Effective Islanding Operation for PV Connected Distributed Generation System with Synchronous Frame Controller

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Abstract—This paper investigates the performances of a dqo based synchronous controlled inverter which is connected with any distributed generators (i.e. dc source-solar fuel cell, etc). This dqo based synchronous controller effectively maintains the magnitude of load voltage & frequency within the allowable range. The control technique can generate the needed phase angle for utility synchronization by using this abc to dqo transformations. This paper also deals with islanding operation which activates when the voltage and frequency of the grid exceeds the specified value at the point of common coupling. The effectiveness of control technique is demonstrated using MATLAB simulation.

Index Terms—PLL, Synchronous controller, DG, abc to dqo transformations

I. INTRODUCTION

In the last few decades, renewable energy sources has been getting more importance due to the increase in the cost of petroleum products and the pollution caused by the use of fossil fuels. The ever increasing population leads to increase in energy demand. To meet this demand distributed power generation systems are penetrated into the power system to form a new type of power system, the micro grid. It can be connected to the main power grid or can operate autonomously. Distributed power generation system has the advantage of reducing blackouts, which affects the power grids. It could also reduce the adverse effects of terrorism, if electric supply is attacked. The deregulated power market is also an important reason for developing the distributed power generation.

Islanding is the situation in which a distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by DG connected to it. As shown in the fig 1. Traditionally, a distribution system doesn’t have any active power generating source in it and it doesn’t get power in case of a fault in transmission line upstream but with DG, this presumption is no longer valid. Current practice is that almost all utilities require DG to be disconnected from the grid as soon as possible in case of islanding. IEEE 929-1988 standard [24] requires the disconnection of DG once it is islanded. Islanding can be intentional or Non intentional. During maintenance service on the utility grid, the shutdown of the utility grid may cause islanding of generators. As the loss of the grid is voluntary the islanding is known. Non-intentional islanding, caused by accidental shut down of the grid is of more interest. As there are various issues with unintentional islanding. IEEE 1547-2003 standard.

Fig 1 Block Diagram of DG System

PV SYSTEM

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays. The voltage and
current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices. This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig.2.

**Photovoltaic cell** A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incident light on the cell generates charge carriers that originate an electric current if the cell is short circuited! The equivalent circuit of PV cell is shown in the Fig.3.

![Fig.3. Electrical Model of PV](image)

In the above figure the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage form PV cell are represented by I (1) and V. Usually the equivalent circuit of a general PV model consists of a photocurrent, a diode, a parallel resistor which expresses a leakage current, and a series resistor which describes an internal resistance to the current flow. The voltage characteristic equation of a solar cell is given as

\[
I_p = I_{ph} - I_s \left[ \exp \left( \frac{q(V_{ph} + I_p R_s)}{k T} \right) - 1 \right] - I_s \left( V_{ph} + I_p R_p \right) / R_p
\]  

The photocurrent mainly depends on the cell’s working temperature and solar irradiation, which is explained as

\[
I_{ph} = I_{ph0} \exp \left( \frac{T - T_{ref}}{T_{ref} \alpha} \right)
\]

The saturation current of the cell varies with the cell temperature, which is represented as

\[
I_s = I_{ph}(T/T_{ref})^3 \exp \left[ \gamma E_g (1/T_{ref} - 1/T) / k A \right]
\]

The shunt resistance Rs of the cell is inversely related with shunt leakage current to the ground. Usually efficiency of PV array is insensitive to variation R and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. Alternatively a small variation in series resistance Rs will significantly affect output power of the PV cell. The appropriate model of PV solar cell with suitable complexity is shown in Fig. 5. Equation (3) can be modified to be

\[
I_{ph} = I_{ph} - I_s \left[ \exp \left( \frac{q(V_{ph} + I_p R_s)}{k T} \right) - 1 \right]
\]

There is no series loss and no leakage to ground for an ideal PV cell, i.e., Rs = 0 and Rs = ∞. So equation (3) can be rewritten as

\[
I_{ph} = I_{ph} - I_s \left[ \exp \left( \frac{qV_{ph}}{k T} \right) - 1 \right]
\]

A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. So the current and voltage equation of the array with Np parallel and Ns series cells can be represented as

\[
I_{ph} = N_p I_{ph} - N_s I_s \left[ \exp \left( q \left( \frac{V_{ph}}{N_p} + I R_s / N_p \right) / k T A \right) - 1 \right] - (N_p V_{ph} / N_s + I R_s)
\]

The efficiency of a PV cell is sensitive to small change in series resistance but insensitive to variation in shunt resistance. The role of series resistance is very important for a PV module and the shunt resistance is approached to be infinity which can also be assumed as open. The mathematical equation of the model can be described by considering series and parallel resistance as

\[
I_{ph} = N_p I_{ph} - N_s I_s \left[ \exp \left( q \left( \frac{V_{ph}}{N_p} + I R_s / N_p \right) / k T A \right) - 1 \right]
\]

The equation (3) can be simplified as

\[
I_{ph} = N_p I_{ph} - N_s I_s \left[ \exp \left( q \frac{V_{ph}}{k T A} \right) - 1 \right]
\]

The open-circuit voltage \(V_{oc}\) and short-circuit current \(I_{sc}\) are the two most important parameters which describes the cell electrical performance. The above mentioned equations are implicit and nonlinear; hence, it is not easy to arrive at an analytical solution for the specific temperature and irradiance. Normally \(I_{ph} > I_s\), so by neglecting the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit current is approximately equal to the photocurrent, i.e.

\[
I_{ph} = I_s
\]

The open-circuit voltage parameter is obtained by assuming the zero output current. With the given open-circuit voltage at reference temperature and ignoring the shunt-leakage current, the reverse saturation current can be acquired as

\[
I_{ph} = I_s \left[ \exp \left( q V_{ph} / k T \right) \right]
\]

Additionally, the maximum power can be stated as

\[
P_{max} = V_{max} I_{max} = \frac{V_{oc}^2}{R_s}
\]
II. ISLANDING ISSUES

Although there are some benefits of islanding operation, there are some drawbacks as well. Some of them are as follows: Line worker safety can be threatened by DG sources feeding a system after primary sources have been opened and tagged out. The voltage and frequency may not be maintained within a standard permissible level. Islanded system may be inadequately grounded by the DG interconnection which is shown in fig 2. Instantaneous reclosing could result in out of phase reclosing of DG. As a result of which large mechanical torques and currents are created that can damage the generators or prime movers. Also, transients are created, which are potentially damaging to utility and other customer equipment. Out of phase reclosing, if occurs at a voltage peak, will generate a very severe capacitive switching transient and in a lightly damped system, the crest over-voltage can approach three times rated voltage. Various risks resulting from this include the degradation of the electric components as a consequence of voltage & frequency drifts.

III. TYPES OF ISLANDING TECHNIQUES

Islanding detection techniques can be classified into three categories: the direct method, the passive method and the active method. The direct method is to monitor the states of all breakers in the power system. This method is the most efficient to detect islanding but hard to implement due to the involvement of comprehensive monitoring systems. The passive method is based on the measurement of power system parameters such as frequency variation, phase displacement, and power variation. This idea relies on the fact that islanding conditions will result in the variations of power system parameters. The active method is to breed small variations in the output of DGs. When the utility source remains connected with the DGs, these variations are relatively insufficient to trip protective relays. However, in the islanded networks, this designated deviation will enlarge to activate the relays. The active method is generally considered more effective than passive methods because passive methods have a relatively large Non-Detection Zone (NDZ).

IV. PHASE LOCK LOOP METHOD

Due to the development of power-electronic devices, inverters can provide versatile controls to DGs this paper focuses on the development of an islanding detection method that is befitting to the inverter-interfaced DG systems. The proposed method uses the internal signals of the Phase Locked Loop (PLL) circuits in order to detect the phase angle variation of the system voltage. This feature offers some advantages: it improves the speed of detection and control of the islanding conditions because the detection method is integrated with the inverter controller and there is little communication delay; and this method is economical because it shares the measurement equipment with the inverters whereas other protective relays. In addition, to reduce the NDZ, this paper proposes to insert small reactive power disturbances to the DG output power. The performance of the proposed method is simulated and evaluated using MATLAB SIMULATION.

V. SYNCHRONOUS FRAME CONTROLLER

The grid side inverter is connected to the dc link of proposed system. The conversion unit which performs the interface functions between the dc bus and three phase ac grid followed by the L filter that transports and distributes the energy to the end user and the load. The controller provides a constant output and maintains the voltage at the point of common coupling. The inverter works in a constant current control mode to provide a constant power to the main grid. This controller provides a constant current output. In this current control, inverted output current from filter is measured and transformed into a synchronous rotating reference frame, i.e. abc transformed into dq frame. In other words, it is easier to regulate and solve the two phase variables as dq quantities.

Then it is compared with the reference currents. This comparison gives an error value that is fed to the current regulator to generate the reference voltage for inverter. Again dq is transformed into abc frame to produce the voltage references, then it is compared with the measured grid voltages to produce error. These voltage errors are amplified with a gain and the amplified signals are compared with the fixed frequency triangular carrier wave of unity amplitude to generate gating signals or IGBT’s of the grid side inverter. [3]
VI. RESULTS AND DISCUSSIONS

The proposed system is simulated in MATLAB/SIMULINK using Sim power systems tool boxes. The overall simulated diagram for grid connected PV based DG system.

DG system is depicted in fig 3. The system is operated in grid connected mode and when any fault or any fault in system it goes under islanding mode of operation. The grid voltage is depicted in Fig.7, the inverter is operated to deliver for the load of 1kW.

During grid fault or swells the voltage get affected and it goes beyond its limit that is it may exceed it rated value as shown in Fig 7.

By the detection logic the fault or swell is detected with help of IEEE 2003 standard, that is when the voltage, frequency exceed this specified standard circuit breaker trips which acts as a reclosure.

The circuit breaker is connected to the PCC for which synchronization algorithm works for islanding operation, the simulated model is shown in fig 5.

After the fault is cleared the inverter voltage is synchronized with grid. The detection logic is shown in fig 9.
The voltage at fault condition is shown in fig 8. Thus the paper describes about grid voltage to be operated in the NDZ regions.

Once synchronization with the grid is completed, the DG was reconnected to the grid that is from islanding operation to grid connected mode.

VII. CONCLUSION

In this research work, the modeled hybrid distributed generation system is devised to accomplish the task of supplying uninterrupted power to meet the load demands with intentional islanding algorithm. In addition to the benefits mentioned, control strategy addresses the immense bottlenecks (arising due to meteorological uncertainty) in reliably coordinating different sources with the utility. In future the multi agent applications maybe developed that provides intelligence to this developed model. The multi agent systems are used to control distributed generation system in a simulated environment during various fault conditions.

REFERENCES

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