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Modified Sinusoidal Voltage & Frequency Control of Microgrid in Island Mode Operation

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Abstract— A distribution system that is equipped with distributed generators, such as roof-mounted photovoltaic systems, can operate as a micro-grid (i.e., separated from the grid) under some specific conditions. A key feature of a micro-grid is its ability to separate and isolate itself from the utility seamlessly with little or no disruption to the loads within the micro-grid. Then, when the utility grid returns to normal, the micro-grid automatically resynchronizes and reconnects itself to the grid, in an equally seamless manner. This thesis addresses the conditions necessary for proper micro-grid operation: these include voltage and frequency control across the load when microgrid operated in Island mode. For this purpose we develop an advanced inverter control mechanism based on improved sinusoidal pulse width modulation technique for Inverter switching. Computer simulations using Matlab Simulink will be conducted under various scenarios to validate such necessary conditions.

Index Terms— Micro-grid, Island Mode, Modified Sinusoidal Control

1 INTRODUCTION

A microgrid is a cluster of interconnected distributed generators, loads and intermediate energy storage units that co-operate with each to be collectively treated by the grid as a controllable load or generator [1]. It is connected to the grid at only one point, the point of common coupling or PCC. The main objective of its conception is to facilitate the high penetration of distributed generators without causing power quality problems to the distribution network. Another important objective is to provide high quality and reliable energy supply to sensitive loads. The components that constitute the microgrid may be physically close to each other or distributed geographically. Figure 1 depicts a typical microgrid. The microsources are the primary energy sources within the microgrid. They may be rotating generators or distributed energy (DE) sources interfaced by power electronic inverters.The installed DE may be biomass, fuel cells, geothermal, solar, wind, steam or gas turbines and reciprocation internal combustion engines. The overall efficiency may be improved by using combined heat and power sources (CHP). The connected loads may be critical or non-critical. Critical loads require reliable source of energy and demand stringent power quality. These loads usually own the microsources because they require a continuous supply of energy. Non-critical loads may be shed during emergency situations and when required as set by the microgrid operating policies. The intermediate energy storage device is an inverter interfaced battery bank, supercapacitors or flywheel. The storage device in the microgrid is analogous to the spinning reserve of large generators in the conventional grid. They ensure the balance between energy generation and consumption especially during abrupt changes in load or generation. Another method of integrating energy storage to the microgrid is to install battery banks in the dc links of the inverters of the microsources [2].

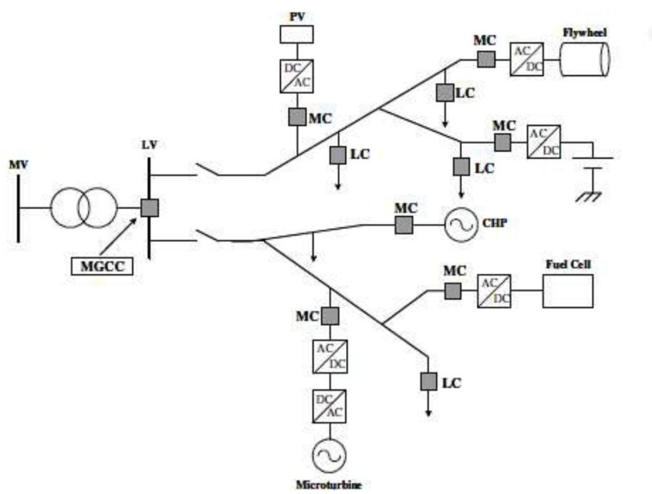

Figure 1: An example microgrid

2 MICROGRID OPERATION MODE

The microgrid can operate in grid-connected mode or in island mode. In grid-connected mode, the microgrid either draws or supplies power to the main grid, depending on the generation and load mix and implemented market policies. The microgrid can separate from the main grid whenever a power quality event in the main grid occurs [3].

3 ISLAND OPERATION OF MICROGRID

When a microgrid is grid-connected, it behaves as a controllable load or source. It should not actively regulate the voltage at the PCC [4]. Furthermore, the harmonics and dc current it injects to the grid should be below the required levels. During

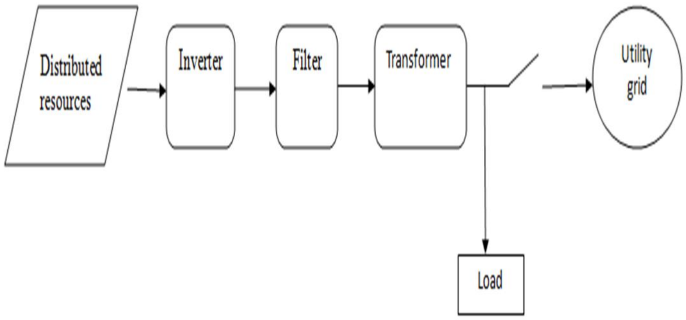

Figure 2: Island mode of a microgrid

this mode of operation, the primary function of the microgrid is to satisfy all of its load requirements and contractual obligations with the grid. The microgrid should disconnect when an abnormal condition occurs in the grid. It shifts to island mode of operation, and the microgrid is faced with the following issues:

The voltage and frequency are established by the grid when the microgrid is connected. When the microgrid islands, one or more primary or intermediate energy sources should form the grid by establishing its voltage and frequency, otherwise, the microgrid will collapse.
Both voltage and frequency should be regulated within acceptable limits. If the frequency has dropped to excessively low levels, loads may be shed to hasten its recovery towards the nominal value [5].

. Island mode of operation of a microgrid is shown in Figure 2.

4 Methodology

The whole work consists of several approaches and steps. We develop our thesis according to the following procedure. Block diagram of our complete work are shown in Figure 3.

- The DC output of the PV array is connected to a full-bridge Inverter to convert the direct current (DC) to alternating current (AC).
- The output from the inverter is square wave and necessary to convert this square wave to a pure sine wave with appropriate frequency.
- A LC filter with a inductor [L] and a capacitor [C] is used to produce pure sinusoidal voltage.
- The output of filter then pass through a electrical isolation transformer to produce grid quality voltage.

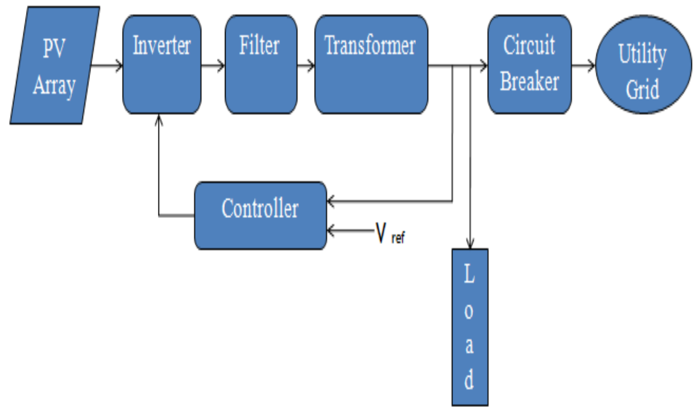

Figure 3: Block diagram for controlling voltage and frequency of a Microgrid operated in Island mode.

- An Inverter control Mechanism is used to synchronize the inverter output voltage with the grid voltage.
- A phase-locked-loop (PLL) is utilized to maintain a constant reference voltage.
- From the controller we get the gating signal for the Switching device of an Inverter.

5 Controller

The basic inverter controls can be broadly classified into two types: current control and voltage control. When the inverter is connected to the utility, the grid controls the amplitude and frequency of the inverter output voltage and the inverter itself operates in the current control mode. Other types of inverter controls such as power flow control and VAR/voltage control can be derived from the basic current control.

In contrast, in case of grid failure (grid faults, maintenance, etc.), the connected loads have to be supplied by the inverter. In such a scenario, which is often referred to as islanded operation, the inverter has to maintain the amplitude and the frequency of the voltage so that the connected loads are not affected by the utility interruption. The inverter operates in voltage control mode for such scenario providing the reference voltage and frequency.

5.1 Voltage Controller

For the voltage control mode, the IGBT switches are controlled using bipolar pulse-width modulation (PWM) switching such that the inverter output voltage follows the reference voltage. An external voltage signal with 220V AC, 50Hz is first fed into a discrete single-phase phase-locked-loop (PLL). The gain at the input of PLL is used to normalize the actual voltage signal. The output of the PLL block generates a phase angle ($\theta=\omega t$). The phase angle together with the AC voltage set point (Vac set) is used to generate the reference voltage, V_{ref}. The PLL is necessary to make sure that when utility voltage is present, although inverter is operating in islanded mode, the inverter

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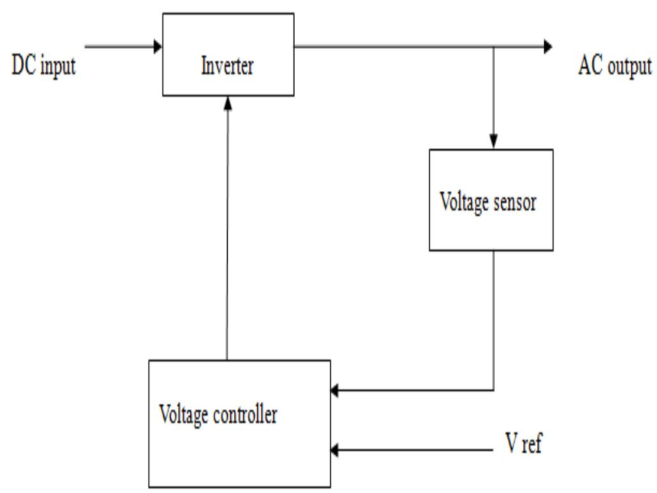

Figure 4: A voltage control block diagram

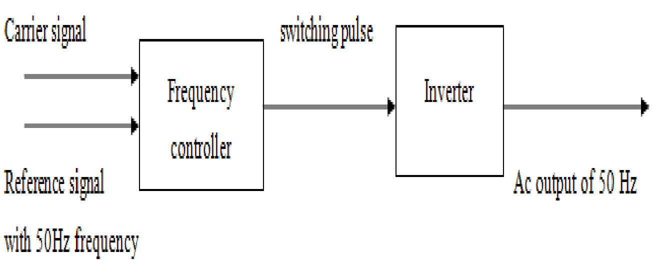

Figure 5: A frequency control block diagram

voltage is synchronized with the utility voltage.

In conventional PWM generation schemes, a sinusoidal control signal is compared to a triangular carrier signal to generate the PWM pattern.we used a different control method. We compared the actual voltage to the reference signal and the error was then fed to a proportional controller. The output of the controller was then scaled and added to a feed forward loop. The final output of the controller is a duty cycle value (D), as given by equation (1)

$$D = 0.5 + Vref / (K_1 Vdc) + (Vref - Vinv) / (K_2 Vdc) \qquad (1)$$

where, Vref is the reference voltage, Vinv is the inverter output voltage, Vdc is the input DC voltage and K_1, K_2 are the proportional gain.

This duty cycle, D, is computed and then compared to a 10kHz triangular wave to generate a 10kHz PWM switching signal with positive duty cycle of D. Based on the PWM switching pattern, IGBT switches are turned on and off in a bipolar fashion, such that two diagonally opposite switches in the H-bridge turn on and off simultaneously[6]. A voltage control block diagram is shown in figure 4.

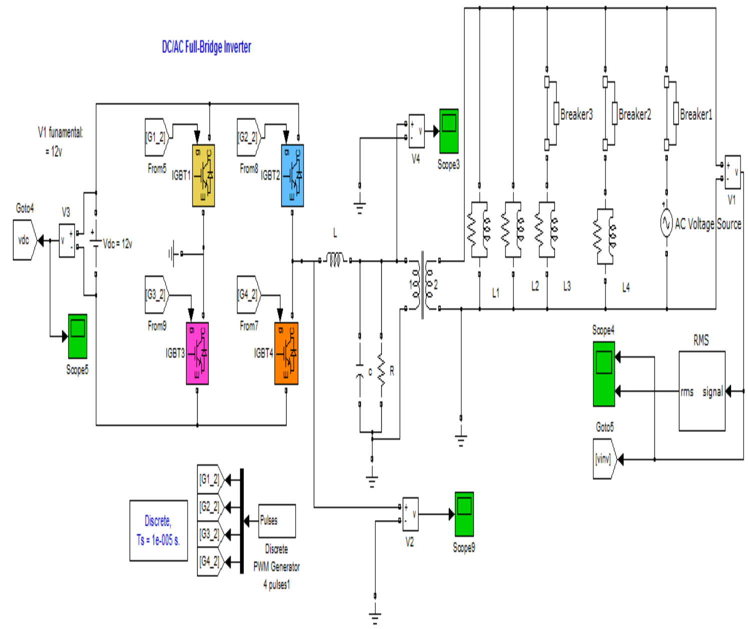

Figure 6: Matlab simulink model of a complete micro-grid power circuit

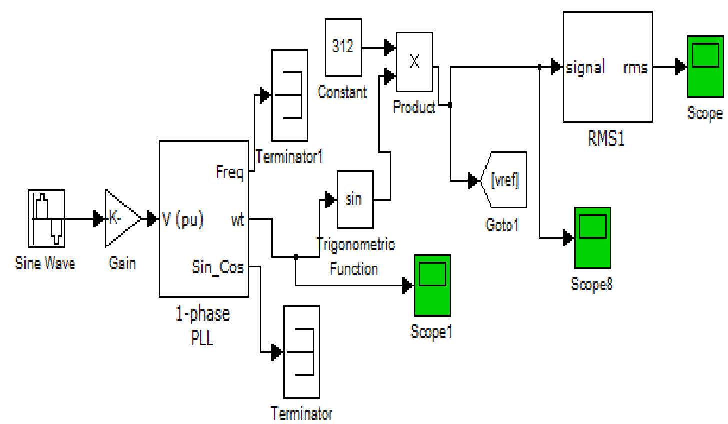

Figure 7: Matlab simulink block diagram for generating reference voltage

5.2 Frequency Controller

The output frequency of the Inverter is depends on the frequency of the reference signal. Here we use a 50Hz reference signal. So the output frequency of the inverter is 50Hz. A frequency control block diagram is shown in figure 5.

6 Matlab Simulink Model

In figure 6, a complete Micro-grid Power Circuit modeling in Matlab simulink platform is shown.
Matlab simulink block diagram for generating reference voltage is shown in figure 7.

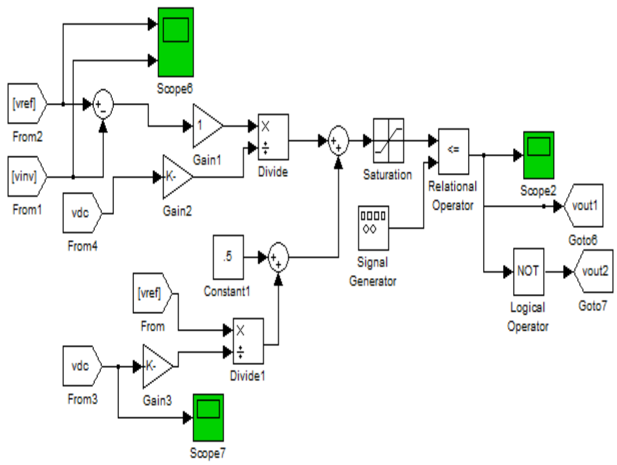

Figure 8: Matlab simulink block diagram for Inverter output voltage control

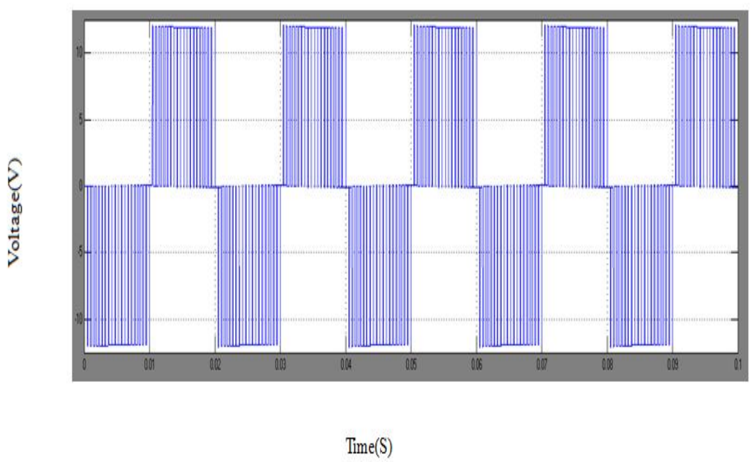

Figure 9: Output voltage waveform of a full bride single phase Inverter

Matlab simulink block diagram for Inverter output voltage control is shown in figure 8.

7 RESULT

The output waveform of inverter is square wave which amplitude is 24V (peak to peak).The output voltage waveform of a single phase full bridge inverter which is used in our simulation is shown in figure 9.

After filtering the output of an inverter, we obtain a pure sinusoidal wave of frequency 50 Hz and amplitude of 24V (peak to peak). The output voltage waveform of a single phase full bridge inverter with a LC filter which is used in our simulation is shown in figure 10.

After using transformer we obtain a grid quality voltage of

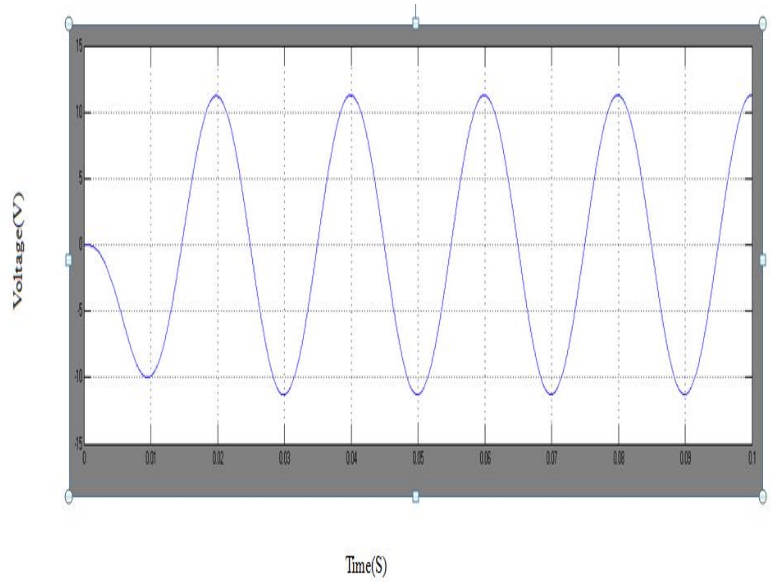

Figure 10: Output voltage waveform of a full bridge Inverter with LC filter

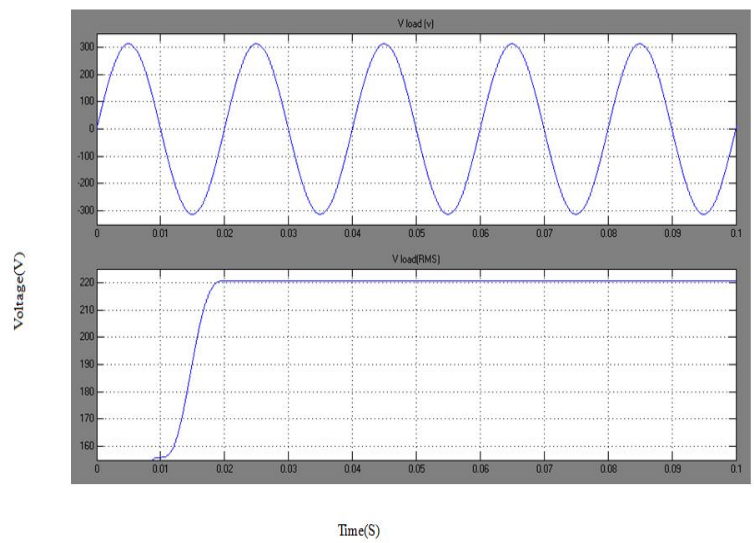

Figure 11: Output voltage waveform of an Inverter after using a Transformer

50Hz frequency and 220V rms value. The output voltage waveform of an Inverter which we obtain after using a Transformer is shown in figure 11.

In uncontrolled Island mode of operation when breaker1 is opened at 0.2s, the utility grid is disconnected from the load. Then load is shared only by microgrid. At this moment voltage across the load is decreased significantly. Breaker-2 and Breaker-3 which are used to disconnect load are opened respectively at time0.4s and 0.6s. This breaker operation causes reduction of load. Due to the reduction of load voltage across the load is increased. Thus in uncontrolled island mode of operation voltage across the load is not constant .Output voltage waveform of an microgrid operated in uncontrolled Island mode is shown in figure 12.

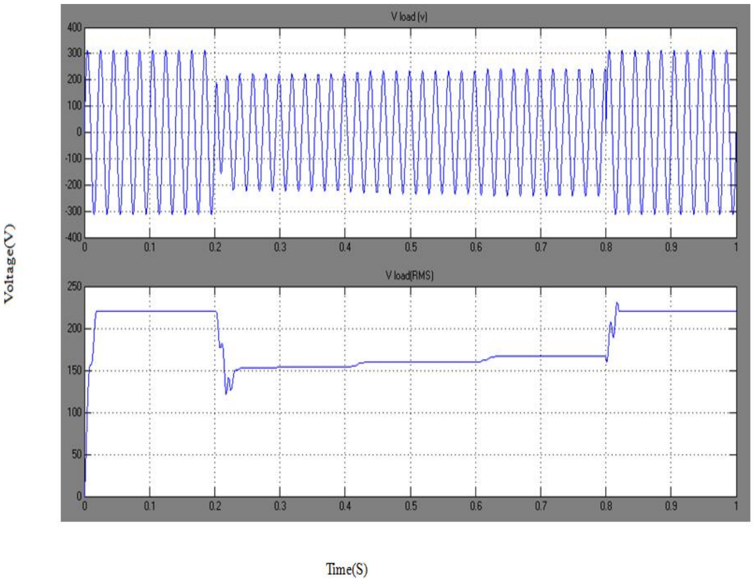

Figure 12: Output waveform of uncontrolled Islanded mode of operation of a Micro-grid

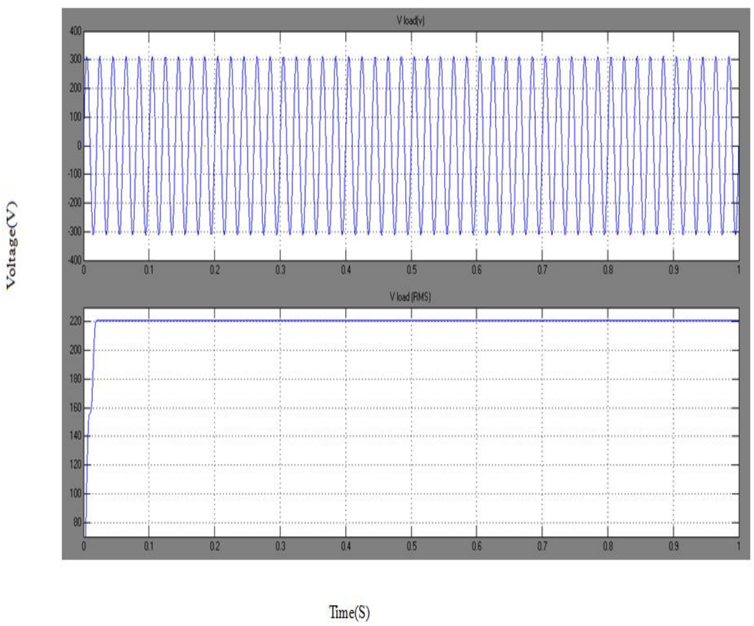

Figure 13: Output voltage waveform of controlled Island mode operation of a micro-grid using triangular waveform as a carrier signal for PWM.

In controlled island mode when breaker1 is opened at 0.2s, the utility grid is disconnected from the load. At this time load is shared only by microgrid. But at this time the voltage across the load is same as it was remain at grid connected mode. Because, In control mode we used a controller which compare the inverter output with the reference signal and increase the output in same proportion that is decrease due to disconnection of utility grid.

Breaker-2 and Breaker-3 which are used to disconnect load are opened respectively at time 0.4s and 0.6s. This breaker operation causes reduction of load. But voltage across the load is remains

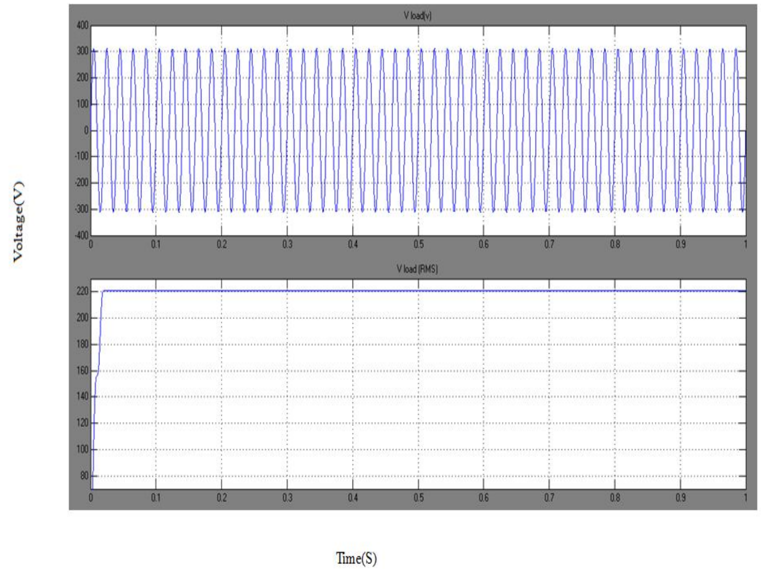

Figure 14: Output waveform of controlled Island mode operation of a micro-grid using rectangular waveform as a carrier signal for PWM

constant in spite of reduction of load due to the controller operation. Output voltage waveform of a microgrid operated in controlled Island mode is shown in figure 13 & 14.

From figure 12, figure 13, figure 14 we can conclude that, In uncontrolled Island mode the voltage across the load is not constant. It varies according to the load and utility connection.
But in controlled Island mode a constant voltage is always maintained across the load. It does not depend on load variation and utility connection.

8 Conclusion

When an islanding occurs, the voltages and frequencies in the islanded area cannot be controlled by the grid system. To avoid this event, the detailed modeling and control of a single phase DC to AC inverter is shown here that operates in both island mode and utility-connected mode. Modeling results are given to demonstrate the ability of the developed inverter to provide advanced control functions such as Frequency control and voltage regulation.

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