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Performance of Grid Connected DG Inverter System by Using Intelligent Controllers

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Abstract

Recent development in the small scale power generation using distributed energy resources combined with application of power electronic systems initiated the researchers to the concepts of future power generation technologies such as microgrid.

The paper presented involves the control techniques required for microgrid operation and implementation of a simple control strategy in a microgrid model realized with MATLAB. To demonstrate the operation of a microgrid in Grid connected mode and intentional islanded mode, a simulink model has been designed with necessary parameters by connecting with the main grid allowing the sharing of different laods with reference to Grid connection and disconnection. An islanding-detection algorithm has been used to act as a switch between the two controllers and this has minimised the effect of losses in the time of transistion. A reclosure algorithm has been used for the DG to resynchronize the inverter voltage with the grid.

***Index Terms*: Distributed Generation, Intentional Islanding, microgrid, Grid tie inverter, Algorithm, PLL, synchronization controller,**

INRODUCTION

The recent trends in small scale power generation using the with the increased concerns on environment and cost of energy, the power industry is experiencing fundamental changes with more renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and microturbines being integrated into the power grid in the form of distributed generation (DG). These RES-based DG systems are normally interfaced to the grid through power electronics and energy storage systems[1]

One of the most critical sections of the control system for a distributed generation (DG) unit's interconnection to the utility grid lies within the grid-connected converter's control and protection system; specifically the islanding detection algorithms. Through this controller subsection, the system is able to determine whether or not it is safe to remain connected to the grid. These islanding detection algorithms, which are integrated into the control system, are mainly present to prevent the undesirable feeding of loads during fault conditions and disconnections from the grid, whether or not the disconnection as intentional[2]

This is required by standards since the creation of such "power islands" is forbidden. Thus, in effect, standards require DG control systems to sense islanding events and disconnect themselves from the grid. This brings into question the method of how to implement such a detection scheme.[Islanding Detection Using a Coordinate Transformation Based Phase-Locked Loop]

Islanding is a condition in which a microgrid or a portion of the power grid, which contains both load and distributed generation (DG), is isolated from the remainder of the utility system and continues to operate Some distinctions of islanding are:

non-intentional islanding occurs if after the fault it is not possible to disconnect the DG; non-intentional islands must then be detected and eliminated as fast as possible;

intentional islanding refers to the formation of islands of predetermined or variable extension; these islands have to be supplied from suitable sources able to guarantee acceptable voltage support and frequency, controllability and quality of the supply, and may play a significant role in assisting the service restoration process

microgrids, seen as particular types of intentional islands, basically operated in autonomous mode, not connected to the supply system; the whole microgrid can be seen from the distribution system as a single load nd has to be designed to satisfy the local reliability requirements , in addition to other technical characteristics concerning frequency, voltage control and quality of supply.[2]

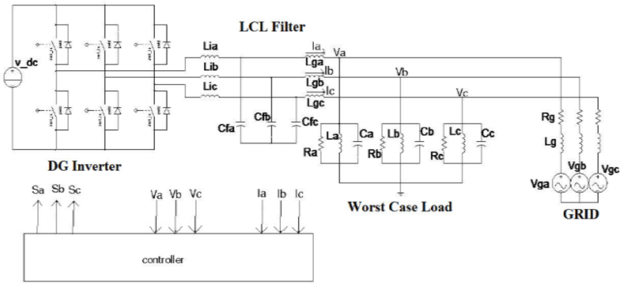


Fig 1. Schematic diagram of Grid connected Inverter

POWER MISMATCHES

The effects of power mismatches between the DG and the loads have upon the system in terms of voltage and frequency, the most rudimentary of sensed parameters, need to be known.[3]

Considering the generic system depicted in Fig. 2, and that the DG can supply anywhere from partial to the full load demand, or even an excess of power to source the grid. A parallel RLC load is used for this study's example; also that this is a local load to the DG and there will not be a large reactance between the DG and the PCC. As such, there can exist a power demand mismatch between the DG and loads[9], which the grid supplements; however when the grid is no longer supplying the remaining power demand of the loads, the system voltage and frequency at the PCC will be affected.

A. Active Power Mismatch

If the active power portion of the load demand that is calculated is coming from the DG, the following is found.

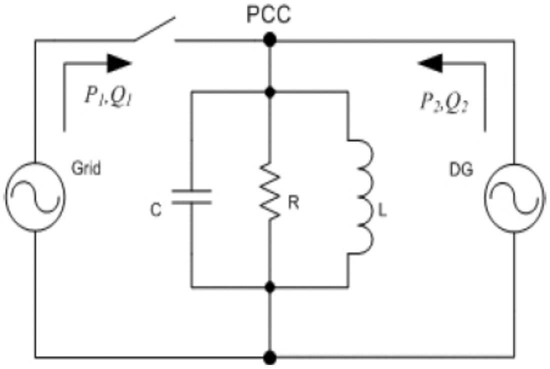


Fig. 2: Generic Interconnected System

$$P_{DG} = \frac{3V_{PCC}^2}{R_{eff}} \qquad (1)$$

Where *Reff* is the equivalent resistance seen by the DG for the amount of power it is supplying. If the grid fails and only the DG is left to supply the load at a constant active power, the voltage at the PCC would naturally change, represented in (2).

$$P_{DG} = \frac{3(V'_{PCC})^2}{R} = \frac{3(V_{PCC}+\Delta V)^2}{R} \qquad (2)$$

As such, *Reff* can be written as a function of true load resistance, the voltage and change of voltage that would occur at the PCC, seen in (3) by equating and solving (1) and (2).

$$R_{eff} = f(R, V_{PCC}, \Delta V) = R\left(\frac{V_{PCC}}{V_{PCC}+\Delta V}\right)^2 \qquad (3)$$

Thus, to find the power mismatch from the load demand and DG, we can write the following:

$$\Delta P = P_{demand} - P_{DG} = 3V_{PCC}^2\left(\frac{1}{R} - \frac{1}{R_{eff}}\right) \qquad (4)$$

Plugging (3) into (4), we get the reduced equation of (5), showing that an active power mismatch between load and DG will cause voltage variations if the grid fails.

$$\Delta P = \frac{3V_{PCC}^2}{R}\left(1 - \left(\frac{V_{PCC}+\Delta V}{V_{PCC}}\right)^2\right) \qquad (5)$$

B. Reactive Power Mismatch

Now consider the reactive power mismatch between the DG and load during a grid fault. The demand required by the load is equated in (6).

$$Q = \frac{3V^2}{\omega_{line}L}\left(1 - \omega_{line}^2 LC\right) \qquad (6)$$

The resonant frequency of the load is determined by the LC relationship. Therefore we can re-write (6) as (7).

$$Q = \frac{3V^2}{\omega_{line}L}\left(1 - \frac{\omega_{line}^2}{\omega_{resonant}^2}\right) \qquad (7)$$

As such, if the grid stopped supplying its portion of the load's demand of reactive power, the line frequency would drift to the resonant frequency to force the mismatch to become zero.

Therefore, let us write the resonant frequency as a term of the line frequency and the frequency drift due to a mismatch.

$$\Delta Q = \frac{3V^2}{2\pi f_{line}L}\left(1 - \frac{f_{line}^2}{(f_{line}+\Delta f)^2}\right) \qquad (8)$$

When the max/min values of the voltage and frequency deviations are plugged into (5) and (8), an NDZ range for power mismatch can be calculated. As such, it is seen that the standard OVP/UVP, OFP/UFP schemes are not enough to minimize the NDZs.[3]

ISLANDING DETECTION ALGORITHM

Islanding is the condition where the DG remains operating in the distribution system with the utility disconnected. In the past years, several islanding detection methods have been proposed and the detection methods can be categorized into two main groups: passive and active methods. Passive methods depend on measuring system parameters and then thresholds are set to these parameters to differentiate between an islanding and a nonislanding condition Active methods directly interact with the power system operation by introducing perturbations in the inverter output. The most commonly used islanding detection method is the Over/Under Voltage (OVP/UVP) and Over/Under Frequency (OFP/UFP). [4],[8]

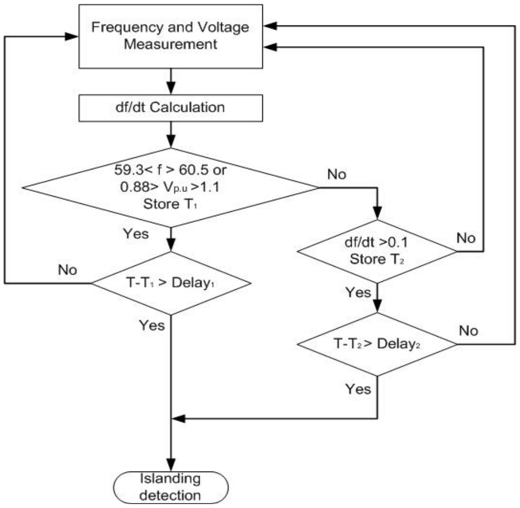


Fig 3. Intentional Islanding Algorithm

The DG interface control designed in this paper provides constant DG output and maintains the voltage at the Point of Common Coupling (PCC) at 1 p.u. Maintaining both the voltage and power constant during an islanding condition is not feasible for standalone operation of the DG since both depend on each other, and the OVP/UVP and OFP/UFP could be used to detect islanding[4]. This detection method will operate efficiently for large mismatches between load and DG capacity. Unfortunately, if the load closely matches the DG capacity, the frequency will reach the threshold value after a very long time. The DG was designed to supply 100 kW and the load connected absorbs approximately 100 kW. The grid disconnects at t = 5 seconds and the frequency at the PCC drifts away from the 60 Hz value. It can be seen that the time for the frequency to reach the 59.3 Hz threshold is greater than 5 seconds..[8]

CONTROLLERS:

The system consists of a microsource that is represented by the dc source. Under normal operation, each DG inverter system in the microgrid usually works in constant current (or constant power) control mode in order to provide a pre-set power to the main grid. When the microgrid is cut off from the main grid, each DG inverter system must detect this islanding situation and switch to a voltage control mode. In this mode, the microgrid will provide a constant voltage to the local load[2].

Condition 1: WHEN GRID IS DISCONNECTED

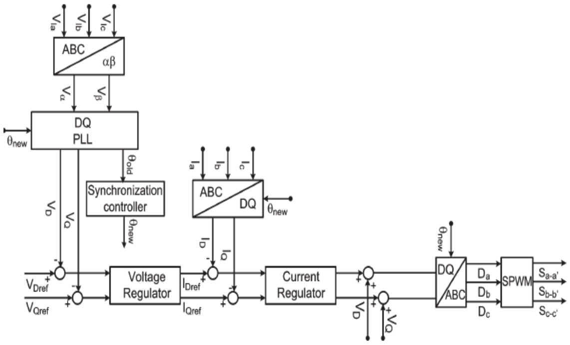


Fig: 4 Voltage-controller when the Grid is Disconnected

Condition II: WHEN GRID IS CONNECTED

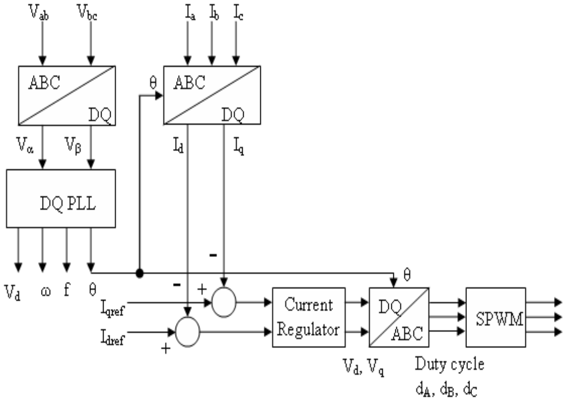


Fig 5: Current Controller when Grid is Connected

For grid-connected operation, the controller shown in Fig 5. is designed to supply constant current output. A phase locked loop is used to determine the frequency and angle reference of the Point of Common Coupling (PCC) voltage. To simplify the design and operation of the controller, the control of the system is designed in a synchronous reference frame (SRF) [5]. Fig. 6 shows this control topology employing synchronous frame current control.[6]

The inverter currents are transformed into a synchronous frame by Park's transformation and regulated in dc-quantity corresponding to the current references Idqref. In the following stage, the voltage references in dc-quantities Vdq which being processed by PI controllers are transformed into a stationary frame by the inverse of Park's transformation and utilized as command voltages for generating high frequency pulse width modulated (PWM) voltage.[11]

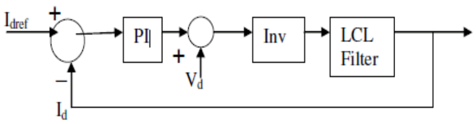


Fig 6: Block diagram of Current controlled Inverter

When using the current control, the output current from the filter is fed back and compared with reference current Iref and the error is passed to the PWM to generate voltage reference for the inverter. In order to get a good dynamic response V dq is fed forward. Fig. 6 shows the block diagram of the DG interface control for grid-connected operation. For unity power factor operation, iqref is set to zero.[2]

A Intentional-Islanding Operation Mode

The voltage closed-loop control for intentional-islanding operation is shown. The control works as voltage regulation through current compensation. The controller uses voltage compensators to generate current references for current regulation.

As shown, the load voltages (*V*d and *V*q) are forced to track its reference by using a PI compensator (voltage regulator). The outputs of this compensator (*I*Dref and *I*Qref) are compared with the load current (*ID* and *IQ*), and the error is fed to a current regulator (PI controller). The output of the current compensator acts as the voltage reference signal that is fed to the sinusoidal pulsewidth modulator to generate the high frequency gating signals for driving the three-phase voltage source inverter. The current loop is included to stabilize the system and to improve the system dynamic response by rapidly compensating for near-future variations in the load voltages. In order to get a good dynamic response, *V*DQ is fed forward. This is done because the terminal voltage of the inverter is treated as a isturbance, and the feedforward is used to compensate for it .

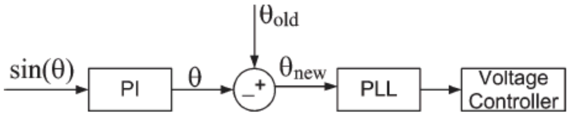


Fig 7: Sychronisation Controller

B Synchronization for Grid Reconnection

When the grid-disconnection cause disappears, the transition from islanded to grid-connected mode can be started. To avoid hard transients in the reconnection, the DG has to be synchronized with the grid voltage . The DG is operated in the synchronous island mode until both systems are synchronized. Once the voltage in the DG is synchronized with the utility voltage, the DG is reconnected to the grid, and the controller will pass from the voltage to the current control mode. This synchronization is achieved by implementing the following algorithm.[5]

1) Assume that the phase difference between the grid and inverter voltages is given by

$$\theta = \angle V_G - \angle V_I. \quad (9)$$

2) In order to obtain the information of θ, two sets of voltage values are used

$$\begin{aligned} k &= V_{Ia}V_{Ga} + V_{Ib}V_{Gb} + V_{Ic}V_{Gc} \\ &= \frac{3}{2}\left[\cos(\theta)\right] \\ g &= V_{Ia}V_{Gb} + V_{Ib}V_{Gc} + V_{Ic}V_{Ga} \\ &= \frac{3}{4}\left[-\cos(\theta) + \sqrt{3}\sin(\theta)\right]. \end{aligned} \quad (10)$$

Using the variables *k* and *g*, sin(*θ*) can be found as

$$\sin(\theta) = \frac{\frac{4}{3}g + \frac{2}{3}k}{\sqrt{3}}. \quad (11)$$

Fig. Syn cotrl shows how sin(*θ*) is used to obtain the new phase angle for which the grid and inverter voltages are synchronized.

MODELLING OF CIRCUIT IN MATLAB SIMULINK.

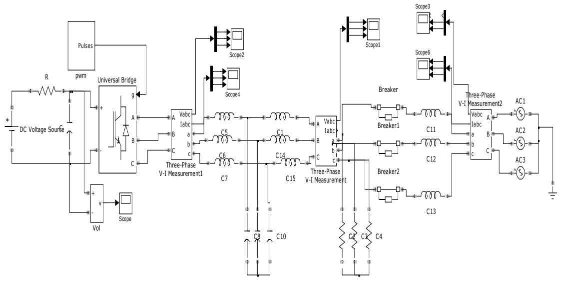


Fig.8: Without any controllers

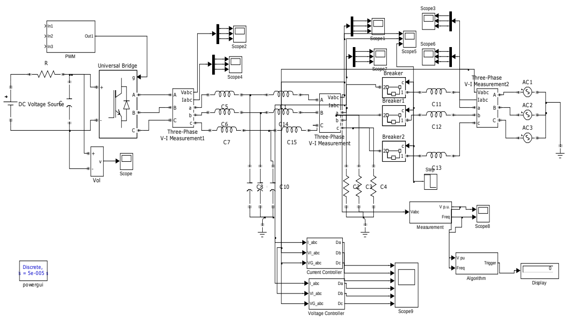


Fig 9. With controllers

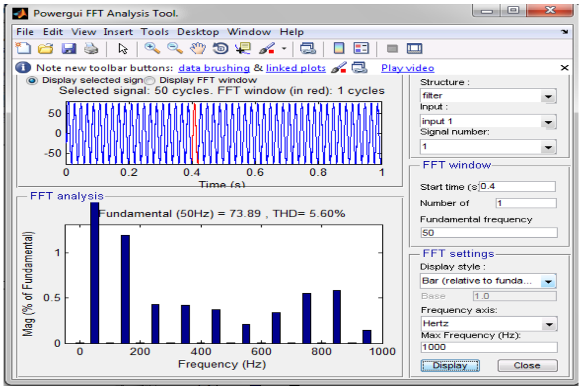
SIMULATION RESULTS

The performance of the proposed control strategies was evaluated Fig. shows the simulated system. This system was tested under the following conditions:

1) switching frequency *fs*: 10 kHz;
2) output frequency: 60 Hz;
3) filter inductor *Li*: 1 mH;
4) filter inductor *LL*: 0.5 mH;
5) filter capacitor *Cf*: 31 μF;
6) dc-link voltage *Vdc*: 400 V;
7) output phase voltage $Vo1\phi$: 120 Vrms;
8) output capacity: 10 KW.

The *RLC* load was adjusted to be resonant at 60 Hz and to consume 10 KW. The DG system was designed to supply 10 KW and zero reactive power. The system was operated initially in grid-connected operation. The grid was disconnected at 0.3 s, and this event was detected at 0.30155 s. After 0.30155 s, the control mode was changed from current- to voltage controlled operation.

FFT Analysis for the Inverter.



Note new toolbar buttons: data brushing & linked plots Play video

Selected signal: 50 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 73.89 , THD= 5.60%

Structure : filter

Input : input 1

Signal number: 1

Start time (s: 0.4

Number of 1

Fundamental frequency 50

Display style : Bar (relative to funda...

Base 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig 10: FFT analysis of Inveter

Using the above analysis we can observe that the inverter has operated with the THD of 5.6%

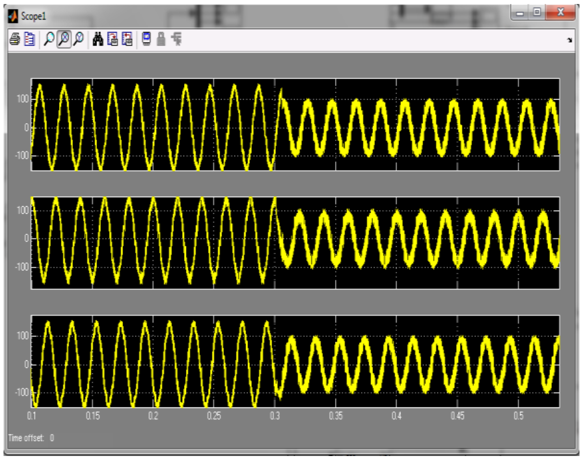


Fig 11. Inveter Voltages when connected to the Grid.

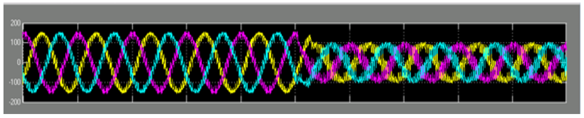


Fig:12 Voltages Without Synchronisation Algorithm

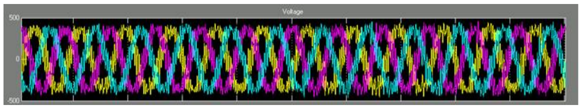


Fig 13: Voltages With Synchronisation Algorithm

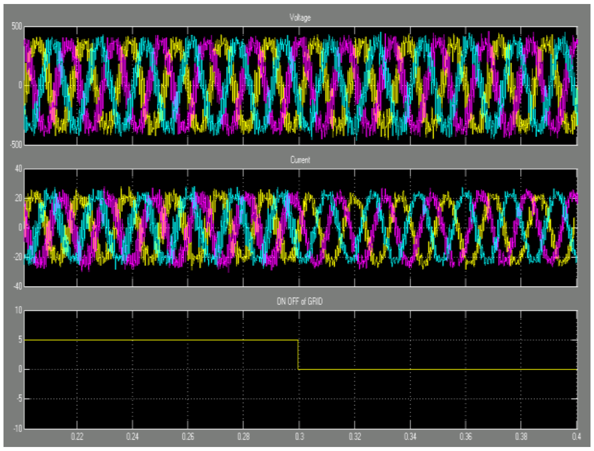


Fig 14. shows the voltages and currents at the PCC before and after grid disconnection. The grid was reconnected at 0.3 s.

The DG was operated in the synchronous island mode until both systems were resynchronized. Fig. 14 shows the synchronization of the voltages at both ends of the PCC when the synchronization algorithm starts to work in the intentional-islanding mode. As can be seen, the proposed algorithm successfully forces the voltage at the DG to track the voltage at the grid.

Once the synchronization was completed, the DG was reconnected to the grid, and the controller was switched from the voltage to the current control mode. Fig. 12,13 shows the phase voltage *Va* without and with the synchronization algorithm implemented. Notice that the algorithm avoids a hard transient in the reconnection from intentional-islanding to grid-connected operation to keep the magnitude of the voltage in its normal operational range when there is a power mismatch.

CONCLUSION:

Here in this paper a controller is designed both for grid connected operation and the other for Intentional islanding operation. An algorithm for the detection of islanding is presented which was responsible for the switch between the two controllers and also a reclosure algorithm which causes the DG to resynchronize itself with the grid is also designed.

Thus the paper summarizes the traditional independent inverter and Grid-connected inverter control strategy, combining the distributed power and microgrid inverter characteristics, a suitable microgrid inveter control strategy is put forward. Switching between Grid-connected mode and Grid-disconnected mode for microgrid inverter has been studied. On the Grid-disconnected operation microgrid inveter supplies the important loads that ensures load voltage and frequency stability. Microgrid inverter can smoothly switch between Grid-connected operation and Grid-disconnected operation, and switching operation of the system has good performance. The system controller design is simple, practical and efficient, easy to implement . The simulation results show that the proposed control method is feasible and effective.

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