voltage vb and state of charge (SOC) as follows

$$V_b=V_o+R_b*i_b-(k(q/(q+\int i_b\, dt)))+A*\exp(B\int i_b dt) \qquad (6)$$

$$soc=100(1+(\int i_b dt/Q) \qquad (7)$$

Where R_b is internal resistance of the battery, Vo is the open circuit voltage of the battery, i_b is battery charging current, K is polarization voltage, Q is battery capacity, A is exponential voltage, B and is exponential capacity.

C. z-source inverter technique for converter

The hybrid grid has to be controlled with a technique that the converter present in the grid fulfills the requirement of smooth and fast power flow in the entire grid.[7][8] This criteria is fulfilled by the z-source inverter technique when compared with the other techniques its response is pretty good. So this technique is used in this grid, and it is experimentally proved with the results shown in the table1.

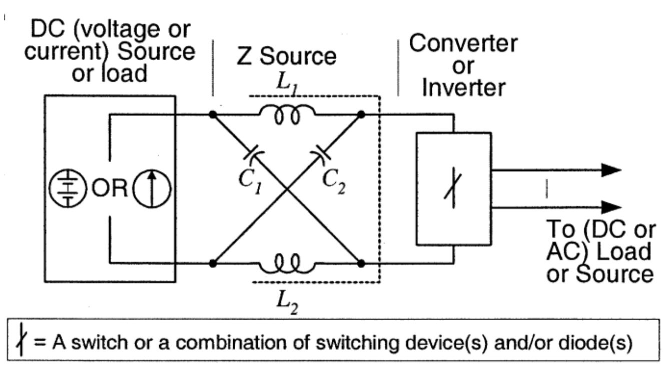


Figure 4. General structure of z-source inverter

The general structure of the z-source converter is shown in the figure4. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively.

The Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage.[10] The traditional V- and I-source inverters cannot provide such feature. The traditional pulse width-modulation (PWM) schemes can be used to control the Z-source inverter and their theoretical input–output relationships.Figure5 shows the traditional PWM switching sequence based on the triangular carrier method.

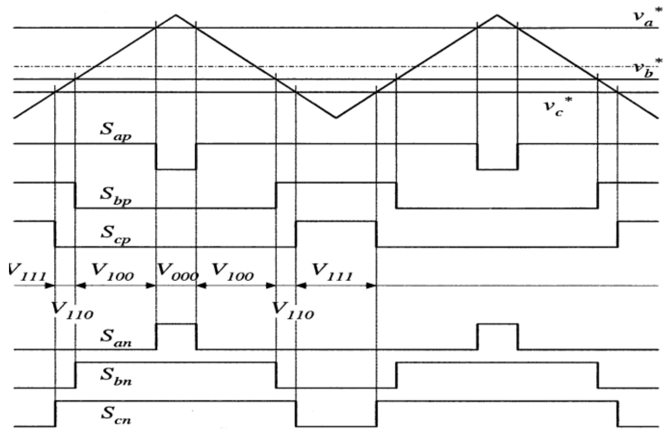


Figure 5. Traditional carrier-based PWM control without shoot-through zero states

The shoot-through zero states are used along with two adjacent active states to synthesize the desired voltage. When the dc voltage is high enough to generate the desired ac voltage the traditional PWM of figure5 is used. While the dc voltage is not enough to directly generate a desired output voltage, a modified PWM with shoot-through zero states will be used as shown in figure6 to boost voltage. It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot through states. It is noticeable here that the equivalent switching frequency viewed from the Z-source network is six times the switching frequency of the main inverter.

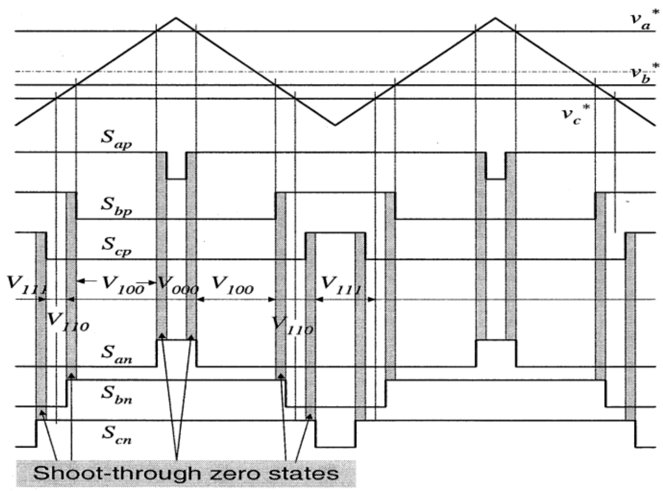


Figure6. Modified carrier-based PWM control with shoot-through zero states

III. RESULTS AND DISCUSSIONS

The simulation has been performed in the matlab/simulink with the above mentioned system module. in this module the photovoltaic panel are maintained at 400v (dc) with the combination of wind turbine generator both acting as a source. In this the z-source inverter technique is used to overcome the slow power conversion problem and with the z-source technique the photovoltaic power also been increased without any change in the solar irradiation. comparison of both the power level is shown in the figure below (solar irradiation level is constant- 1000 w/m2). figure7 shows the output pv power comparison with and without the z-source technique.

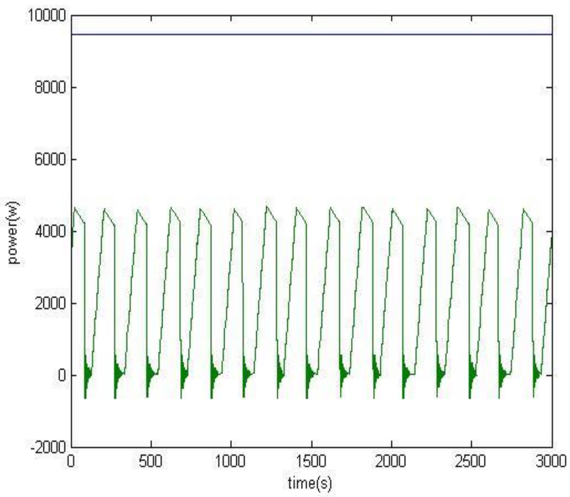


Figure7 Output power of solar panel

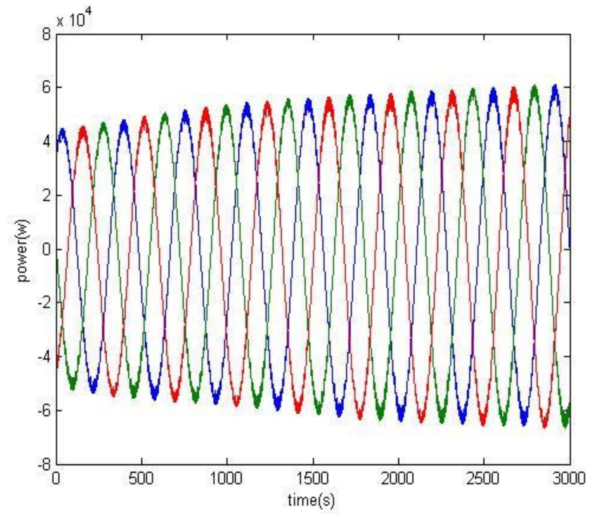
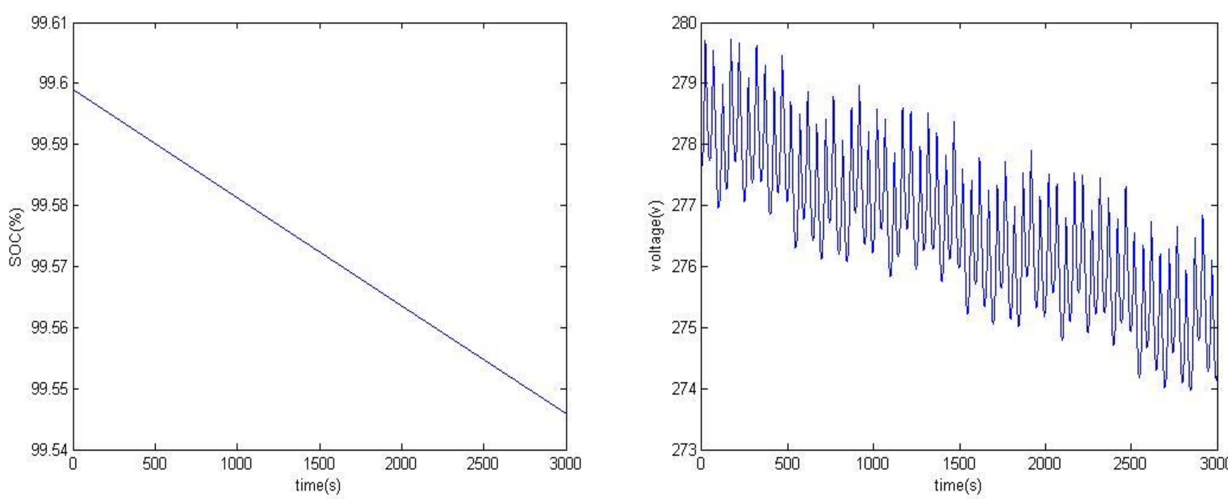


Figure8.Output power of wind turbine generator

The output power of the wind turbine generator is shown it is about 20kw of power generating during the max load condition and considering the wind speed is rated. Then this maximum power can be extracted b this wind turbine source shown in figure8.



(a) (b)

Figure9 :(a) SOC and (b) Voltage of battery with z-source

Now considering in case of battery which acts as both storage device and source, whenever the load changes the battery changes it's mode i.e. when output load is higher than the generation the battery acts as source and when the output load is less than the generation then the battery acts as the storage device then the state of charge (SOC) decreases and increases respectively. Figure 9 shows the battery voltage, SOC of the battery in the operating mode.

It is seen from the figure 9 that the voltage level goes down to the and the SOC is reached to 99.55 in the figure9.

In the table.1 the coordination control and the z-source inverter technique performance is compared when these techniques are implemented in the hybrid grid MATLAB/SIMULINK. The z-source technique shows better performance when compared with coordination technique.

	Coordination technique	z-source inverter
PV power	1900W	4500W
PV voltage	310V	410V
Wind turbine voltage	100V	100V
DC bus voltage	500V	600-500V
Battery voltage	425V	430-400V
Load voltage	300V	150V
Load current	100A	50A

Table1. Comparison of Coordination and Z Source inverter

The total load that is connected is 60KW and the dc bus voltage is around 600V and the voltage waveform is not steeply decreasing ,it is nearly constant when the transient occures or when the shift in power take place(i.e from AC to DC or from DC to AC). As shown in the figure 10.

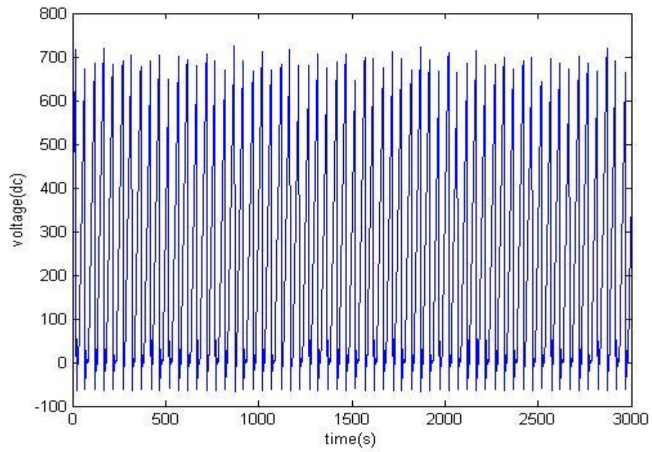


Figure10. DC bus voltage with z-source technique

In the waveform it can be seen that the voltage and the current at the load side rating is at nearly 60A for the 60KW when compared to the other technique where the current is nearly 150A for the same load thus it is more economical when compared to other techniques where the current rating is more high it is compared and shown in the figure 10. The load voltage and current response are shown in the figure11 and figure12 respectively. And similarly The gating signal voltage of the z-source inverter is shown in the figure13.

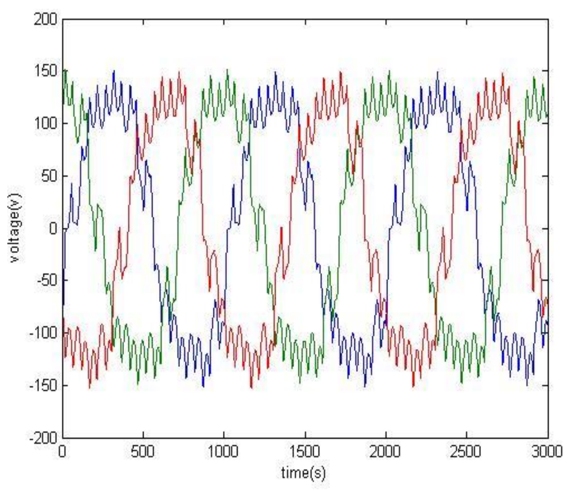


Figure11. load voltage of hybrid grid

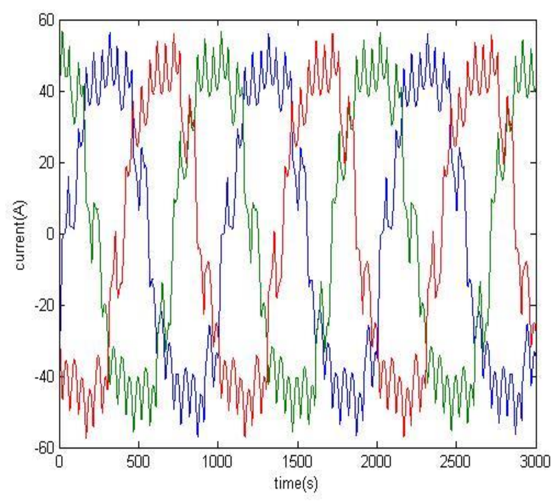


Figure12. load current of hybrid micro ac-dc grid

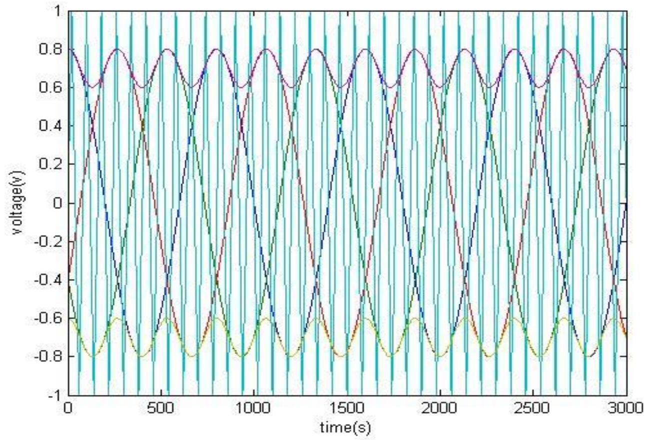


Figure13. Voltage signal for a singel thyristor

IV.CONCLUSION

In this paper the smooth power flow between the source and the load with an auxiliary battery connected between them has been achieved by the proposed techniques depending on the load condition. The Z-source inverter is introduced for the smooth power flow control and this strategy has been verified and compared with the other conventional strategies in the MATLAB/SIMULINK. From the results and analysis it has been observed that Z-source inverter gives better performance characteristics compared with other techniques which are proposed in the past years. In the proposed technique the overall grid performance is maximized and is tabulated in table1. The performance of the grid is improved by the proper coordination among the areas so that the smoother operating conditions can be achieved.

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