Current Control in Grid-Connected Photovoltaic systems to Avoid Over voltages

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Abstract: Independent current control of each phase of a three-phase voltage source inverter under unbalanced voltage sags is proposed to effectively meet grid code requirements for grid-connected photovoltaic power plants. Under current grid codes, GCPPPs should support grid voltages by injecting reactive currents during voltage sags. Such injection must not allow the grid voltages of the nonfaulty phases to exceed 110% of their nominal value. However, grid over voltages can occur in the nonfaulty phases, especially if the currents injected into the grid by the GCPPP are balanced. Based on a new requirement of the transmission system a transmission system operator is allowed to introduce a requirement for unbalanced current injection. In this paper, this grid code is addressed by controlling individual phases and injecting unbalanced currents into the grid during voltage sags.

1. Introduction

The control of grid-connected voltage source inverters (VSIs) under unbalanced voltage sags has been widely addressed in the technical literature. Some research has focused on active power control strategies, and two methods have been presented to provide the current references for the VSIs [1], [2]. As in the case of synchronous generators in conventional power plants, VSIs should remain connected during voltage sags and support the grid voltages with the injection of reactive currents [3], [4]. This is necessary to ride-through any type of fault.

The injection of balanced reactive currents to support unbalanced voltage sags may lead to over voltages in the nonfaulty phases [5]. To prevent this, new grid codes (GCs) require the injection of unbalanced reactive currents during unbalanced voltage sags, and for this purpose different control been proposed. In [6] and [7], a flexible voltage support method was introduced based on the type and severity of the voltage sags. For this purpose, the amount of reactive power injected via positive- and negative-sequences is controlled with an offline control parameter. An extended generalization of previous studies was carried out in [8], whereby the reactive power reference and the control parameter were updated in order to restore the dropped voltage amplitudes.

The objective of this project is to propose a control method based on individual control of the phase currents under unbalanced voltage sags. The amount of reactive current in each phase is determined based on the amount of voltage drop in that phase, which implies no reactive current injection for the nonfaulty phases. Implementation of this method requires knowledge of the grid-voltage angle of each phase. For this purpose, thephase-lockedloop(PLL)proposedin isused.Moreover, the grid currents, including both active and reactive currents, are limited in order to protect the grid-connected photovoltaic power plants (GCPPPs) from ac overcurrents, addressing the fault-ride-through requirement. Since the grid currents are defined independently for each phase, two methods are proposed to prevent the controllers from trying to inject a zero-sequence into the grid. In this study, the proposed control technique was tested experimentally in a scaled-down GCPPP connected to a low-voltage (LV) programmable ac power supply.

2. The Photovoltaic System

A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance. There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources.

3. Photovoltaic Inverter

The inverter is the heart of the PV system and is the focus of all utility-interconnection codes and standards. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV array is a dc source, an inverter is required to convert the dc power to normal ac power that is used in our homes and offices. To save energy they run only when the sun is up and should be located in cool locations away from direct sunlight. The PCU is a general term for all the equipment involved including the inverter and the interface with the PV (and battery system if used) and the utility grid. It is very important to point out that inverters are by design much safer than rotating generators. Of particular concern to utility engineers is how much current a generator can deliver during a fault on their system. Inverters generally produce less than 20% of the fault current as a synchronous generator of the same nameplate capacity. This is a very significant difference.

4. Power Quality Problems with PV Inverters

Large numbers of PV inverters on low-voltage feeders can give power quality problems and may result that in certain cases; temporarily the national standard for power quality EN50160 is exceeded. This is the result even when all the PV inverters individually satisfy the IEC 61000-3 specification. Not completely covered by standards at this moment is the effect of harmonic current emission by PV inverters as a response on harmonic distortion of the grid voltage. Also not completely covered by standards at this moment is the production of harmonic current emission due to a resonance phenomenon between the network and PV inverters. All these effects can lead to a higher harmonic current emission of the PV-inverters, which is design dependent. These harmonic emissions can be minimized by good design practice, which anticipates on future standardization.

5. Power Quality of PV Inverters Related to Topology and Control Aspects

Converters for PV systems can be divided into two groups, namely: Line commutated inverters and self commutated inverters. Line commutated inverters are commonly used for high power converters, while self-commutated converters are commonly used for small PV-inverters. Only inverters with line currents up to maximum 16 amperes per phase and therefore only self-commutated inverters will be discussed. A further limitation will be the focus on single-phase inverters. Within the mentioned limitations, PV inverters consist in general of different stages and transformer options. To comply with standards, these inverters with their pulse-width modulation (PWM) converter controllers generate a sinusoidal output current. In practice switching frequencies of 20 - 500 kHz are used in different power stages.

Several inverter concepts are used in these group of small single-phase inverters, examples are:

· Single-stage concept of H-bridge pulse-width-modulated (PWM) DC-DC converter directly coupled to the grid

· Single-stage concept of H-bridge PWM DC-DC converter coupled to the grid with a low frequency (LF) isolation transformer

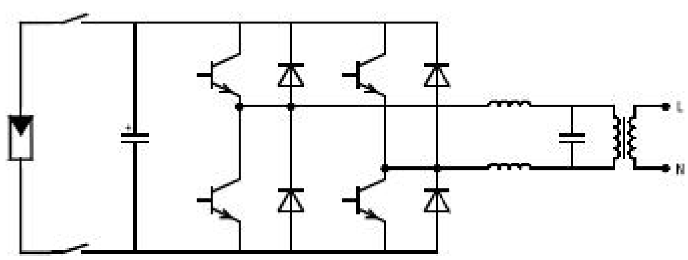


Fig:1 Single-stage H-Bridge PWM converter and low-frequency transformer

6. PI Controller

The general block diagram of the PI speed controller is shown in Figure 2

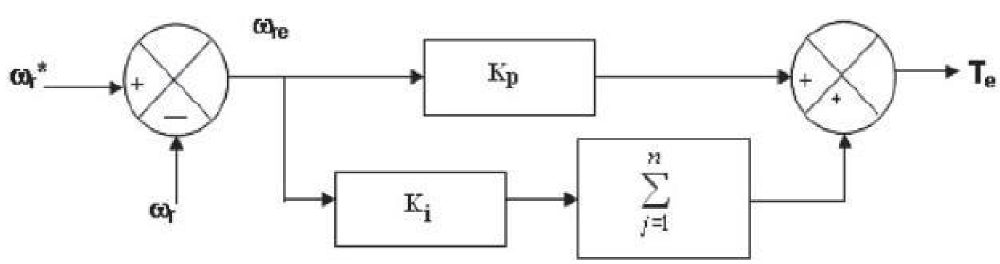


FIG. 2. Block diagram of PI speed controller.

The output Of the speed controller (torque command) at *n*-th instant is expressed as follows:

$$Te(n) = Te(n-1) + Kp\_\omega re(n) + Ki\omega re(n) \quad (1)$$

Where $Te(n)$ is the torque output of the controller at the n-th instant, and Kp and Ki the proportional and integral gain constants, respectively.A limit of the torque command is imposed as

$$T_{e(n+1)} = \begin{cases} T_{e\max} & \text{for} \quad T_{e(n+1)} \geq T_{e\max} \\ -T_{e\max} & \text{for} \quad T_{e(n+1)} \leq -T_{e\max} \end{cases}$$

The gains of PI controller shown in (1) can be selected by many methods such as trial and error method, Ziegler–Nichols method and evolutionary techniques-based searching. The numerical values of these controller gains depend on the ratings of the motor.

7. Limiting the Phase Currents

Under a voltage sag condition, the controller increases the active currents to maintain the power injected into the grid. At the same time, reactive current needs to be injected into the faulty phases to support the grid voltages. Consequently, the total phase currents may increase above the maximum acceptable values, which would eventually trigger the over current protection. To avoid this situation, priority is given to the reactive current injection to support the grid voltages. Therefore, the amplitudes of the active currents are limited based on the reactive current required for each phase. The priority under voltage sag is to support the grid voltages with the injection of reactive currents. However, the current of each phase cannot go beyond the maximum acceptable value defined for the inverter. Therefore, in the case of over current in one phase, the active current of that phase should be limited. The current limiter in Fig. 2 is defined as follows:

$$\hat{i}_{Ax} = \begin{cases} \hat{i}_A, & \text{if } \sqrt{\hat{i}_{R-x}^2 + \hat{i}_A^2} \leq \hat{I}_n \\ \sqrt{\hat{I}_n^2 - \hat{i}_{R-x}^2}, & \text{if } \sqrt{\hat{i}_{R-x}^2 + \hat{i}_A^2} > \hat{I}_n \end{cases} \quad (2)$$

where x stands for phases a, b, and c. The actual current reference for each phase is obtained by multiplying the amplitudes of the active and reactive currents by the cosine and sine, respectively, of the phase angle obtained from the PLLs. The final current reference for each phase is achieved by adding the active and reactive current components.

Therefore, this zero-sequence should be removed from the current references.

8. RESULTS AND DISCUSSIONS

Experimental results were obtained by connecting the scaled down GCPPP to the laboratory "weak" grid. First, balanced currents were injected. In this case, the lowest line-to-line voltage was considered for the droop control. This implies the injection of balanced reactive currents into all three phases. The detailed control method under balanced currents can be found. Fig. 4 –Fig.10 shows the results obtained under a line-to-ground (LG) voltage sag with 100% voltage drop in phase *a* imposed at the grid side of the transformer. The voltage magnitudes are scaled down by a factor of 20 to be able to show them on the oscilloscope. As demonstrated, the injection of balanced reactive currents under unbalanced voltage sags leads to voltage rise in the non-faulty phase. In this case, the amplitudes of the grid voltages rise from $8.547 \times 20 = 170.94$ V to $8.731 \times 20 = 174.63$ V, which equates to an increase of 1.84% of the grid voltages during the voltage sag. Although this value does not reach the limit defined by the GCs, this test shows the effect of raising the voltage of the non-faulty phases above the nominal value.

The performance of the proposed method was demonstrated in the following test. Consider the same voltage sag as the one in the previous test. Since the LG voltage sag is of Type *B*, the respective voltage sag at the LV side of the transformer, after passing through a *Dyn*11 transformer, is a Type *C* voltage sag. As a result, the reactive current should be injected only into the two faulty phases at the inverter side.. In this case, since there is no injection of reactive current into the non-faulty phase (green phase), there is no voltage rising in that phase, while the voltages of the other two phases rise owing to the injection of the appropriate reactive currents.

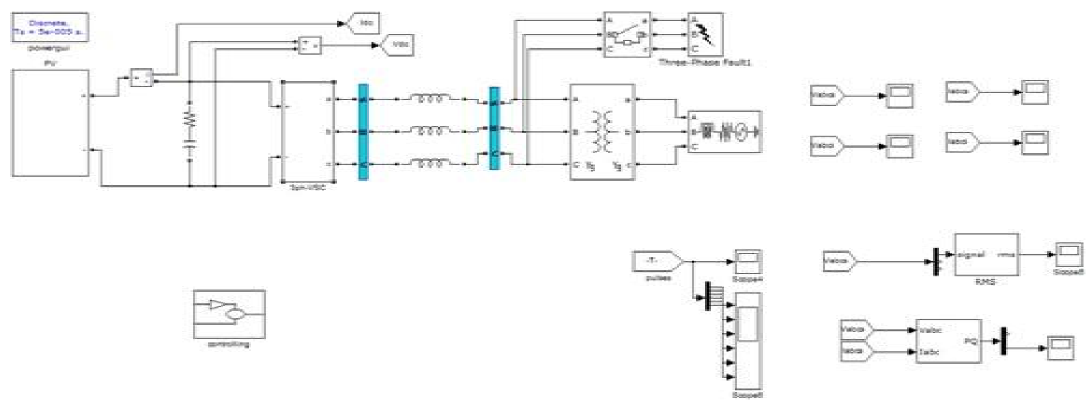
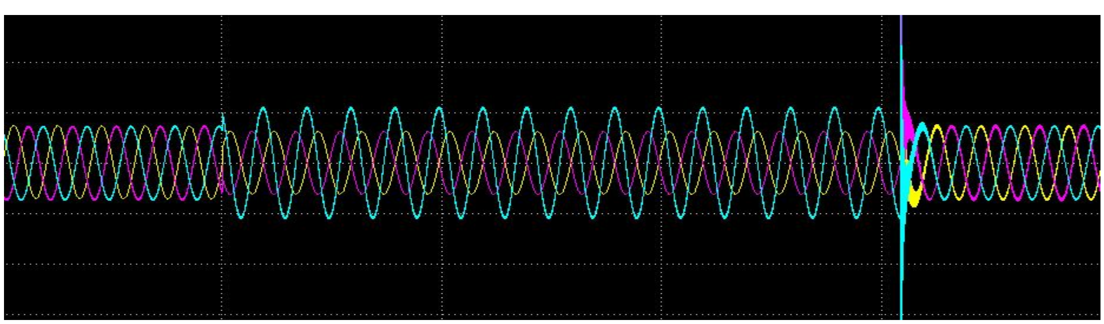


Fig.3 Simulink diagram of a proposed system



Fig, 4 Voltage source waveform

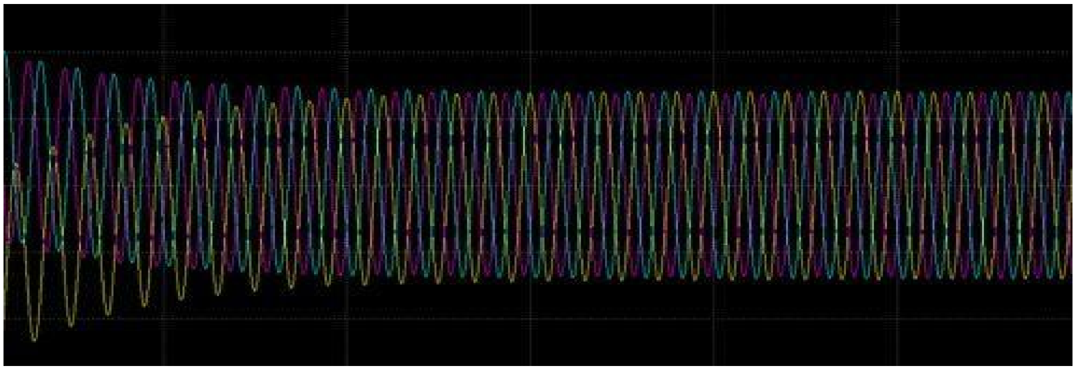


Fig.5 Voltage Reference wave form

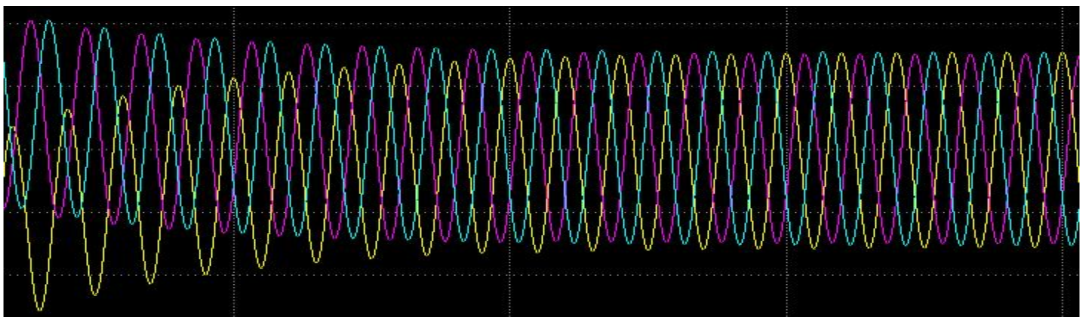


Fig.6 Current Source wave form

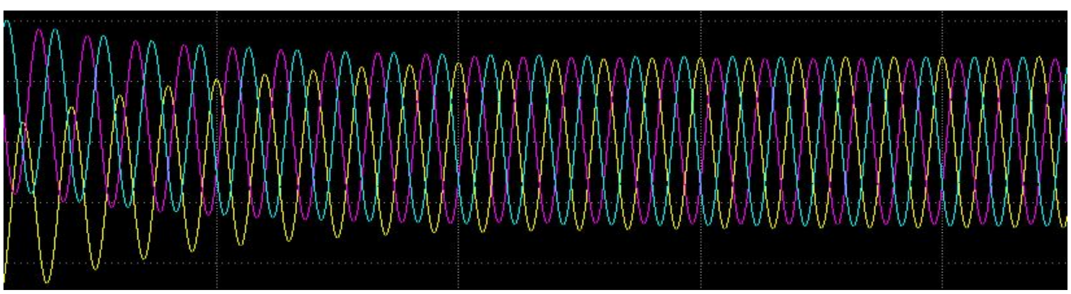


Fig.7 Current Reference wave form

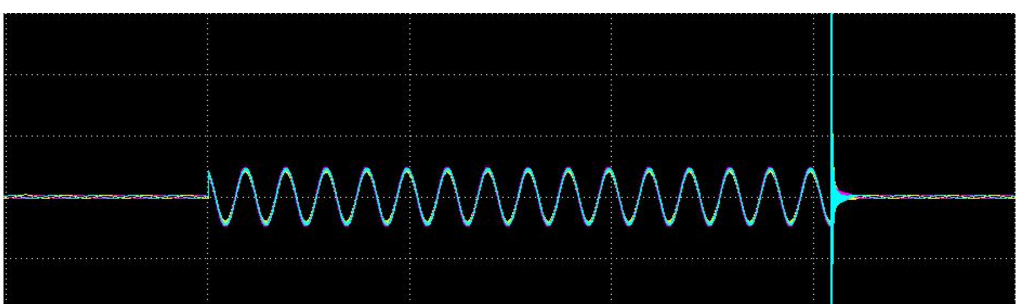


Fig.8 Reactive current Input wave form

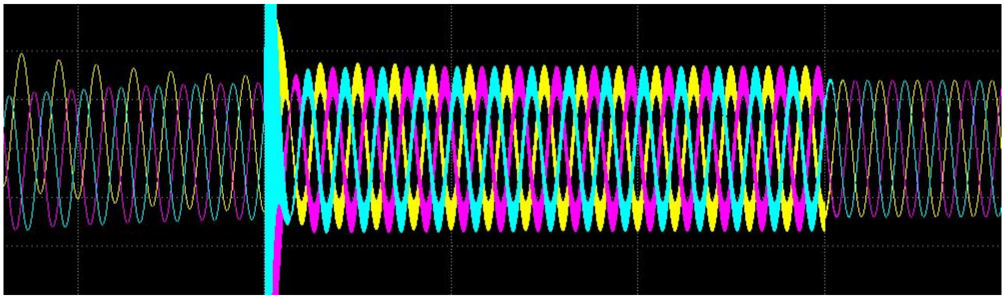


Fig.9 Reactive current Output wave form

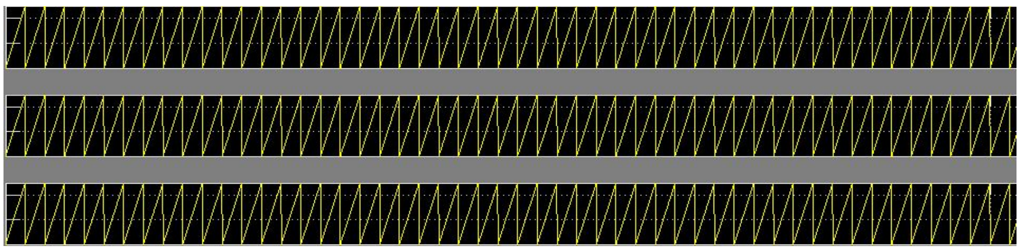


Fig.10 Induvidual Phase Angles

9. CONCLUSION

In this project, a new control method based on individual control of the three phases of a GCPPP has been proposed. The independent control of the reactive currents injected into the grid protects the non-faulty phases from overvoltage. The reactive currents are determined separately based on the amount of voltage drop in each phase. The active current references of each phase need to be limited based on the required amount of reactive currents. Furthermore, in a three-phase system, it is necessary to eliminate the zero-sequence from the current references generated. In this project, two solutions for removing the zero-sequence component have been proposed. Finally, a method for rescaling the instantaneous current references to avoid producing over-voltages in the non-faulty phases, while preventing the GCPPP from over-currents has also been proposed. This proposed control method has been tested experimentally on a scaled-down laboratory prototype operating with a "weak" grid.

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