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Analysis of Tertiary Control for PV based Microgrid System

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Abstract—With the rising demand in electricity, increasing fuel cost, global climatic changes and concern on greenhouse gas emission the use of renewable energy resources is becoming a necessity. Microgrid is a systematic integration of various Distributed Energy Resources (DERs) and connected loads to operate as single entity which can either be connected to the grid or can operate as a separate independent island. Power electronic converters are employed to provide flexibility for the integration of various distributed energy sources in the grid. Microgrid draws power from utility grid or supplies to the grid depending upon load demand and generationin grid connected mode. In case of power interruption or load shedding microgrid can be switchedto island mode of operation. One of the important issues of microgrid is to achieve the bump less transition between the grid and islanded mode of operation. In this paper Photo voltaic (PV) sources based microgrid system has been considered and a coordinated control scheme for the control of a microgrid system is implemented in Matlab / Simulink environment. This paper investigates the bump less transition between the grid and islanded mode of operation with reduced harmonic distortion and frequency variation.

Keywords*-Microgrid; grid connected mode ; islanded mode ; controller*

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I. INTRODUCTION

The increase in demand of energy ,concern of climatic changes and need of reduction in greenhouse gas emission provoked the increasing interest in use of renewable energy resources such as solar energy, wind energy, bio mass energy etc. These distributed generation systems forms decentralized network providing improved reliability and power quality. Among various distributed generation configurations, Microgrid is the most attractive configuration which provides better flexibility and reliability for power systems. A microgrid is a cluster of various distributed generation systems, storage units and loads which can be controlled in an optimal coordinated fashion with improved power quality as well as the performance of overall distribution system. The power electronic converters are used to interface distributed generation systems and grid to provide required flexibility and reliability for the Microgrid concept.

The microgrid can operate in two modes. The one when it is connected to the utility grid called grid connected mode and the other when it is operated independently and separated from utility grid called islanded mode. Depending on the working conditions, the microgrid has to disconnect or re-join from the grid. In grid-connected mode microgrid supplies or draws power to the utility grid depending on the generation and load demand. In case of an emergency and power shortage during power interruption the microgrid shifts to island mode of operation.

Microgrid is a very relevant concept which helps in integrating renewable energy resources to the power grid. It has many advantages including higher reliability, surety, energy security and it provides various system efficiency improvements [1]. Several technical problems happen in the operation and control of microgrid. The key issues are power quality, voltage and frequency control, power flow balancing, load sharing during islanding, protection, stability, integration of small scale renewable energy generation at the distribution level and overall operation. Proper design of converters and implementation of effective control strategy can improve the performance of microgrid. Many innovative control techniques have been used for enhancing performance and stability of microgrid. Power quality improvement is achieved in [2] by controlling the PWM carrier frequency to reduce switching losses and Total Harmonic Distortion (THD). A new method for constant voltage and frequency management by varying angle and magnitude of line current is proposed [3]. A highly reliable mode adaptive control helps in proper load sharing and transition between modes [4]. The optimal angle droop technique aims in achieving proper load sharing with reduced variation in grid parameters [5]. Protection and restoration of pre fault condition is ensured by using a phase angle restoration loop in [6]. Ramp control technique is used to realize supply-demand balance and maintain stability of microgrid without the help of energy storage system [7]. Proper power sharing performance is achieved in microgrid system by using multi loop hierarchical control [8]. A coordinated control method based on decomposition and parameterization of overall control problems is explained in [9]. A two stage control strategy based on energy storage systems (ESS) is proposed in [10].In general Microgrid control strategies can be classified into primary secondary and tertiary levels. The primary and secondary level strategies are associated with microgrid operation itself whereas tertiary level deals with coordinated operation of microgrid and the utility grid [12].Such a coordinated control strategy for grid connected and islanded mode operation of microgrid is explained in this paper.

II. OVERVIEW OF THE SYSTEM

The microgrid considered here is a PV based grid connected system. As shown in the Fig. 1 this system includes photovoltaic arrays, DC/DC converters, Multi-level inverter, transformer and local load. PV array with 15kW power is used as source in this microgrid system. Boost converter is used for DC to DC conversion and Maximum Power Point Tracking (MPPT) is integrated to it for maximum power extraction. The output of boost converter is given as the DC input for multi-level inverter. AC output produced by multi-level inverter is supplied to the local loads connected to microgrid and also to the utility grid through a transformer. Point at which the microgrid connected to utility grid is called Point of Common Coupling (PCC). Main feature of microgrid is the smooth power flow through PCC.

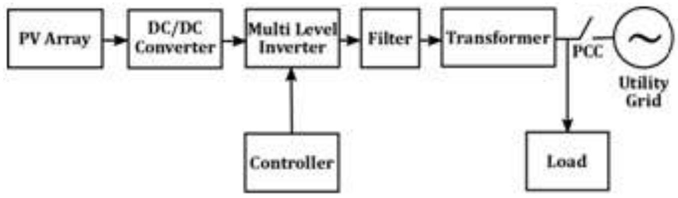

Figure 1. Block diagram of the system.

A. PV Array

PV array is the arrangement of many number of photovoltaic modules or panels in series and parallel manner to generate higher power levels. Performance rating of PV modules are generally done based on their maximum DC power output under standard test conditions. Major factors affecting the performance of solar cells are irradiance and temperature. As the irradiance level increases, short circuit current (I_{sc}) in solar cell also increases proportionally under constant temperature. But open circuit voltage (V_{oc}) of solar cell increases slightly only by increase in irradiance. It is almost unaffected by change in irradiance. When comes to the temperature, open circuit voltage decreases and short circuit current increases by the increase in temperature. The efficiency of a solar cell is the ratio between power generated by the cell and power striking the cell. Commercial solar cells will have efficiency ranging from 12% to over 20%.

B. DC to DC converter

A DC to DC conversion stage is included in the system to provide constant DC input to the inverter. Because DC power output of PV array varies according to the factors like availability of sunlight, irradiance level, temperature etc. So a boost converter is used for providing conditioned DC to inverter. Maximum Power Point Tracking (MPPT) technique is integrated to the boost converter for obtaining constant DC voltage and maximum power at the output. Perturb and observe algorithm (P and O) is used here for maximum power point tracking. As shown in Fig. 2 in P and O algorithm voltage and current values are measured for present and previous instants. Thus change in power value is calculated and duty cycle, D, is varied to achieve maximum power output. This signal is used to control the switching in boost converter.

C. Multi-level inverter

A multi-level inverter is used in the system for the conversion of DC power produced by the PV array to 50Hz Ac. The multi-level inverter used is of 5 level cascaded H bridge topology. As shown in Fig. 3 this inverter consists of Two H Bridge cells which are serially connected and fed by independent DC sources. This topology requires totally eight switches for DC to AC conversion in single phase. The output of each H bridge cells are connected in series and so the generated output waveform is sum of all individual unit outputs.

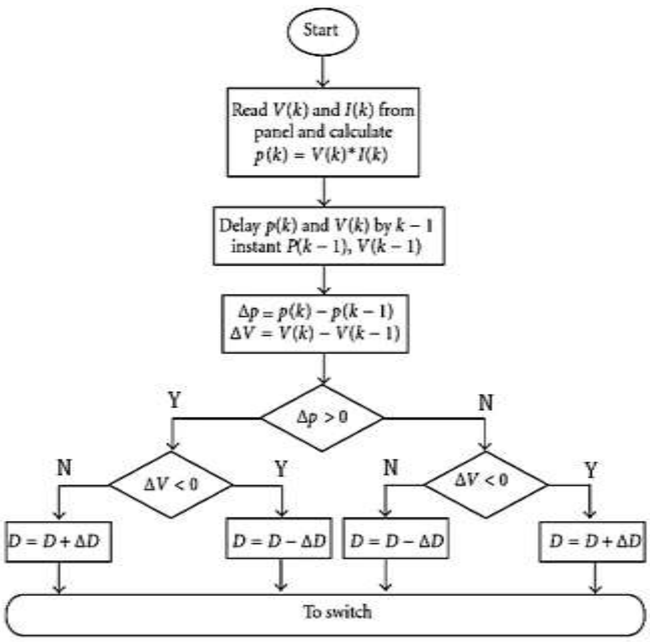

Figure 2. Perturb and Observe MPPT algorithm.

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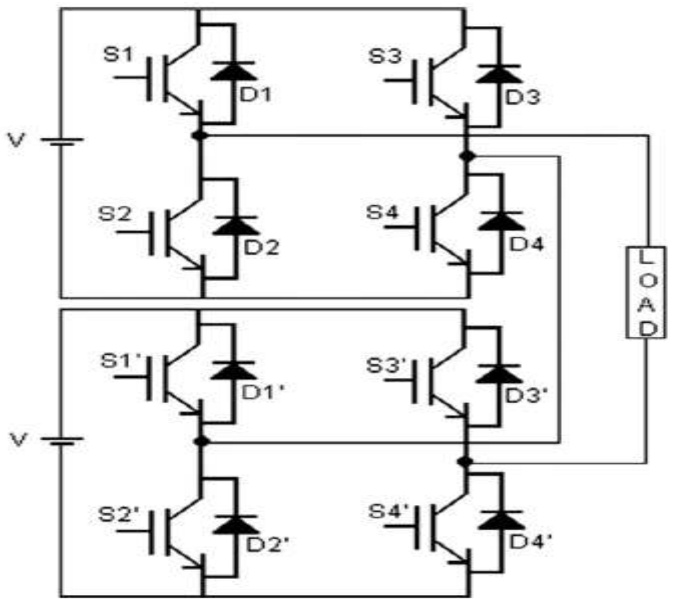

Figure 3. Five level cascaded H bridge topology.

The main advantage of this topology is the less number of components required. This type of inverters are used where high power and power quality is needed. Multi carrier PWM technique is used for providing gating signals for the switches. In this technique a reference waveform is compared with multiple carrier waves to generate the pulses. This technique helps in reducing Total Harmonic Distortion (THD) and enhancing fundamental output voltage

D. Filter

In order to reduce THD further and achieving quality output waveform a filter circuit is also integrated to the system. A LCL filter circuit is used in the output of inverter before connecting to the load and also to the utility grid. So it provides a pure sine wave output with reduced harmonics.

E. Transformer

A transformer is used in the microgrid system for providing isolation. It is connected between the inverter output side and utility grid, thus providing required isolation for microgrid from the main grid. It acts as an interface between microgrid and utility grid and also helps in the synchronization between them

III. CONTROL SCHEME

As explained in Introduction, microgrid has two modes of operation. Here the control action in grid connected mode is executedby a current controller whereas control action in islanded mode is performed by a voltage controller. So the control of microgrid here is a collective action of both the controllers. Switching between voltage and current controller is important to ensure bump less transmission between modes. In islanded condition, voltage controller has to generate references internally and also should maintain the balance between local generation and local load demands. The control objective in this mode is to regulate the amplitude and frequency of load voltage to supply the load current. It regulates the voltage on transformer primary side to match with the reference generated internally.

A. Control action in grid connected mode

During grid connected mode, the current controller uses grid as reference for both voltage and frequency. It regulates the current on transformer primary side, to meet the desired reference currents supplied. The measured value of inverter output current is taken as feedback for the current controller

B. Control action in islanded mode

The control objective in this mode is to regulate the amplitude and frequency of load voltage to supply the load current .In islanded condition, voltage controller has to generate references internally and also should maintain the balance between local generation and local load demands. It regulates the voltage on transformer primary side to match with the reference generated internally.

IV. SIMULATION RESULTS

Simulation studies are performed in themicrogrid system to analyze the performancewith respect to voltage and THD in the Matlab/Simulink environment. A microgrid system with 15kW PV array source,Boost converterwith 160 V output, three phase cascaded five level inverterof 415 V, and 50 Hz output ratingand 10kWload is considered. A415V, 50Hz three phase source is consideredas utility grid.

A coordinated control scheme is developed to control the microgrid in both the grid connected and islanded mode of operation. Fig. 4 shows the model of current controller which controls the considered microgrid system in grid connected mode.Fig. 5 shows the model of voltage controller which controls the microgrid in islanded mode of operation. Vdref and Vqref are the internally generated reference in dq frame. Vd and Vq are measured values of inverter output voltage in dq frame. The PI gain values are, Kp =0.7 and Ki =1010 in the voltage controller.

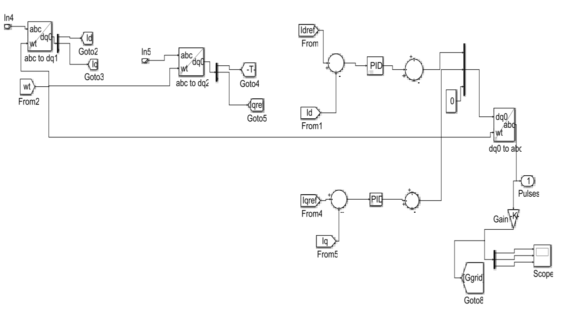

Figure 4. Current controller model.

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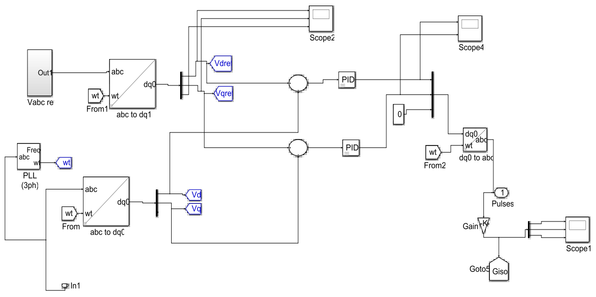

Figure 5. Voltage controller model.

The considered microgrid system is connected to utility grid through circuit breaker at Point of common coupling (PCC). The control of circuit breaker is done by giving a step input in the simulation. The same step input is used to switch between voltage controller and current controller. Fig. 6 shows the output voltage waveforms in islanded mode. Fig. 7 shows the FFT (Fast Fourier Transform) results for this output and according to it the total harmonic distortion is 8.53%. To analyze the output and THD results in grid connected mode, circuit breakers at PCC should be closed. For this a step input is given at time t= 0sec. Fig. 8 shows the phase voltage output waveforms at load end and Fig. 9 shows the FFT results which says the total harmonic distortion in grid connected mode is 0.10%.

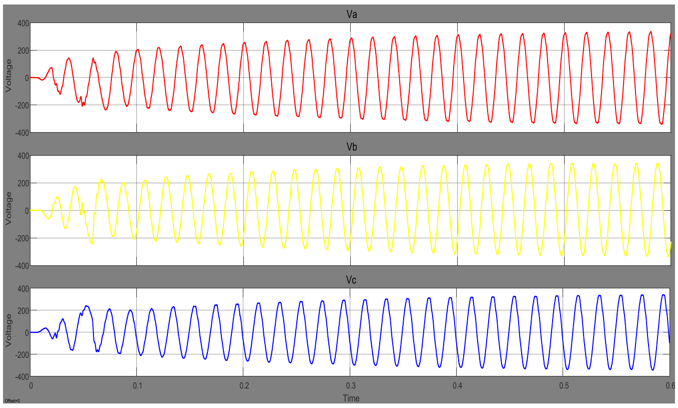

Figure 6. Phase voltage output waveforms in islanded mode.

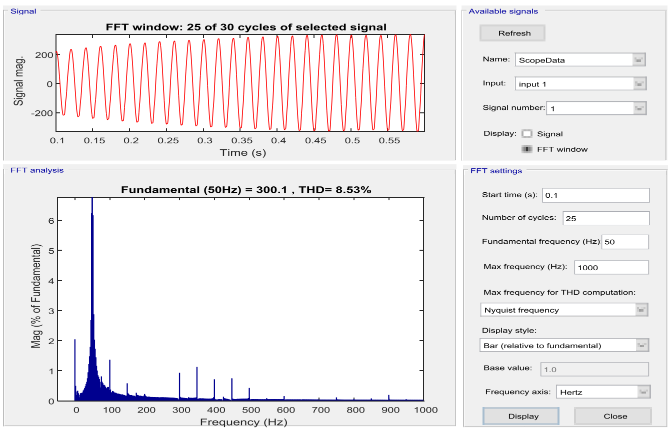

Figure 7. FFT analysis for islanded mode

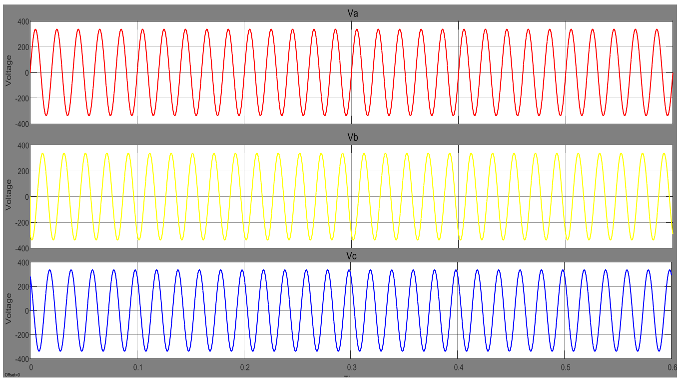

Figure 8. Phase voltage output waveforms in grid connected mode.

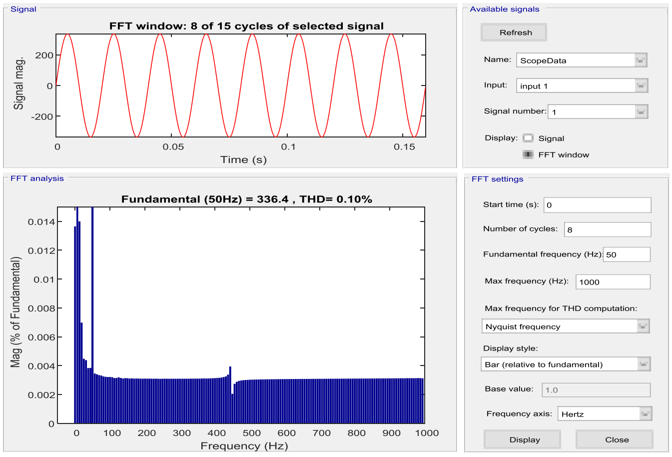

Figure 9. FFT analysis for grid connected mode

The transition between islanded mode and grid connected mode is then analyzed by giving a step input at time t =0.4 sec. Fig. 10 shows the phase voltage waveforms during the transition between modes. In this figure till t= 0.4 sec the system is operating in islanded mode. At t= 0.4 sec it shifts to grid connected mode. The variation in voltage and frequency is comparatively very less as seen in Fig. 11. The variation in frequency from time t=0 sec to t=0.6 sec is given in the Fig. 12. It shows that frequency variation during transitionof modes is very less. The variation in frequency is less than 0.5 Hz.

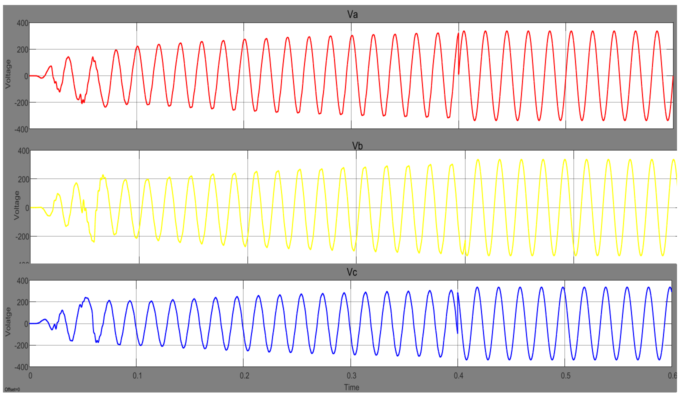

Figure 10. Phase voltage waveforms during mode transition

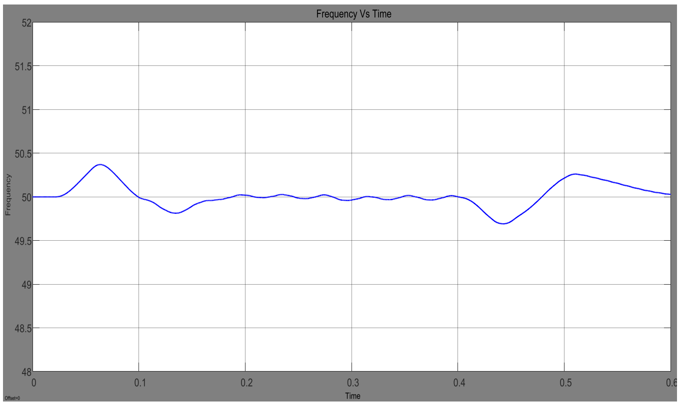

Figure 11. Frequency Vs Time graph during mode transition

V. CONCLUSION

One of the important challenge in microgrid is to maintain constant voltage and frequency, especially during the switching between islanded mode and grid connected mode of operation. A coordinated control scheme for the control of a microgrid system in both islanded and grid connected mode is implemented in Matlab/Simulink environment in this paper. This control scheme improves performance of microgrid system with respect to voltage and frequency during its operation. The voltage and frequency has to be controlled to maintain smooth power flow and power quality in microgrid system. This control strategy provides coordination between islanded mode and grid connected mode of operation of microgrid system. The mode transition process is locally controlled by measuring the values of voltage and frequency corresponding to the utility grid and microgrid. Whenever the grid supply is available the current controller delivers required power to the load by taking voltage and frequency values from grid as reference. When the microgrid is isolated from grid and grid supply is unavailable, voltage controller has to generate the references independently within microgrid. The smooth transition between grid connected mode and islanded mode is achieved by properly coordinating the control between controllers. Here the variation in frequency during the switching between modes is less than 0.5Hz. The control scheme design is evaluated using simulation in Matlab/Simulink environment.

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