Functionalities of Smart Inverter System for Grid-Connected Applications

O.I. Adekola and A.K. Raji

Abstract—The effects on the atmosphere of the global use of conventional fossil fuel have given rise to the use of renewable energy sources as distributed generation (DG) generators. The renewable energy source is considered as a clean source of power generation which is also known as an alternative energy to conventional fossil fuels. Among the renewable energy sources, high interest is on the solar energy which generates electricity using PV (photo voltaic) modules. This has led to the increasing number of the grid-connected inverter affecting the power quality of the system and also causing instability in the grid. The smart inverter has gained more attention for mitigating the negative impacts of grid interfaced variable and intermittent energy sources such as solar energy. This paper presents the functionalities of the various configurations of the grid-connected inverter and how efficient each of the configurations is and their benefits. Simulation results were carried out in MATLAB/SIMULINK to demonstrate the capability of grid-connected distributed generation to provide ancillary services.

***Index Terms*— Distributed generation (DG), Inverter, Photovoltaic (PV), Renewable energy source (RES), Voltage source inverter (VSI)**

1. INTRODUCTION

In recent times, there has been continuous increase in energy consumption which has also led to the increase of renewable energy production. There are different sources of energy currently in use but unfortunately, most of the energy sources come from conventional fossil fuels[1]. The use of conventional fossil fuels for the production of electricity in South Africa contributes more than 90% of total consumption making South Africa the biggest polluter on the continent. The [1]environmental impact of fossil fuels such as oil, coal and gas is very enormous and hazardous. Apart from contaminating the air, polluting and harming the environment, it has been identified as the main culprit in increasing greenhouse gases in the atmosphere which is causing global climate change. The greenhouse gases such as carbon dioxide, nitrous oxide and methane are released when fossil fuels are used for energy generation.

Therefore, it has become essential to look at other means of diversifying the power generating modes through the use of renewable resources. The real power output from these energy sources is unstable. The unpredictable and inconsistent renewable energy often relies on the weather for its source of power which has made the integration of intelligent grid systems very important in order for this not to be so. To achieve a reliable and consistent generation through RES, new control strategies must be developed for the efficient operation of the grid system to improve the reliability of the system. Due to the intermittent nature of renewable energy, there is the need to integrate in the grid system appropriate filter, the monitoring and control of varying energy flows and to plan for standby capacity to absorb the intermittent generation. Solar photovoltaic (PV) systems are used for many applications due to their low maintenance requirements and no pollution emitted.

This paper highlights the functionalities of the smart inverter. Fig. 1 below shows that South Africa uses a very high percentage of coal to generate electricity than any other source of energy. The decrease in the cost of renewable energy technology in the past years till the next five years is also shown in the graph in Fig. 2.

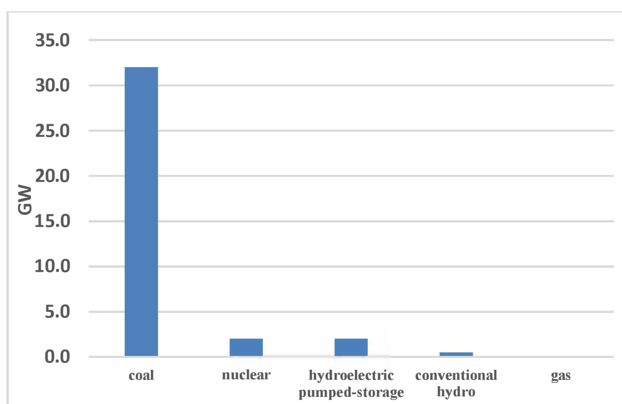

Fig. 1. Energy mix in South Africa [2]

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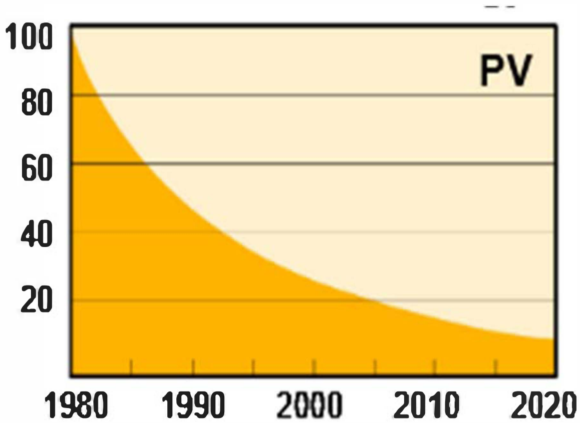

Fig. 2. Cost reduction curve for renewable energy technology [3]

For an inverter to be considered smart, it must have a digital architecture, bidirectional communications capability and robust software infrastructure. The system begins with reliable, rugged and efficient silicon-centric hardware, which can be controlled by a scalable software platform incorporating a sophisticated performance monitoring capability. Power electronics technology provides the platform upon which such intelligent and smart interface may be developed. Development has occurred vastly in the area of power electronics in recent times. The fundamental features of Power Electronics are semiconductor device technology, system engineering and mounting technology including cooling, control and protection. The smart inverter is a very essential part of the distributed generation (DG) interface as it increases the reliability and efficiency of the utility grid. Distributed generation generators have developed interest in the use of renewable energy as their source recently. There are different types of renewable energy sources which are used by distributed generators but the power outputs from these sources are unstable. Smart technologies and Power Electronics are key factors in the operation of distributed generation and therefore, power electronics interface system as smart inverter will be the most efficient way to achieve the stability. The smart technology is gradually penetrating the market and Fig. 3 shows the world market share for inverters in recent years.

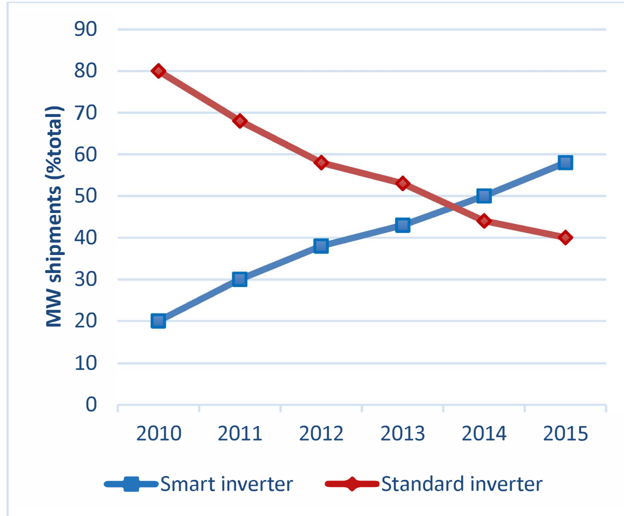

Fig. 3. World market share of standard inverter and smart inverter graph [4]

2. TOPOLOGIES OF GRID-CONNECTED INVERTERS

The multifunctional inverters are power electronics interface system used to convert DC to AC power. The inverter interface to the grid ensures that it operates at the MPPT (maximum power point tracking). In order to utilize the maximum power produced by the PV modules, the power conversion equipment has to be equipped with a maximum power point tracker (MPPT). This MPPT is a device which tracks the voltage where the maximum power is utilized at all times[5]. The inverter topologies have been categorized based on their applications and characteristics of the grid-tied inverter conversion stage:

- Central inverters
- String inverters
- Multi-string inverters
- Module inverters (micro inverters)

2.1 Central Inverters

In this kind of inverter, the PV arrays are connected in parallel to one central inverter. It is mostly used in three phase power plants between 10kw to 1000kw. This type of inverter has a very high efficiency due to low losses in the power conversion stage but the disadvantage of this system is that the cost is higher because of the long cables required to connect the PV array to the inverter and the centralized MPPT. Also there is an increased cost for installation and maintenance of the system. The conventional solar PV installations feed DC voltage to a central inverter for distribution locally and across the utility grid[4], [6].

2.2 String Inverters

This architecture was presented to improve on the disadvantages of the central inverters. In this topology, the PV strings are connected to separate inverters. String converters provide DC-DC conversion to enhance the power delivered to the central inverter by each string. The efficiency of the PV array and reliability of the entire system is improved in this configuration compared to the central inverter that depends on a single inverter. The configuration reduces the impact of a poor performing single panel to its string rather than the entire system. String inverters eliminate the need for a central inverter by converting from DC to AC at the output of each string. This system allows the MPPT at each string [4], [6].

2.3 Multi-String Inverters

This architecture combines configuration of both the string and module inverters. As it is shown in Fig.4c, it is a development of the string inverter. The power range of this configuration is 5KW and the strings use an individual DC to DC converter before connection to a common inverter. MPPT is implemented for each string in this configuration as well thereby improving the efficiency of the system[4].

2.4 Module Inverters

This is the present and future technology. In this architecture, the inverter consists of single solar panels so therefore, MPPT is implemented for every each panel. It provides DC to AC conversion from each individual panel rather than an entire string [4], [6].

Fig. 4 below shows the different types of PV grid tied inverter configurations.

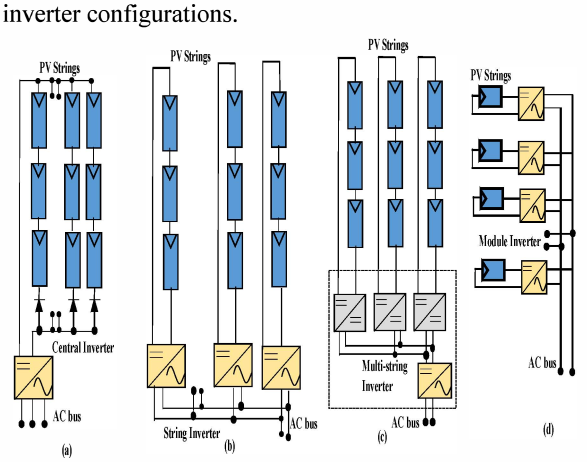

Fig. 4. PV grid connected systems configurations[4]

a. Central Inverter b. String Inverter c. Multi-string Inverter d. Module Inverter

3. HARMONIC FILTERING

Harmonic filtering is required to improve the output waveform of the inverter in order to reduce its respective harmonic content, consequently the size of the filter used and the level of electromagnetic interference (EMI) generated by switching operation of the inverter[7]. A lot of work is being done to improve the power distribution system requirement that is, the voltage quality and reliability. Random voltage disturbances might occur due to fluctuating output power of solar or wind generation. There has been major interest in the use of LCL filter in grid connected inverters which yields better attenuation of switching harmonics thereby allowing the use of a lower switching frequency that meets the harmonic limits, and reduces the electromagnetic interference also defined by standards IEEE-1547 and IEEE-519 [8][9].

One of the major things to be considered in the designing of the inverter is that the power quality must comply with interconnection standards. The commonly used inverter is the voltage source inverter (VSI) but the output is a modulated voltage which needs to be filtered to produce the output voltage required by the utility grid. The mostly used filter is the inductor-capacitor-inductor (LCL) due to its better harmonic attenuation, reduced power consumption and reduced electromagnetic interference. However, more work is still being done on the evaluation of LCL filter for designing purposes [10].

4. VSI CONTROLS

Voltage source inverter (VSI) is used to convert energy from a DC source to an AC output, both in a standalone mode or when connected to the utility grid[11]. One of the major control strategies used to operate an inverter is the VSI controls. VSI control was explained as a condition whereby the inverter is controlled to supply the load with specified values of voltage and frequency. Depending on the load, the VSI real and reactive power output is defined automatically[12], [13]. The three phase voltage source inverter (VSI) is commonly used as the interface between RES-based DG generators and the grid system in designing applications. The switching signals for VSI which are mostly the current signals when designing a smart inverter, may have information on the active power supplied from the RES and the reactive power needed to compensate for the power quality disturbances at the PCC (point of power coupling)[14]. It is uncommon to find a synchronous generator that can be controlled fully in a micro grid which is responsible for the frequency and voltage controls in conventional power systems. Microsource technologies that are mostly installed in a microgrid (MG) are not suitable to be connected directly to the electrical network due to the kind of energy that is produced. However, a power electronic interface such as an inverter will be suitable. The block diagram of this inverter interface setup is shown in Fig. 5. It is required that the VSI are able to sustain over currents for a larger time interval than the time required for fault clearance. Hence, when there is a case of short-circuits of induction machines the VSI will provide reactive power within the specified current limits and this behavior will be sustained until the induction machines recover[12].

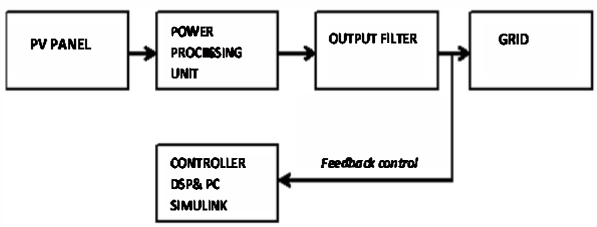

Fig. 5. Block diagram of grid connected inverter

5. SIMULATION RESULTS

The schematic of the three phase voltage source inverter is shown in Fig. 6. However, to test the practicability of this system, the model in Fig. 7 was built and simulated using the SimPowerSystems toolbox in Matlab/Simulink. The simulation results are shown in Fig.8 and Fig. 9 respectively.

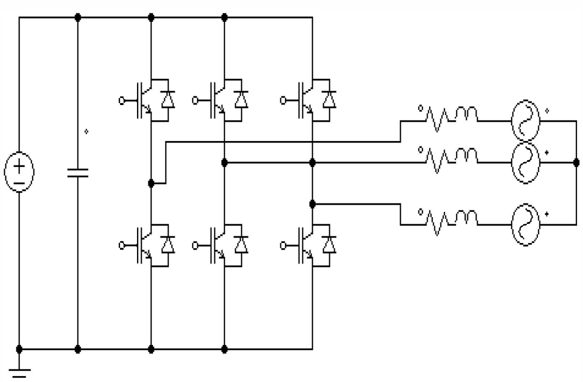

Fig. 6. Three phase Voltage source inverter topology

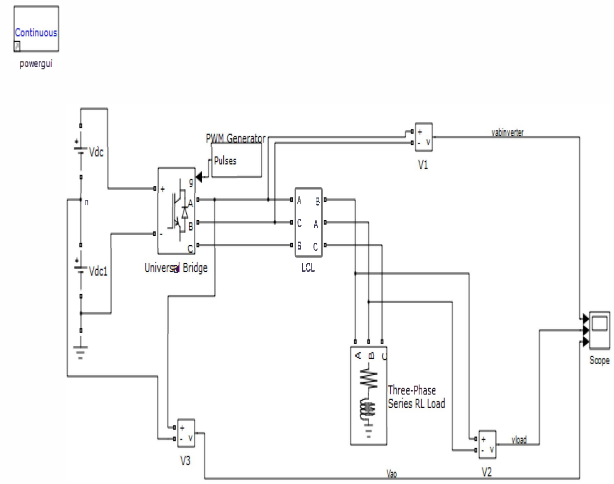

Fig. 7. Simulink model of a three phase inverter with LCL filter and load

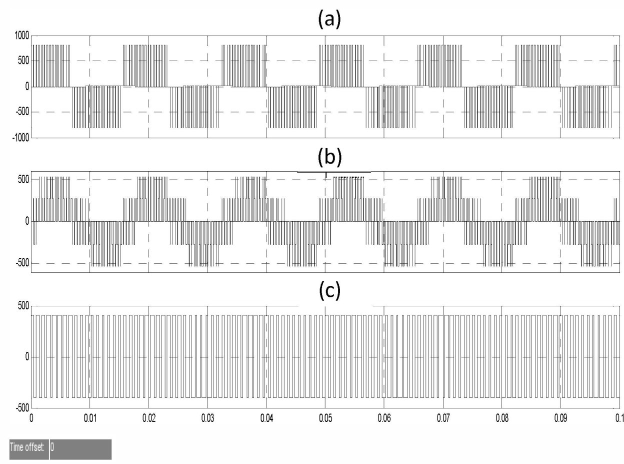

Fig. 8. a) Inverter output voltage V_{ab} b) load voltage V_{abc} before the filter was connected c) V_{an}

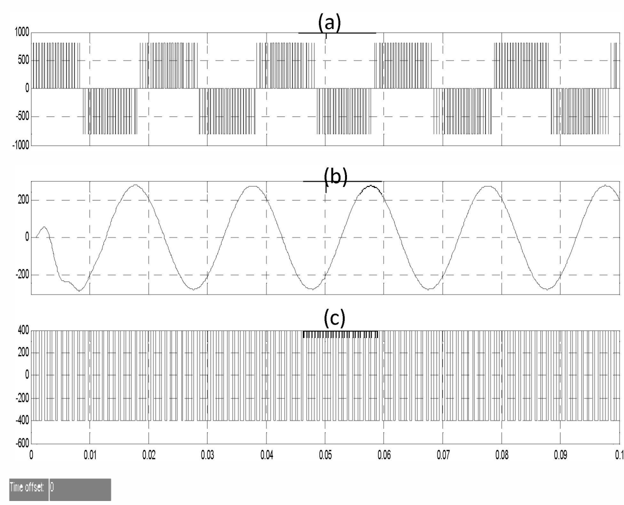

Fig. 9. a) Inverter output voltage V_{abc} b) load voltage V_{abc} after the filter was connected c) V_{an}

6. RESULT DISCUSSION

PWM switching strategy was used for the simulations carried out. This compares reference signal with the triangular carrier signal which generates the switching signals for the switches in the inverter. The reference signal frequency or the fundamental frequency is 50 Hz which is the operating frequency for one of the legs of the inverter while the carrier signal frequency which was 5 KHz is the operating frequency for the other leg of the inverter. The switching frequency is an important factor as regards to the inverter efficiency since major source of losses is due to switching losses. Also, the higher the switching frequency, the lesser the cost and size of the filter though there is a limit not to be exceeded as regards to standard requirements [9]. The shape of the output voltage of the inverter is usually determined by the modulation index 'M'. The value chosen for M in Fig. 8 and Fig. 9 was 0.5 while the dc link voltage of the inverter was kept at 800 V. The inverter output voltage and the load voltage waveforms indicates harmonics present before the filter was connected as seen in Fig. 8. Also, it can be seen in Fig. 9 that the voltage output waveform after the LCL filter has been connected is much smoother with very minimal ripples. This shows that the LCL low pass filter is capable of reducing low order harmonics.

7. CONCLUSION

This paper reviewed the background study on means of energy production and consumption rate. Since it has become evident that the use of conventional fuel is hazardous to human health and would also no longer be sufficient in the nearest future, the use of alternative energy as solar is being emphasized. However, to achieve stability with the solar and other RES, the design of the output filter is very important. The output filter was designed in such a way that the harmonics present in the inverter can be filtered out and also to comply with the total harmonic distortion requirements by producing a sinusoidal voltage and current which is acceptable. The methodology proposed in this paper can be applied in DG applications.

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