Digital Simulation of Power Converter and it's Control in Microgrid

K. Vinod Kumar, G. Kishor

Abstract- ***Microgrids (MGs) and Distributed Generation are becoming an important role because of their peculiar characteristics. MGs are composed of small power sources which can be renewable, placed near customer sites. Moreover, they have the inherent property of islanding. The attention focuses on the control technique of the converters during grid connected and islanding operation of the MGs. The converters can be represented as an ideal converter with its specified parameters and proper control techniques. Some of the power converters like voltage source converters or current source converters are analysed based on the grid requirement in the system. Similarly some of the control loops like voltage control, current control or power control can be analysed based on the performance of the grid connection. Based on these conditions we may have the attention towards the phase transformations for the control strategies. All the control operations with their performances can be simulated using MATLAB/SIMULINK.***

Keywords- ***Microgrid, PWM, Voltage Source Inverter, SRF-PLL, Micro sources.***

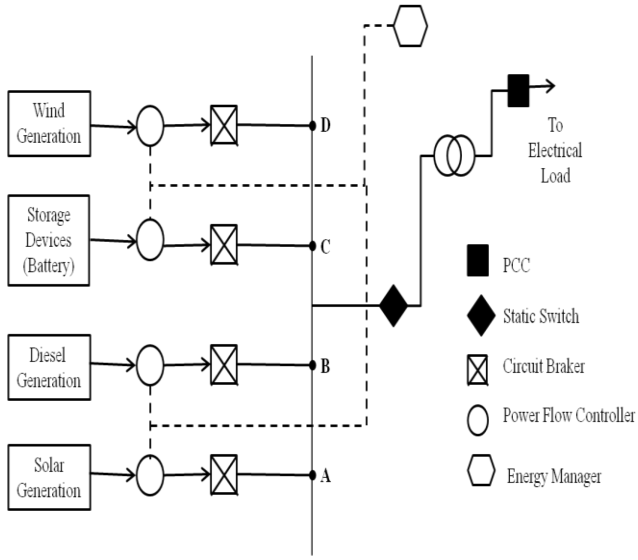

Fig.1. Structure of Microgrid

I. INTRODUCTION

A MG is composed by electrical sources placed near local loads and it becomes more interesting when those sources are of different kinds, such as wind turbines, photovoltaic (PV) panels, fuel cells, etc. In that case, the MG can be considered a Hybrid Energy System (HES) and it is very suitable to support the electrical network in rural areas and remote sites. A MG is an HES with an inherent characteristic, the islanding capability [1]. Islanding is the disconnection of the MG from the main grid without interruption of the energy generation for the loads connected to the islanded part. It is also possible to have an islanding of only one part of the MG instead of all the MG. The habitual sources which exist in a MG are usually low power micro-sources (MS), normally under 100-200kW, with power electronics interfaces. The main advantages of MS are their high reliability, low cost and in addition, they have a low level of greenhouse gases production.

MG is a weak grid where the effects of renewable resources or load variations are more intense than in interconnected systems. For a proper analysis and evaluation of the behaviour of the MG a complete model of the investigated system has been developed.

The simplest architecture of a MG consists of a radial connection of several feeders with a set of associated loads and MS [2]. Fig. 1 shows a model of MG with four feeders, named A, B, C and D. As it can be seen, each feeder has a circuit breaker and a power flow controller commanded by the energy manager. The radial system is connected to the distribution system through the point of common coupling (PCC). The static switch is a separation device used to island all the MG from the main grid, while the circuit breaker is used to island a feeder from the rest of the MG.

The control and flexibility needed by the MG is achieved by means of power electronics interfaces. MGs can be considered as inverter dominated electrical networks because those power converters are employed as interface with the main grid. When the MG is connected to the main grid, inverters use the signal of main grid as reference to obtain an AC signal with the correct frequency and voltage. But, in islanding, the reference of the main grid is lost, so inverters must find new references to continue the generation of good power quality. So some control techniques are necessary to allow the good operation of inverters with MG in islanding. This paper outlines a first research work in order to investigate the behaviour of a particular MG and its control.

II. VOLTAGE SOURCE INVERTER

Single-phase VSI converters are used for low-range power applications and three-phase VSI converters are used for the medium to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the

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applications require sinusoidal voltage waveforms like UPSs, FACTS, VAR compensators, arbitrary voltages are also required in some emerging applications like active filters, voltage compensators.

The standard three phase VSI topology is shown in Fig. 2 and the eight valid switch states are available. As in single phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply.

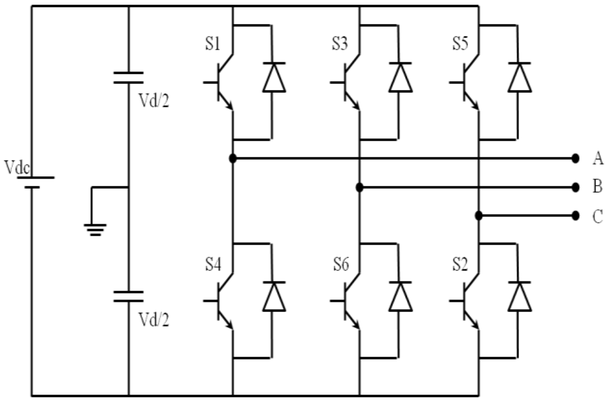

Fig.2. Three phase voltage source inverter using power transistors

Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another [4]. Thus the resulting ac output line voltages consist of discrete values of voltages that are V, 0, and -V for the topology. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.

III. PWM TECHNIQUES

The concept of Pulse Width Modulation (PWM) for inverters is described with analysis extended to different kinds of PWM strategies.

A. Single pulse width modulation

In this control, there’s only one pulse per half cycle and the width of the pulse is varied to control the inverter output. The gating signals are generated by comparing a rectangular reference signal of the amplitude with triangular carrier wave of amplitude, the frequency of the carrier wave determines the fundamental frequency of output voltage. The pulse width can be varied from 0 to 100 percent. The ratio of rectangular reference signal of the amplitude with triangular carrier wave of amplitude is the control variable and defined as the modulation index [3].

B. Multiple pulse width modulation

The harmonic content can be reduced by using several pulses in each half cycle of output voltage. The generation of gating signals for turning ON and OFF switch by comparing a reference signal with a triangular carrier wave. The frequency determines the number of pulses per half cycle. The modulation index controls the output voltage. This type of modulation is also known as uniform pulse width modulation [3].

C. Sinusoidal pulse width modulation (SPWM)

Instead of maintaining the width of all pulses of same as in case of multiple pulse width modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The distortion factor and lower order harmonics are reduced significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency Fc. The frequency of reference signal Fr, determines the inverter output frequency and its peak amplitude controls the modulation index M, and Vrms output voltage Vo. The number of pulses per half cycle depends on carrier frequency.

Inverters that use PWM switching techniques have a DC input voltage that is usually constant in magnitude. The inverters job is to take this input voltage and output AC where the magnitude and frequency can be controlled. There are many different ways that pulse width modulation can be implemented to shape the output to be AC power. A common technique called sinusoidal PWM will be explained. In order to output a sinusoidal waveform at a specific frequency a sinusoidal control signal at the specific frequency is compared with a triangular waveform as shown in Fig. 3. The inverter then uses the frequency of the triangle wave as the switching frequency.

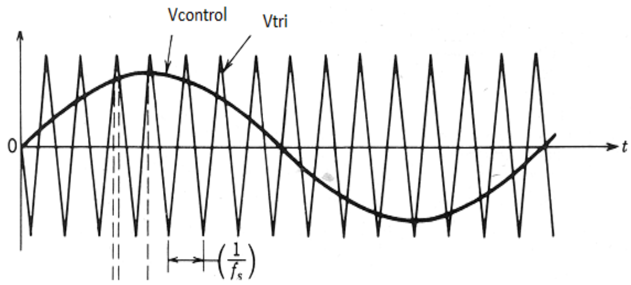

Fig.3. Desired frequency is compared with a triangular waveform

This is usually kept constant. The triangle waveform, Vtri, is at switching frequency Fs, this frequency controls the speed at which the inverter switches are turned off and on. The control signal, Vcontrol, is used to modulate the switch duty ratio and has a frequency. This is the fundamental frequency of the inverter voltage output. Since the output of the inverter is affected by the switching frequency it will contain harmonics at the switching frequency. The duty cycle of the one of the inverter switches is called the amplitude modulation ratio.

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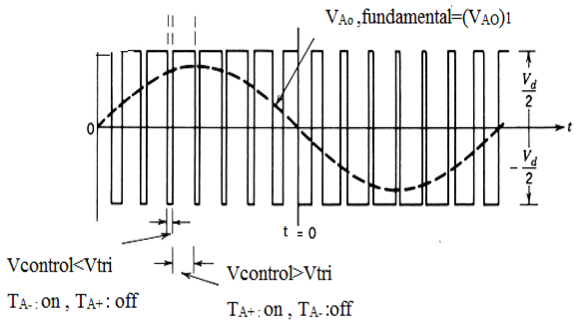

Fig.4. Pulse width Modulation.

Vcontrol > Vtri TA pos is on, VAo = Vd/2,

Vcontrol < Vtri TA neg is on, VAo = - Vd/2,

In Fig. 4 the switches Ta+ and Ta- are controlled based on the comparison of Vcontrol and Vtri as shown in above equations. The two switches are never off at the same time which results in the output voltage fluctuating between +/- Vd/2.

IV. TRANSFORMATIONS

Process of replacing one set of variables by another related set of variables is called transformation. The term transformation means the transformation from 'old' to 'new' set of variables or vice versa is governed by linear equations.

The AC system voltage equation obtains in matrix form contained time variant equations, these equations are to obtain the solution using routine procedures of matrix inversion. These routine procedures can be applied successfully if the equations contain constant time invariant coefficients. Therefore it is necessary to apply certain transformations in series, which converts the equations to linear equations with constant coefficient. Thus the resulting matrix make it possible to obtain solution easily and quickly.

- Linear transformation are usually carried out for purpose of obtaining new equations which are few in number(only d-axis and q-axis voltage equations)
- For a 3-phase system, its generalised model requires only two voltage equations which can be solved easily as compared to 3-phase voltage equations.
- The circuit equations for 3-phase system are more complicated because of phase displacements in the system.
- The equations expressing old variables in terms of new variables are vice-versa have the following general form

[New Variables] =
[Transformation Matrix] [Old Variables]
And
[Old Variables] =
[Transformation Matrix][NewVariables]

Thus the transformation matrix is defined as matrix containing the coefficients relating the old and new variables.

- The physical consideration used in the transformation is the equivalence of invariance of power. When such a physical consideration is not used in transformation it is necessary to convert the results to original system for its performance.

Mainly we are analyze the various transformation methods as follows,

- Linear transformation,
- Phase transformation, etc.,

We are prefering the phase transformation in the analysis. The 3 phase (a,b,c) system can be replaced by an equivalent 2 phase(d,q) system and vice versa . A zero sequence is required for the transformation of unbalenced systems.

V. PI-CONTROLLER

Controllers use a 3 basic behavior types or modes, P - proportional, I - integrative and D - derivative. While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used on it's own in control systems. Combinations such as PI and PD control are very often in practical systems.

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when,

a) fast response of the system is not required
b) large disturbances and noise are present during operation of the process
c) there is only one energy storage in process (capacitive or inductive)
d) there are large transport delays in the system

VI. SIMULATION WORK

The VSI uses the main grid electrical signals as reference. However, in islanding, the inverters lose that reference and new references must be fund. Consequently, the VSI must be able to operate in both configurations as grid connected inverter and stand alone inverter. When the MG is in islanding, it is necessary to start the pertinent control mechanisms. The objective is to obtain a frequency deviation equal to zero and to maintain the amplitude voltage value in the islanded MG. To assure this, the inverters must find new voltage and frequency references, maintaining a good power quality.

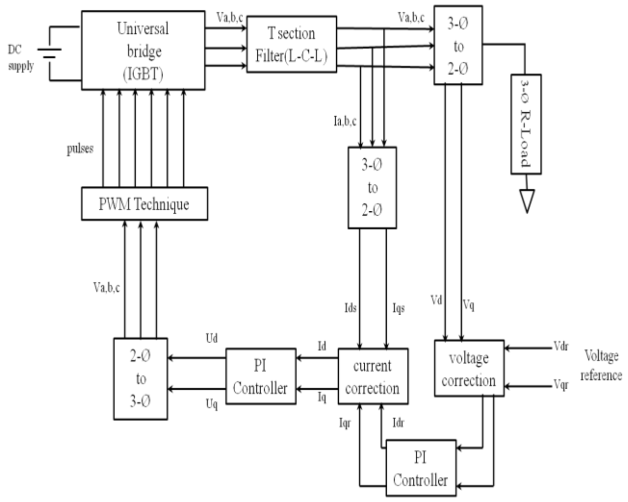

Fig.5. Control structure in three phase VSI with PWM technique

In this case, the MG can be considered as an inverter dominated system, because its frequency is controlled by the power electronics.

Fig. 5 shows the inverter control scheme in case of grid connected operation. To control the active power through the inverter, the voltage DC-bus VSI side is measured and compared to DC-bus reference. The DC-bus voltage error feeds a PI controller having a current reference as output. In this configuration, the distributed generation is not in operation and the inverter is line-commutated. Its control is performed in d,q synchronous frame rotating at the fundamental frequency based on current loop controller. A characteristic feature for this voltage and current controller is processing of signals in coordinate system as synchronously rotating d,q coordinate system. This transformation combined with PI controllers allows the steady state error to be eliminated.

The phase-locked loop technology has extensively been used to synchronize grid-connected power converters with the grid voltage. In three phase systems, the synchronous reference frame phase locked loop (SRF-PLL) has been broadly used for this purpose. The structure of the SRF-PLL is depicted in Fig.5. The SRF-PLL translates the three phase instantaneous voltage waveforms from the a,b,c reference frame into the rotating d,q reference frame, by means of the Phase transformation. The angular position of this d,q reference frame is controlled through a feedback control loop which drives the Vq component to zero. In this synchronization structure, the estimated grid frequency is ω [5].

VII. SIMULATION RESULTS

Simulations have been run with the system to investigate its behaviour during sinusoidal pulse width modulation technique. The input voltage source is considered to be of Vin = 700v. Here some of filter components like inductor, resistors are used for the analysis. For the filter components we consider the filter inductance as 3mH and filter resistance as 0.1Ω

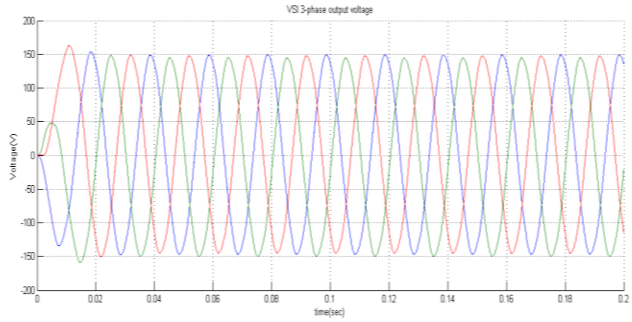

Fig.6. Three phase output voltage of VSI

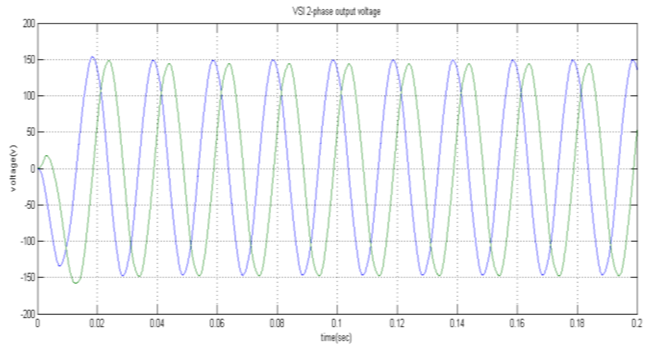

Fig.7. 3-phase to 2-phase converted voltage output

VSI gives an output voltage of nearly magnitude of 150V and a constant frequency of 50Hz. it's 2-phase output voltage is obtained with help of phase transformations and obtained as above.

Output currents of two phases Ids and Iqs are obtained as fallows for a resistive load of 10 Ω.

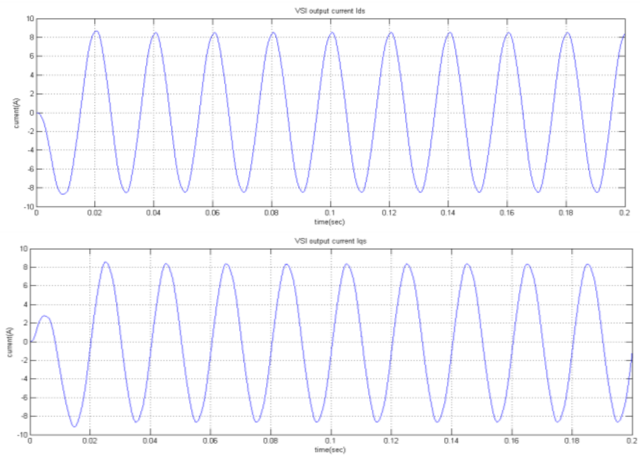

Fig.8. 2-phase Output currents of VSI

The controller output voltage is obtained as of nearly 50V and is feedback to the process of PWM technique as given in the simulation work.

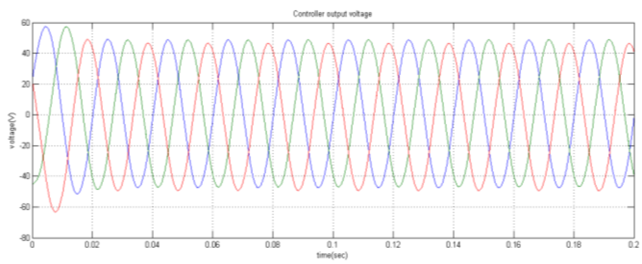

Fig.9. Controller output voltage

VIII. CONCLUSION

The model is based on a wind turbine, a PV panels array, a backup DG and a VSI used for the interconnection with the main grid. The VSI plays an important role because it acts as interface and fixes the AC voltage amplitude and frequency of the signal into the MG.

Control structures for the grid-side converter, and control strategies under faults were primarily addressed. Different implementation structures like d,q and stationary and natural frame control structures were presented. The present work is a first step in the MG behaviour investigation field.

Thus the simulation work is done for the various techniques of the control of the VSI and the total architecture is finalised with the various transformation techniques and PI control technique to the fulfilment of the MG operation with various renewable energy sources. Finally it is an eco friendly system which is mostly useful in Island areas and available of more energy sources.

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