MODELING OF PV CELL BASED H-BRIDGE MULTILEVEL TOPOLOGY FED DISTRIBUTED GENERATION SCHEME USING UNIQUE CONTROL STRATEGY

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Abstract—This paper presents the use of the renewable sources applicable to the distributed generation (DG) in the distribution system. The DG systems are powered by micro sources such as fuel cells, photovoltaic (PV) systems, and batteries. Most of these resources are connected to the utility through power electronic interfacing converters, i.e., three-phase inverter. DG is a suitable form to offer high reliable electrical power supply, as it is able to operate either in the grid-tied mode or in the islanded mode. In the grid-tied operation, DG delivers power to the utility and the local critical load. The proposed control strategy composes of an inner inductor current loop, and a novel voltage loop in the synchronous reference frame. The multilevel inverter is regulated as a current source just by the inner inductor current loop in grid-tied operation, and the voltage controller is automatically activated to regulate the load voltage upon the occurrence of islanding. Furthermore, the waveforms of the grid current in the grid-tied mode and the load voltage in the islanding mode are distorted under local load with the conventional strategy. This paper presents PV cell based H-Bridge Multilevel Topology Fed Distributed Generation Scheme using Unique Control Strategy that enables both islanded and grid-tied operations of three-phase inverter in distributed generation, with no need for switching between two corresponding controllers or critical islanding detection using MAT Lab/Simulink.

Key words- Three Phase Inverter, Distributed generation (DG), islanding, Multi level inverter, PV Cell.

I. INTRODUCTION

In contemporary world interconnection of distributed generations (DG) which operate in parallel with electrical power networks, is currently changing the paradigm we are used to live with. Distributed generation is gaining worldwide interest because of environmental issues and rising in energy prices and power plant construction costs. Distributed generations are relatively small and many of them make use of renewable energy such as fuel cells, gas turbines, micro-hydro, wind turbines and photovoltaic. Many DGs use power electronic inverters, instead of rotating generators. The inverters typically have fast current limiting functions for self-protection, and may not be damaged by out-of-phase reclosing. The operation of distributed generation will enhance the power quality in power system and this interconnection especially with reverse power flow may lead to some problems like voltage and frequency deviation, harmonics, reliability of the power system and islanding phenomenon. Islanding is one of the most technical concerns associated with the proliferation of distributed generation connected to utility networks. Islanding can be defined as a condition in which a portion of the utility system contains both load and distributed generation remains energized while being isolated from the remainder of the utility system. Islanding detection is a mandatory feature for grid-connected inverters as specified in international standards and guidelines. Inverters usually operate with current control and unity power factor and employ passive monitoring for islanding detection methods based on locally measured parameters. Under islanding conditions, the magnitude and frequency of the voltage at the point of common coupling (PCC) tend to drift from the rated grid values as a function of the power imbalance (ΔP and ΔQ). As it is known that distribution system does not have any active power generating source and does not receive power in case of a fault in transmission line.

However, with Distributed Generation this presumption is no longer valid. In current practice DG is required to disconnect the utilities from the grid in case of islanding. The main issues about islanding are: 1) Safety issues since a portion of the system remains energized while it is not expected. 2) Islanded system may be inadequately grounded by the DG interconnection. 3) Instantaneous reclosing could cause out of phase in the system. 4) Loss of control over voltage and frequency in the system 5) Excessive transient stresses upon reconnection to the grid. 6) Uncoordinated protection.

The strategy of islanding detection is to monitor the DG output parameters for the system and based on the measurements decide whether an islanding situation has occurred from monitoring of these parameters. Islanding detection techniques can be divided into remote and local techniques.

1) Passive methods
This method is fast to detect the islanding. But it has large non-detection zone and it needs special care to set the thresholds for it is parameters. Passive method can classified into: Rate of change of output power, Rate of change of frequency, Rate of change of frequency over power, Change of impedance, Voltage unbalance, and Harmonic distortion.

2) Active methods

Active method tries to overcome the shortcomings of passive methods by introducing perturbations in the inverter output. Active method can detect the islanding even under the perfect match of generation and load, which is not possible in case of the passive detection schemes because it caused degradation of power quality. Active method can be classified into Reactive power export error detection, Impedance measurement method, and Phase (or frequency) shift methods, Active Frequency Drift, Active Frequency Drift with Positive Feedback Method, Adaptive Logic Phase Shift, and Current injection with positive feedback.

3) Hybrid methods

Hybrid method based on implementing of two assortment of active and passive method. The active technique is implemented only when the islanding is suspected by the passive technique. It can be classified into Technique based on voltage and reactive power shift, Technique based on positive feedback and voltage imbalance. In general, once the main grid source supply is lost the DG has to take charge of the remaining network and the connected loads. Passive detection scheme, on the other hand, monitors parameters for detecting the islanding operations of DG voltage unbalance, frequency, active and reactive power along with total harmonic distortion (THD).

In the hybrid voltage and current mode control, there is need to switch the controller when the operation mode of DG is changed. During the interval from the occurrence of utility outage and switching the controller to voltage mode, the load voltage is neither fixed by the utility nor regulated by the DG, and the length of the time interval is determined by the islanding detection process. Therefore, the main issue in this approach is that it makes the quality of the load voltage heavily reliant on the speed and accuracy of the islanding detection method [1]–[3]. In the grid-tied mode, the output current of DG is generally desired to be pure sinusoidal.

This paper proposes a unified control strategy that avoids the aforementioned shortcomings. First, the traditional inductor current loop is employed to control the three-phase inverter in DG to act as a current source with a given reference in the synchronous reference frame (SRF). Second, a novel voltage controller is presented to supply reference for the inner inductor current loop, where a proportional-plus-integral (PI) compensator and a proportional (P) compensator are employed in D-axis and Q-axis, respectively. In the grid-tied operation, the load voltage is dominated by the utility, and the voltage compensator in D-axis is saturated, while the output of the voltage compensator in Q-axis is forced to be zero by the PLL. Therefore, the reference of the inner current loop cannot regulated by the voltage loop, and the DG is controlled as a current source just by the inner current loop. Moreover, the proposed control strategy, benefiting from just utilizing the current and voltage feedback control, endows a better dynamic performance, compared to the voltage mode control.
II. PROPOSED CONTROL STRATEGY

A. Power Stage

This paper presents a unified control strategy for a three phase inverter in DG to operate in both islanded and grid-tied modes. The schematic diagram of the DG based on the proposed control strategy is shown by Fig.1. The DG is equipped with a three-phase interface inverter terminated with a LC filter. The primary energy is converted to the electrical energy, which is then converted to dc by the front-end power converter, and the output dc voltage is regulated by it. Therefore, they can be represented by the dc voltage source $V_{dc}$ in Fig.1. In the ac side of inverter, the local critical load is connected directly. It should be noted that there are two switches, denoted by $S_u$ and $S_i$, respectively, in Fig.1, and their functions are different. The inverter transfer switch $S_i$ is controlled by the DG, and the utility protection switch $S_u$ is governed by the utility. When the utility is normal, both switches $S_i$ and $S_u$ are ON, and the DG in the grid-tied mode injects power to the utility. When the utility is in fault, the switch $S_u$ is tripped by the utility instantly, and then the islanding is formed. After the islanding has been confirmed by the DG with the islanding detection scheme [1]–[3], the switch $S_i$ is disconnected, and the DG is transferred from the grid-tied mode to the islanded mode.

When the utility is restored, the DG should be resynchronized with the utility first, and then the switch $S_i$ is turned ON to connect the DG with the grid.

B. Basic Idea

With the hybrid voltage and current mode control [4]–[12], the inverter is controlled as a current source to generate the reference power $P_{DG} + jQ_{DG}$ in the grid-tied mode. And its output power $P_g + jQ_g$ should be the sum of the power injected to the grid $P_g + jQ_g$ and the load demand $P_{load} = jQ_{load}$ which can be expressed as follows by assuming that the load is represented as a parallel RLC circuit:

$$P_{load} = \frac{3}{2} \frac{V_m^2}{R}$$

$$Q_{load} = \frac{3}{2} \frac{V_m^2}{\omega_L} - \omega C$$

In (1) and (2), $V_m$ and $\omega$ represent the amplitude and frequency of the load voltage, respectively. When the nonlinear local load is fed, it can still be equivalent to the parallel RLC circuit by just taking account of the fundamental component.

During the time interval from the instant of islanding happening to the moment of switching the control system to voltage mode control, the load voltage is neither fixed by the utility nor regulated by the inverter, so the load voltage may drift from the normal range [1].
And this phenomenon can be explained as below by the power relationship. During this time interval, the inverter is still controlled as a current source, and its output power is kept almost unchanged. However, the power injected to the utility decreases to zero rapidly, and then the power consumed by the load will be imposed to the output power of DG. If both active power $P_g$ and reactive power $Q_g$ injected into the grid are positive in the grid-tied mode, then $i_{load}$ and $Q_{load}$ will increase after the islanding happens, and the amplitude and frequency of the load voltage will rise and drop, respectively, according to (1) and (2) With the previous analysis, if the output power of inverter $P_{DG} + jQ_{DG}$ could be regulated to match the load demand by changing the current reference before the islanding is confirmed, the load voltage excursion will be mitigated. And this basic idea is utilized in this paper. In the proposed control strategy, the output power of the inverter is always controlled by regulating the three-phase inductor current $i_{abc}$, while the magnitude and frequency of the load voltage $v_{abc}$ are monitored. When the islanding happens, the magnitude and frequency of the load voltage may drift from the normal range, and then they are controlled to recover to the normal range automatically by regulating the output power of the inverter.

C. Control Scheme

Fig.2 describes the overall block diagram for the proposed unified control strategy, where the inductor current $i_{abc}$, the utility voltage $v_{abc}$, the load voltage $v_{abc}$, and the load current $i_{abc}$ are sensed. And the three-phase inverter is controlled in the SRF, in which, three phase variables will be represented by dc quantity. The control diagram is mainly composed by the inductor current loop, the PLL, and the current reference generation module. In the inductor current loop, the PI compensator is employed in both D- and Q-axes, and a decoupling of the current is implemented in order to mitigate the couplings due to the inductor. The output of the inner current loop $i_{dq}$, together with the decoupling of the capacitor voltage denoted by $1/K_{PWM}$, sets the reference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that $K_{PWM}$ denotes the voltage gain of the inverter, which equals to half of the dc voltage in this paper.

The PLL in the proposed control strategy is based on the SRF PLL [13], which is widely used in the three-phase power converter to estimate the utility frequency and phase. Furthermore, a limiter is inserted between the PI compensator $G_{PLL}$ and the integrator, in order to hold the frequency of the load voltage within the normal range in the islanded operation. In Fig. 2, it can be found that the inductor current is regulated to follow the reference $i_{refdq}$, and the phase of the current is synchronized to the grid voltage $v_{abc}$. If the current reference is constant, the inverter is just controlled to be a current source, which is the same with the traditional grid-tied inverter. The new part in this paper is the current reference generation module shown in Fig.2, which

Regulates the current reference to guarantee the power match between the DG and the local load and enables the DG to operate in the islanded mode. Moreover, the unified load current feedforward, to deal with the nonlinear local load, is also implemented in this module.

The block diagram of the proposed current reference generation module is shown in Fig.3, which provides the current reference for the inner current loop in both grid-tied and islanded modes. In this module, it can be found that an unsymmetrical structure is used in D- and Q-axes. The PI compensator is adopted in D-axes, while the P compensator is employed in Q-axis. Besides, an extra limiter is added in the D-axis. Moreover, the load current feed forward is implemented by adding the load current $i_{LLdq}$ to the final inductor current reference $i_{refdq}$. The benefit brought by the unique structure in Fig.3 can be represented by two parts: 1) seamless transfer capability without critical islanding detection; and 2) power quality improvement in both grid-tied and islanded operations. The current reference $i_{refdq}$ composes of four parts in D- and Q-axes respectively: 1) the output of voltage controller $i_{refdq}$, 2) the grid current reference $i_{grid}$, 3) the load current $i_{LLdq}$, and 4) the current flowing through the filter capacitor $C_f$. 

![Fig.3 Block diagram of the current reference generation module.](image)
In the grid-tied mode, the load voltage $v_{cdq}$ is clamped by the utility. The current reference is irrelevant to the load voltage, due to the saturation of the PI compensator in D-axis, and the output of the P compensator being zero in Q-axis, and thus, the inverter operates as a current source. Upon occurrence of islanding, the voltage controller takes over automatically to control the load voltage by regulating the current reference, and the inverter acts as a voltage source to supply stable voltage to the local load; this relieves the need for switching between different controls architectures.

Another distinguished function of the current reference generation module is the load current feedback forward. The sensed load current is added as a part of the inductor current reference $i_{refdq}$ to compensate the harmonic component in the grid current under nonlinear local load. In the islanded mode, the load current feedback operates still, and the disturbance from the load current, caused by the nonlinear load, can be suppressed by the fast inner inductor current loop, and thus, the quality of the load voltage is improved.

The inductor current control in Fig.2 was proposed in previous publications for grid-tied operation of DG [5], and the motivation of this paper is to propose a unified control strategy for DG in both grid-tied and islanded modes, which is represented by the current reference generation module in Fig. 3. The contribution of this module can be summarized in two aspects. First, by introducing PI compensator and P compensator in D-axis and Q-axis respectively, the voltage controller is inactivated in the grid-tied mode and can be automatically activated upon occurrence of islanding. Therefore, there is no need for switching different controllers or critical islanding detection, and the quality of the load voltage during the transition from the grid-tied mode to the islanded mode can be improved.

Besides, it should be noted that a three-phase unbalanced local load cannot be fed by the DG with the proposed control strategy, because there is no flow path for the zero sequence current of the unbalanced load, and the regulation of the zero sequence current is beyond the scope of the proposed control strategy.

III. OPERATION PRINCIPLE OF DG

The operation principle of DG with the proposed unified control strategy will be illustrated in detail in this section, and there are in total four states for the DG, including the grid-tied mode, transition from the grid-tied mode to the islanded mode, the islanded mode, and transition from the islanded mode to the grid-tied mode.

A. Grid-Tied Mode

When the utility is normal, the DG is controlled as a current source to supply given active and reactive power by the inductor current loop, and the active and reactive power can be given by the current reference of D- and Q-axis independently. First, the phase angle of the voltage is obtained by the PLL, which consists of a Park transformation expressed by (3), a PI compensator, a limiter, and an integrator

$$(x_a) = \frac{2}{\pi} \times \left( \begin{array}{c} \cos \theta \cos(\theta - \frac{2\pi}{3}) \\ \sin \theta \sin(\theta - \frac{2\pi}{3}) \end{array} \right) \times \left( \begin{array}{c} x_d \\ x_q \end{array} \right) \times (3)$$

Second, the filter inductor current, which has been transformed into SRF by the Park transformation, is fed back and compared with the inductor current reference $i_{refdq}$, and the inductor current is regulated to track the reference $i_{refdq}$ by the PI compensator $G_i$.

The reference of the inductor current loop $i_{refdq}$ seems complex and it is explained as below. It is assumed that the utility is stiff, and the three-phase utility voltage can be expressed as

$$\begin{align*}
v_{ga} &= V_g \cos \theta^* \\
v_{gb} &= V_g \cos \left( \theta^* - \frac{2\pi}{3} \right) \\
v_{gc} &= V_g \cos \left( \theta^* + \frac{2\pi}{3} \right)
\end{align*}$$

(4)

Where $V_g$ is the magnitude of the grid voltage, and $\theta^*$ is the actual phase angle. By the Park transformation, the utility voltage is transformed into the SRF, which is shown as

$$\begin{align*}
v_{ga} &= V_g \cos(\theta^* - \theta) \\
v_{gq} &= V_g \sin(\theta^* - \theta)
\end{align*}$$

(5)

Where $v_{ga}$ is regulated to zero by the PLL, so $v_{ga}$ equals the magnitude of the utility voltage $V_g$. As the filter capacitor voltage equals the utility voltage in the grid-tied mode, $v_{cd}$ equals the magnitude of the utility voltage $V_g$, and $v_{cq}$ equals zero, too.

In the D-axis, the inductor current reference $i_{refd}$ can be expressed by (6) according to Fig. 3

$$i_{refd} = I_{refd} + i_{LDA} - w_0 \cdot C_f \cdot v_{cd}$$

(6)

The first part is the output of the limiter. It is assumed that the given voltage reference $v_{max}$ is larger...
than the magnitude of the utility voltage \( v_{cd} \) in steady state, so the PI compensator, denoted by \( G_{vd} \) in the following part, will saturate, and the limiter outputs its upper value \( I_{grefd} \). The second part is the load current of D-axis \( i_{Lld} \), which is determined by the characteristic of the local load. The third part is the proportional part \(-\omega_0 \cdot G_r \cdot v_{cd}\), where \( \omega_0 \) is the rated angle frequency, and \( G_r \) is the capacitance of the filter capacitor. It is fixed as \( v_{cd} \) depends on the utility voltage. Consequently, the current reference \( i_{Lrefd} \) is imposed by the given reference \( I_{grefd} \) and the load current \( i_{Lld} \), and is independent of the load voltage.

In the Q-axis, the inductor current reference \( i_{Lrefq} \) consists of four parts as

\[
i_{Lrefq} = v_{cq} \cdot k_{gvq} + I_{grefq} + i_{LLq} + w_0 \cdot G_r \cdot v_{cd}
\]  

(7)

Where \( k_{gvq} \) is the parameter of the P compensator, denoted by \( G_{vq} \) in the following part. The first part is the output of \( G_{vq} \) which is zero as the \( v_{cq} \) has been regulated to zero by the PLL. The second part is the given current reference \( I_{grefq} \), and the third part represents the load current in Q-axis. The final part is the proportional part \(-\omega_0 \cdot G_r \cdot v_{cd} \) which is fixed since \( v_{cd} \) depends on the utility voltage. Therefore, the current reference \( i_{Lrefq} \) cannot be influenced by the external voltage loop and is determined by the given reference \( I_{grefq} \) and the load current \( i_{LLq} \).

With the previous analysis, the control diagram of the inverter can be simplified as Fig.4 in the grid-tied mode, and the inverter is controlled as a current source by the inductor current loop with the inductor current reference being determined by the current reference \( I_{grefdq} \) and the load current \( i_{Lldq} \). In other words, the inductor current tracks the current reference and the load current. If the steady state error is zero, \( I_{grefdq} \) represents the grid current actually, and this will be analyzed in the next section.

**B. Transition from the Grid-Tied Mode to the Islanded Mode**

When the utility switch \( S_u \) opens, the islanding happens, and the amplitude and frequency of the load voltage will drift due to the active and reactive power mismatch between the DG and the load demand. The transition, shown in Fig.5, can be divided into two time interval. The first time interval is from the instant of turning off \( S_u \) to the instant of turning off \( S_l \) when islanding is confirmed. The second time interval begins from the instant of turning off inverter switch \( S_l \).

During the first time interval, the utility voltage \( v_{gabc} \) is still the same with the load voltage \( v_{sabc} \).

\[ Q_g > 0 \quad \text{Island is confirmed} \]

\[ S_u \text{off} \quad \text{Interval#1} \quad S_l \text{off} \quad \text{Interval#2} \]

\[ v_{gabc} = v_{sabc} \quad v_{cab} = 0 \]

As the switch \( S_l \) is in ON state. As the dynamic of the inductor current loop and the voltage loop is much faster than the PLL [14], while the load voltage and current are varying dramatically, the angle frequency of the load voltage can be considered to be not varied. The dynamic process in this time interval can be described by Fig.6, and it is illustrated later.

In the grid-tied mode, it is assumed that the DG injects active and reactive power into the utility, which can be expressed by (8) and (9), and that the local critical load, shown in (10), represented by a series connected RLC circuit with the lagging power factor

\[
P_g = \frac{3}{2} \left( v_{ca} i_{ga} + v_{cq} i_{qa} \right) = \frac{3}{2} v_{ca} i_{ga} \quad (8)
\]

\[
Q_g = \frac{3}{2} \left( v_{ca} i_{ga} - v_{cd} i_{ga} \right) = -\frac{3}{2} v_{ca} i_{ga} \quad (9)
\]

\[
Z_{sload} = R_s + jwL_s + \frac{1}{jwC_s}
\]
When islanding happens, \( i_{gd} \) will decrease from positive to zero, and \( i_{gq} \) will increase from negative to zero. At the same time, the load current will vary in the opposite direction. The load voltage in D- and Q-axes is shown by (11) and (12), and each of them consists of two terms. It can be found that the load voltage in D-axis \( v_{cd} \) will increase as both terms increase. However, the trend of the load voltage in Q-axis \( v_{cq} \) is uncertain because the first term decreases and the second term increases, and it is not concerned for a while

\[
v_{cd} = i_{Lld} R_s - i_{Ldq} X_s \quad (11)
\]

\[
v_{cq} = i_{Ldq} R_s + i_{Lld} X_s \quad (12)
\]

With the increase of the load voltage in D-axis \( v_{cd} \), when it reaches and exceeds \( V_{max} \), the input of the PI compensator \( G_{VD} \) will become negative, so its output will decrease. Then, the output of limiter will not impose to \( i_{ref\_gd} \) any longer, and the current reference \( i_{ref\_gd} \) will drop. With the regulation of the inductor current loop, the load current in D-axis \( i_{Lld} \) will decrease. As a result, the load voltage in D-axis \( v_{cd} \) will drop and recover to \( V_{max} \).

After \( i_{Lld} \) has almost fallen to the normal value, the load voltage in Q-axis \( v_{cq} \) will drop according to (12). As \( v_{cq} \) is decreased from zero to negative, then the input of the PI compensator \( G_{PLL} \) will be negative, and its output will drop. In other words, the angle frequency \( \omega \) will be reduced. If it falls to the lower value of the limiter \( \omega_{min} \), then the angle frequency will be fixed at \( \omega_{min} \).

Consequently, at the end of the first time interval, the load voltage in D-axis \( v_{cd} \) will be increased to and fixed at \( V_{max} \), and the angle frequency of the load voltage \( \omega \) will drop. If it is higher than the lower value of the limiter \( \omega_{min} \), the PLL can still operate normally, and the load voltage in Q-axis \( v_{cq} \) will be zero. Otherwise, if it is fixed at \( \omega_{min} \), the load voltage in Q-axis \( v_{cq} \) will be negative. As the absolute values of \( v_{cd} \) and \( v_{cq} \) are raised, the magnitude of the load voltage will increase finally.

The variation of the amplitude and frequency in the load voltage can also be explained by the power relationship mentioned before. When the islanding happens, the local load must absorb the extra power injected to the grid, as the output power of inverter is not changed instantaneously. According to (1), the magnitude of the load voltage \( V_m \) will rise with the increase of \( P_{load} \). At the same time, the angle frequency \( \omega \) should drop, in order to consume more reactive power with (2). Therefore, the result through the power relationship coincides with the previous analysis.

The second time interval of the transition begins from the instant when the switch \( S_i \) is open after the islanding has been confirmed by the islanding detection method. If the switch \( S_i \) opens, the load voltage \( v_{cd} \) is independent with the grid voltage \( V_{abc} \). At the same time, \( V_{abc} \) will reduce to zero theoretically as the switch \( S_u \) has opened. Then, the input of the compensator \( G_{PLL} \) becomes zero and the angle frequency is invariable and fixed to the value at the end of the first interval. Under this circumstance, \( v_{cd} \) is regulated by the voltage loop, and the inverter is controlled to be a voltage source.

With the previous analysis, it can be concluded that the drift of the amplitude and frequency in the load voltage is restricted in the given range when islanding happens. And the inverter is transferred from the current source operation mode to the voltage source operation mode autonomously. In the hybrid voltage and current mode control [4]-[12], the time delay of islanding detection is critical to the drift of the frequency and magnitude in the load voltage, because the drift is worse with the increase of the delay time. However, this phenomenon is avoided in the proposed control strategy.

### C. Islanded Mode

In the islanded mode, switching \( S_i \) and \( S_u \) are both in OFF state. The PLL cannot track the utility voltage normally, and the angle frequency is fixed. In this situation, the DG is controlled as a voltage source, because voltage compensator \( G_{VD} \) and \( G_{VQ} \) can regulate the load voltage \( v_{cd} \). The voltage references in D- and Q-axis are \( v_{max} \) and zero, respectively. And the magnitude of the
load voltage equals to \( V_{\text{max}} \) approximately, which will be analyzed in Section IV. Consequently, the control diagram of the three-phase inverter in the islanded mode can be simplified as shown in Fig. 7.

In Fig. 7, the load current \( i_{Ld} \) is partial reference of the inductor current loop. So, if there is disturbance in the load current, it will be suppressed quickly by the inductor current loop, and a stiff load voltage can be achieved.

**D. Transition from the Islanded Mode to the Grid-Tied Mode**

If the utility is restored and the utility switch \( S_u \) is ON, the DG should be connected with utility by turning on switch \( S_t \). However, several preparation steps should be performed before turning on switch \( S_t \).

First, as soon as utility voltage is restored, the PLL will track the phase of the utility voltage. As a result, the phase angle of the load voltage \( v_{abc} \) will follow the grid voltage \( v_{abc} \). If the load voltage \( v_{abc} \) is in phase with the utility voltage; \( v_{ad} \) will equal the magnitude of the utility voltage according to (5).

Second, as the magnitude of the load voltage \( V_{\text{max}} \) is larger than the utility voltage magnitude \( V_g \), the voltage reference \( V_{\text{ref}} \) will be changed to \( V_g \) by toggling the selector \( S \) from terminals 1 to 2. As a result, the load voltage will equal to the utility voltage in both phase and magnitude.

Third, the switch \( S_t \) is turned on, and the selector \( S \) is reset to terminal 1. In this situation, the load voltage will be held by the utility. As the voltage reference \( V_{\text{ref}} \) equals \( V_{\text{max}} \), which PI compensator \( G_{V_D} \) will saturate, and the limiter outputs its upper value \( I_{\text{max}} \). At the same time, \( v_{Cq} \) is regulated to zero by the PLL according to (5), so the output of \( G_{V_Q} \) will be zero. Consequently, the voltage regulators \( G_{V_D} \) and \( G_{V_Q} \) are inactivated, and the DG is controlled as a current source just by the inductor current loop.

**IV. PHOTOVOLTAIC (PV) SYSTEM**

In the crystalline silicon PV module, the complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Fig. 5. For that equivalent circuit, a set of equations have been derived, based on standard theory, which allows the operation of a single solar cell to be simulated using data from manufacturers or field experiments.

The series resistance \( R_S \) represents the internal losses due to the current flow. Shunt resistance \( R_{Sh} \), in parallel with diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell

**V. MATLAB/MODELING & RESULTS**

Here simulation is carried out in different cases, in that

1. PV cell Based Three Phase Three level Inverter Fed
2. Distributed Generation Scheme using Unified Control
2). Proposed PV cell Based Three Phase Five level Inverter Fed Distributed Generation Scheme using Unified Control Scheme.

Case i: PV cell Based Three Phase Three level Inverter Fed Distributed Generation Scheme using Unified Control Scheme.

Fig.9 Matlab/Simulink Model of Proposed PV based Three level Inverter Fed Distributed Generation Scheme using Unified Control Scheme.

Fig.10 Simulation waveforms of load voltage $v_{CA}$, grid current $i_{gs}$ and inductor current $i_{LS}$ when DG is in the grid-tied mode under condition of the step down of the grid current reference from 9 A to 5 A with proposed unified control strategy.

Fig.11 Simulation waveforms of load voltage $v_{CA}$, grid current $i_{gs}$ and inductor current $i_{LS}$ when DG is transferred from the grid-tied mode to the islanded mode with proposed unified control strategy.

Fig.12 Simulation waveforms under DG is transferred from the islanded mode to the grid-tied mode, grid voltage $v_{gs}$, load voltage $v_{CA}$, as well as grid current $i_{gs}$ and inductor current $i_{LS}$.

Fig.13 Simulation waveform when DG feeds nonlinear load in islanded mode with load current feed forward.

Fig.14 Simulation waveforms when DG feeds nonlinear load in the grid tied mode with load current feed forward control.
Case 2: Proposed PV cell Based Three Phase Multilevel Inverter Fed Distributed Generation Scheme using Unified Control Scheme

Fig.15 Matlab/Simulink Model of Proposed PV cell Based Three Phase Multilevel Inverter Fed Distributed Generation Scheme using Unified Control Scheme

Fig.15 shows the Matlab/Simulink Model of Proposed PV cell Based Three Phase Multilevel Inverter Fed Distributed Generation Scheme using Unified Control Scheme using Matlab/Simulink tool.

Fig.16 Simulation waveforms under DG is transferred from the islanded mode to the grid-tied mode, grid voltage $v_{gs}$, & load voltage $v_{Ca}$, as well as grid current $i_{gs}$ & inductor current $i_L$.

Fig.17 Five Level Output Voltage

VI. CONCLUSION

The inverter is a promising inverter topology for high voltage and high power applications. It has the advantages like high power quality waveforms, lower voltage ratings of devices, lower harmonic distortion, lower switching frequency and switching losses, higher efficiency, reduction of $d_u/d_t$ stresses etc. A novel advanced voltage controller was presented. It is inactivated in the grid-tied mode, and the DG operates as a current source with fast dynamic performance. Upon the utility outage, the voltage controller can automatically be activated to regulate the load voltage. Moreover, a novel load current feed forward was proposed, and it can improve the waveform quality of both the grid current in the grid-tied mode and the load voltage in the islanded mode. An advanced control strategy was proposed for five level inverter in DG to operate in both islanded and grid-tied modes, with no need for switching between two different control architectures or critical islanding detection.

REFERENCES


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