Improved Low Voltage - Ride Through (LVRT) Performance of an Active Distribution Grid by Providing a Bidirectional Converter to Control DC Bus Voltage Ripple

Afshin Kadri[1], Reza Ebrahimi[2*], Edris Pouresmaeil[3]

Abstract: In today's world, distributed generation sources through grid-connected inverters perform other roles in addition to generating the required load's power. Among these roles, it is possible to perform the function of the inverter as a virtual synchronous machine in the direction of frequency stability in the presence of a fault, supporting the network in the condition of voltage fault caused by the presence of a fault, and so on. It can be mentioned that doing each of these things, It requires changes in the control system, hardware or new topologies. Supporting the grid in voltage sag conditions, that is called Low Voltage - Ride Through for an inverter, has its own standards and requirements, so meeting them requires new research and designs. In this paper, first, a review of the past work is done and then by presenting a new method, the inverter performance is improved in these conditions. In the presented method, the DC bus ripple will be very low and thus the high order harmonics will be reduced. Also, this ripple is reduced by using a two-way converter and suitable control of the inverter, unlike some of the presented methods that transfer it on the reactive power produced or on the voltage of the solar cell side. Furthermore, in these cases, it is tried to reduce the DC bus ripple to the minimum value of the capacitive capacity of this bus. To evaluate the presented method, simulations have been performed in Simulink / MATLAB software and the results have been presented.

Keywords: Low Voltage - Ride Through, Inverter, Bidirectional converter, Renewable Energy Sources

1. Introduction

Wind, solar, biomass and small hydro turbines as a Renewable Energy Sources (RES), are increasing in power systems. These resources are typically smaller than conventional power plants and geographically more disturbed [1]. For these reasons, they are the most important species of (DG) units. Although until now the main part of electrical power is generated by conventional power plants, but the RES is the world's fastest growing type of power production units [2]. Although recently, government policies based on largess in power markets increases the opportunity of the use of renewable energy resources and DG [3]. One of the major reasons for the importance of this issue is the environmental issues of current power plants. One of the major reasons for the importance of this issue is the environmental issues of current power plants [4]. conventional power plant, with fossil based fuel are one of the major resources of carbon dioxide (CO2) that has an important role greenhouse effect and global warming [4] when the RES are cheap resources. In other words, the increase in the cost of fossil fuels, along with the restrictions on the construction of new large power plants and the remote transmission of electricity, are other reasons for the attractiveness of small power plants that can be connected to strategic points or close to load centers [5- 7].

The integration of RES based DG has significant effects on energy supply and continuity of distribution network services [8]. Traditionally distribution systems are passive networks; deliver the electrical power from transmission

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[1]Department of Electrical Engineering, Gorgan Branch, Islamic Azad University, Gorgan, Iran. E-mail:afshin_kaderi@yahoo.com

[2*]**Corresponding Author:** Department of Electrical Engineering, Gorgan Branch, Islamic Azad University, Gorgan, Iran.
E- mail: ebrahimi.reza61@gmail.com

[3]Department of Electrical Engineering and Automation, Aalto University, 02150 Espoo, Finland.
E-mail: edris.pouresmaeil@aalto.fi

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lines, and feed medium voltage or low voltage loads without any generation units. Most renewable based sources produce DC power and require power electronic devices to connect to AC networks [9, 10].

Today, inverters connected to the grid must be connected and support the grid in low voltage conditions by injecting reactive power according to standard diagrams. This feature is named a low voltage inverter - ride through [1-3]. Implementing this feature for an inverter requires some considerations to avoid possible problems. For example, a grid-connected current source inverter coupled with a photovoltaic generation system may lose stability when the voltage drops.

One of the other important points in the design of control methods required by LVRT is their applicability in different grids and converters, in other words, their generality. While in many articles, the methods presented in them are not able to be implemented in all topologies and types of converters; In the methods presented in [7,8], a general method is proposed for different topologies used in the network. Also, in [11], a common control method for all structures and topologies is presented, in which there is no need to use a voltage sensor, a method based on flux estimation to control the voltage source converter (VSC) used in DG inverters in Unbalanced network voltage conditions are presented. In [12], an adaptive control method of the DC voltage link for a two-stage photovoltaic inverter during LVRT operation is presented. The DC link voltage will be controlled by following the grid voltage changes during LVRT operation to maintain a high modulation rate so that the high frequency harmonics injected into the grid can be dramatically reduced. In addition, at the time of asymmetric grid faults, the presented control method can reduce the ripple value of the DC voltage of the doubled line frequency. In the range of reliable operation by transferring power with doubled frequency of the input DC source line, it can be done by intentionally fluctuating the input DC power or by using a bidirectional DC-to-DC converter depending on the voltage drop rate and the input power level [13]. According to the definition of LVRT, each inverter must have two characteristics of staying connected to the grid for a certain time by injecting active power and supporting the grid by injecting reactive power. There is a standard chart for each of these characteristics, and some countries have their own standard charts. The relevant graphs include the graph of the percentage of voltage drop - time for the first characteristic, It shows in figure (1) and the graph of the amount of injected reactive current - the amount of voltage drop for the second characteristic.

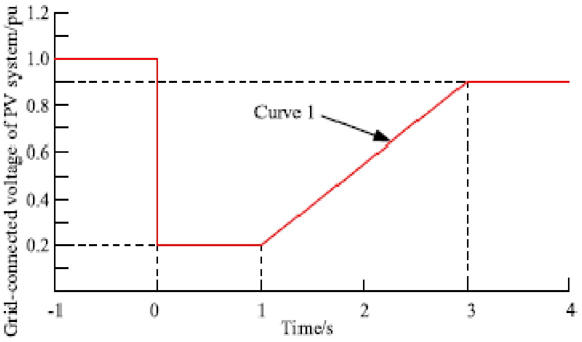


Fig.1. Percentage of voltage drop - time [3]

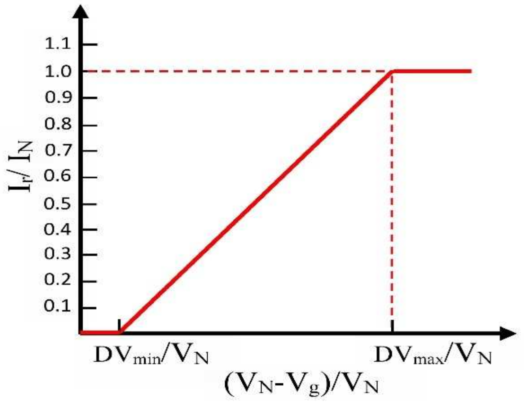


Fig.2. Amount of injected reactive current - the amount of voltage drop[3]

Types of inverter control strategies are discussed in section 2 and the proposed method and bidirectional converter are discussed in section 3. In section 4, the simulation results for the efficiency of the proposed method are given. In the end, the conclusion of the paper is stated in section 5.

2. Types of inverter control strategies and their effects including control in LVRT conditions

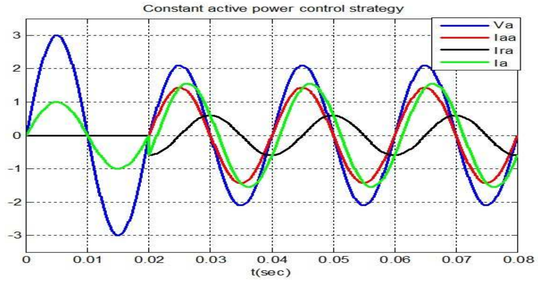
In the conditions of voltage sag detection, the inverter connected to the grid, depending on its nominal capacity, can control the active and reactive power injected into the grid with different strategies, which can both supply the consumed power of loads and help to stabilize the frequency by injecting active power. By injecting reactive power according to the desired diagram, it helped to stabilize the voltage and prevent its collapse. Several methods are used in this case, including constant average active power injection, current injection with constant active component, and injection with constant amplitude or maximum current. Each of these methods has its advantages and disadvantages, and for the implementation of each method, requirements such as having a sufficient nominal capacity for the inverter are necessary.

Some countries have their own standardized curve, but the amount of reactive current can be calculated using a Eq. (1):

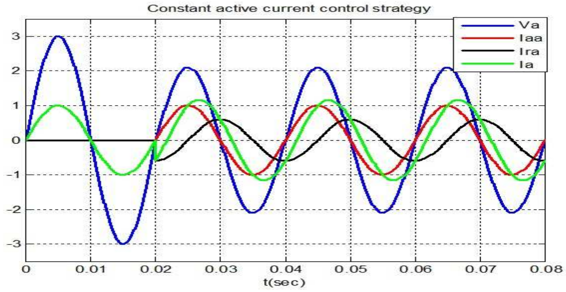
$$\frac{I_r}{I_n}=\begin{cases}0 & V_{p.u}>0.9\\ k\left(1-V_{p.u}\right) & 0.2<V_{p.u}<0.9\end{cases} \qquad (1)$$

Where k is a coefficient which shows the proportion of reactive current (Ir) to the nominal current of power generation (In) as a function of voltage drop of the grid voltage. As this relationship shows, if grid voltage is more than ninety percent of the rated voltage, there is no need to inject reactive current into the grid, while if the amount of voltage sag exceeds twenty percent, the injected reactive current should be equal to the rated current. If the value of voltage sag is between ninety and twenty percent, the value of the reactive current component should be a linear coefficient of a name that is slightly different in different countries [3].

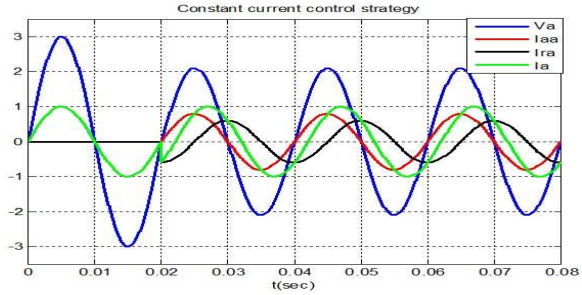
The nominal current of the inverter can be different from the value of the nominal current mentioned in the above paragraph. The meaning of rated current is the current required to generate power as much as the power source and its injection into the network under normal network conditions, while the rated current of the inverter can be considered more than the current required for the total generated power. The reason for this problem is that in voltage sag conditions, in addition to injecting reactive power, you can continue injecting active power in full or in part. This issue has two advantages. Firstly, the goal of the system to generate power does not stop, and secondly, frequency stabilization is helped by generating power. The amount of active and reactive power in voltage sag conditions depends on the control strategy. Considering each control strategy, the amount of active and reactive flow follows different relationships. There are three control strategies in voltage sag conditions. Constant average active power injection, current injection with constant active component, injection with maximum constant current amplitude[1-3].



(a)



(b)



(c)

Fig.3. (a) Constant average active power injection, (b) current injection with constant active component, (c) injection with maximum constant current amplitude

3. Proposed method and bidirectional converter

In case of voltage sag and inverter LVRT operation, the DC bus voltage oscillates with a frequency twice the grid frequency. The presence of double frequency in the dc bus causes the system to leave the MPPT point. Therefore, methods have been provided to remove this ripple, which have defects such as fluctuating injected reactive power and leaving the MPPT point. According to the relationship between active and reactive power in voltage sag conditions, fluctuating power values cause oscillation in the DC bus, because these values cause energy exchange with the DC bus capacitor. To compensate for these fluctuations, a bidirectional converter can be used in parallel with the DC bus, which is presented in Figure (4).

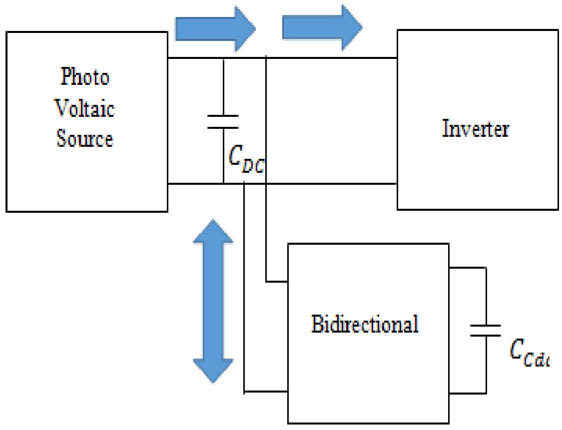


Fig.4. Schematic of the bidirectional converter method

The converter shown should have a controller that performs two tasks. First, it must absorb some active power to set its DC bus voltage to a reference value. This amount of power is to compensate for the losses caused by the internal resistance of the capacitor and the losses of the switches, so its value is very low. Secondly, by controlling the DC bus voltage in its average value, it removes any ripple from it. Since the ripple is sinusoidal either according to the ripple caused by the active power or the reactive power, therefore, if the capacitor voltage of the converter is set at a DC value, both of these ripples can be transferred to the secondary side of the converter and removed from the primary one is the DC bus of the inverter. Figure (5) shows the implementation of this bidirectional converter, which is similar to a buck-boost converter.

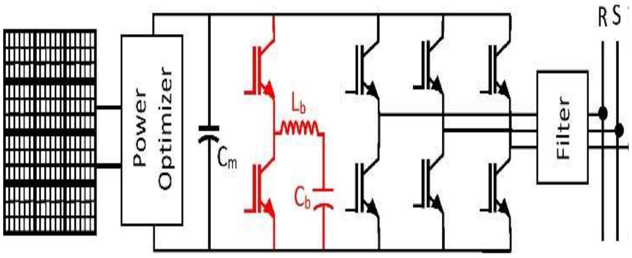


Fig.5. Bidirectional converter to eliminate the oscillatory component of the DC bus

Another advantage of this method is the small nominal capacity of the bidirectional converter, because this converter is only responsible for producing fluctuating active and reactive power, the values of which are very low compared to the average values.

4. Simulation results

4.1 Output results

To check the correctness of the proposed method, a simulation has been done in the MATLAB program. Figures (6),(7) and (8) below show the intended simulation and the answers obtained. For simulation, a semi-controlled current source has been used to equalize the inverter, and the controller enters the bidirectional converter into the circuit at time t=0.3s. As can be seen, the second order frequency ripple from the DC bus is almost eliminated. In addition, in this simulation, the MPPT voltage is equal to 30 volts and the DC bus adjustment voltage of the bidirectional converter is 15 volts.

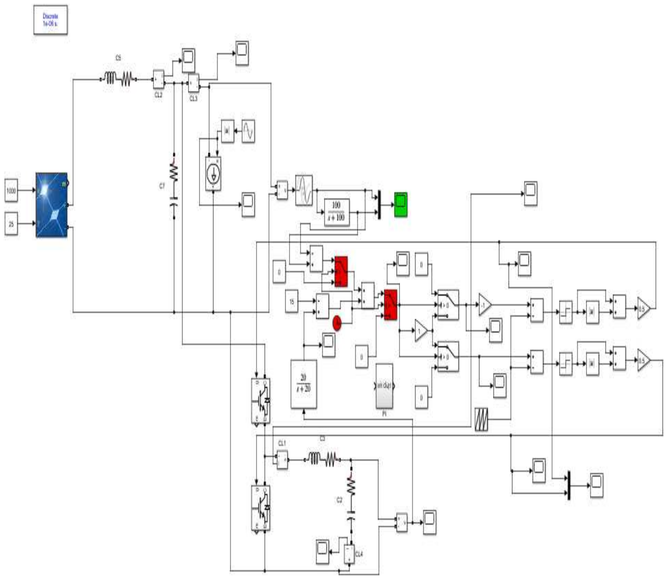


Fig.6. Simulation model

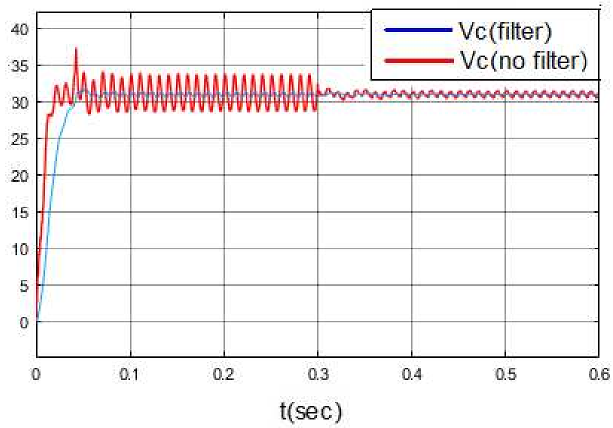


Fig.7. Solar cell capacitor voltage and its filtered value

In fact, this ripple converter transfers the DC bus to its DC bus. Figure (7) shows the DC bus capacitor ripple of the bidirectional converter. Since the corresponding average ripple is equal to zero, it does not change the average value of the DC bus voltage of the bidirectional converter, and the ripple value of the DC bus of the bidirectional converter depends on the value of the DC bus capacitor of the inverter.

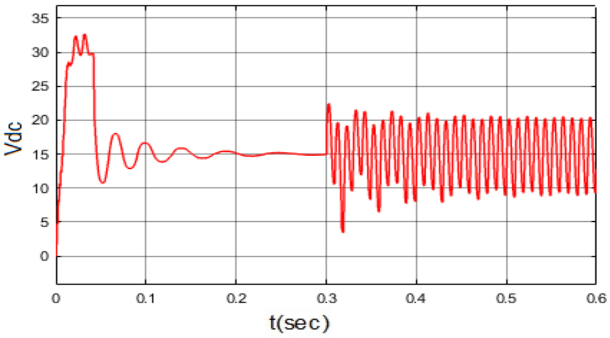


Fig.8. Ripple capacitor bus DC bidirectional converter

4.2 Comparison of the proposed method with the methods done

Table (1) shows the advantages of the proposed method compared to the methods mentioned in the references. As seen, in the proposed method, it guarantees almost zero fluctuation, does not cause fluctuation in the PV output power, uses the excess capacity of the inverter, and can work within the current limit of the PV inverter.

Table 1. Comparison of the proposed method with the existing method to eliminate DC bus ripples

Index	Ref. [7]	Ref. [2]	Ref. [1]	The proposed Method
Zero fluctuation of DC bus voltage	**Does not warranty**	**Warranty**	**Warranty**	**Warranty**
Oscillation in PV power generation	**No**	**Yes**	**No**	**No**
Depending on P-V operating point	**No**	**Yes**	**No**	**No**
Using extra capacity of the inverter	**Yes**	**Yes**	**No**	**Yes**
Operation in current limitation of the inverter	**Yes**	**Yes**	**No**	**Yes**

5. Conclusions

The method of creating a two-way converter is proposed to remove the voltage ripple in the DC bus. Therefore, a smaller size of electrolytic capacitor of a DC bus can be used, which is cheaper, more reliable and has lower series resistance. In addition, its power loss is reduced and it can operate at a lower temperature. As a result, the possibility of the failure of the DC bus capacitor, which causes the inverter to fail, is reduced. The presented simulation results prove the effectiveness of the proposed method in sagging conditions.

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