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A framework for selection of grid-inverter synchronisation unit: Harmonics, phase-angle and frequency

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ABSTRACT

In this paper, a summary of synchronisation approach which explains about the approach starting from older techniques to advanced computational methods are been discussed. There are many techniques that have been developed focusing on the synchronisation. Generally, in order to evaluate grid parameters, phase-locked-loop (PLL) and later to trigonometric function based on synchronous reference-frame phase-locked-loop, are established on the basis of phase estimation and frequency tracking for grid-inverter connection. The most recent technique, where is the synchronous generator characteristics, has been used in controller strategy at multilevel control programming strategy for distribution of power from the energy sources without the dedicated PLL. In addition to this idea, a concept of synchronous generator for the power processing controller has been developed in order to synchronise the converter with a grid or known as synchronverter can be found.

1. Introduction

The diversity of electrical power transmission for grid has become interesting with regards to the introduction to distributed generation system [1]. Distributed Energy Resources (DERs) [2,3] have become more attractive due to various technological been development compared to oil based energy production. Among its advantages include, less emission on greenhouse gases, less maintenance cost if plugged-in hybrid electric vehicle, smart energy infrastructure and so on [4,5] are implemented in the electrical network. The inverter or converter is adopted to connect the (DERs) to AC grid with the aim of sharing loads burden and power by integrating power processing converter with power control strategies [6–8]. As for this control strategy, it should include a synchronisation response in order to secure the DG if grid network contains faulty cases and also to improve the stability of the power transfer [9,10] during power sharing. There are many studies that have been conducted in the field of power control strategies for sending power from DERs to the conventional AC grid. Some examples of the studies are given in [11–13]. Most of DERs offer DC source and DC-storage battery bank inputs which are connected to existing AC grid network through an efficient inverter [14] with synchronisation capability. At some cases, it is also necessary for DGs to operate during a standalone operation, where to operate as current-source inverter (CSI) or voltage-source inverter (VSI) for sending the power to the loads.

Interestingly, the VSI does need an external reference to keep it synchronised as stated in [15], even if it works in AC input source systems. This is especially with regards to frequency and voltage droops for outlining the microgrid network [16] behaviour. By maintaining the grid-inverter synchronised condition, the inverter can inject a good quality power into the grid even if there is any change in voltage, frequency and phase-angle [17] on the grid side. However, the idea of synchronisation is often understood as, the frequency, amplitude and the phase-angle of grid voltage will be the inputs references for power controller [18] strategy for the inverter and the grid-connected inverter-controlling policy as mentioned [19,20]. The power angle control as well as torque angle control and current vector control in VSI are the mostly studied methods.

Fig. 1 shows the concept of power distribution between the DG-converter and the grid. This exchange of power happens when the reactive power Q is controlled by regulating the amplitude of the generated voltage and grid voltage [21,22] while the real power is transferred when it has a phase angle difference between inverter-grid voltage. However, by using a proper control topology and algorithm,

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Nomenclature

The notations and symbols used throughout the paper are stated below:

V_{grid}	Grid voltage (volts)
E_{gen}	Generator terminal voltage (volts)
θ_{gen}	Generator voltage phase-angle (deg)
θ_{grid}	Grid voltage phase-angle (deg)
P	Real power (watt)
Q	Reactive power (watt)
X_S	Generator synchronous reactance (Ω)
V_{dc}	dc source voltage (volts)
I_C	Inverter current (amp)
L_s	Inverter series inductor for filter (mH)
L_g	Filter grid side inductor (mH)
C_f	Filter capacitor (µF)
R_d	Filter damping resistance (Ω)
V_{in}	Input voltage (volts)
θ	Phase-angle (deg)
I_L	Load current (amp)
Z_{grid}	Grid impedance (Ω)
V_d	d-axis voltage (volts)
V_q	q-axis voltage (volts)
T_e	Electromagnetic torque (N-m)
T_m	Mechanical torque (N-m)
P_{in}	Input mechanical power (watt)
P_{out}	Output electrical power (watt)
M	Rotor inertia ()
D	Friction coefficient
K	Synchronizing gain
δ_m	Internal phase-angle (deg)
ω_n	Rotor angular speed (rad/sec)
T_{ev}	Virtual electromagnetic torque (N-m)
T_{mv}	Virtual mechanical torque (N-m)
M_f	Rotor virtual magnetic field (Nm/amp)
i_f	Rotor virtual field current (amp)
$\dot{\theta}$	Rotor virtual angular speed (rad/sec)
D_p	Rotor virtual damping coefficient
$\ddot{\theta}$	Rotor virtual angular acceleration (rad/s^{-2})
e	Virtual internal generated voltage (volts)
Q_v	Virtual reactive power (var)
$\theta_{n/g}$	Nominal angular grid frequency (rad)
V_n	Nominal grid voltage (volts)

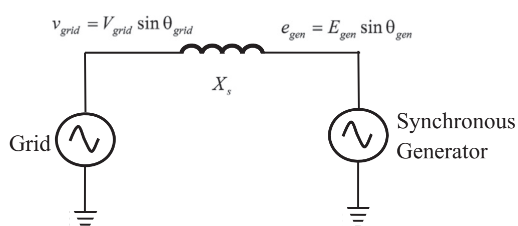

Fig. 1. SG-infinite bus connection model connected to an infinite bus.

VSI is the most capable structure to share real power and reactive power including controlling facilities [23]. It is where, the real power and reactive power flowing, between the DG-converter voltage and grid voltage that can be expressed in (1) and (2),

$$P = \frac{V_{grid} E_{gen}}{X_S} \sin(\theta_{gen} - \theta_{grid}) \tag{1}$$

$$Q = \frac{V_{grid}}{X_S} [E_{gen} \cos(\theta_{gen} - \theta_{grid}) - V_{grid}], \tag{2}$$

where V_{grid} and E_{gen} are grid voltage and generator terminal voltage respectively, $(\theta_{gen} - \theta_{grid})$ is the phase-angle difference between generator voltage and grid, while X_S as line impedance between the connection of grid source and synchronous generator. This is where the inverter phase angle requires sequences estimations such as positive or negative sequences [23] in three phase converter, a flexible power control [10,24] of grid-connected converters in distributed energy sources and active power filters [23] under the distorted and imbalanced circumstances in order to have the capability of power transfer. In addition, a fast and precise synchronisation are straightforward requirements while having wide range of reactive and real power controlling options [23] is an advantage to the congifuration. Fig. 2 shows, the connection of inverter with the distribution grid which contains synchronisation unit for synchronising the inverter with the grid.

In this paper, various synchronising tricks will be discussed in the synchronisation concept between DERs converter and the electrical grid. The most important and basic conditions for such applications are to possess inverter voltage synchronisation with the grid voltage before and after the inverter being connected to the grid. The consequences of this are; (1) the inverter can connect to the grid, and (2) the inverter can feed the right amount of power to the grid even when the grid voltage changes its frequency, phase, and amplitude [24,25]. In the meantime, this paper is structured as a comprehensive review of the recently developed PLL techniques for synchronisation process. A comparison and selection guide is also provided in the Appendix. For the paper structure, this paper will be divided into the following sections: the concepts of synchronisation techniques are summarised and its technique based on their performance parameters are discussed in Section 2. Section 3 is accommodated for modern methods and followed by the conclusion part in Section 4 that focuses on comparison among different mechanisms of grid terminology with tabulated in the table given in Appendix.

2. PLL in grid-inverter synchronisation techniques

The concept of “plug and play” or distributed microsource is a key to microgrids. To accomplish this goal, the ideas of active-power/frequency droop and reactive-power/voltage droop controls have been used. Its allow microsource to share the generation power and maintain stability without the need for fast communications [26]. But, it has been a norm to adopt a synchronisation unit, e.g. PLL to make sure that the inverter is synchronised with the grid.

The most extensively acknowledged synchronisation is a key signal which can be defined by the elementary block diagram as shown in Fig. 3. It shows, a change between phase-angle with the voltage input are determined by the Phase Detection (PD) and then flows through the Loop Filter (LF). The output signal of LF triggers the Voltage-Controlled Oscillator (VCO) to produce the phase angle of the voltage, which would use to monitor the input signal which give the basic fundamental of PLL process.

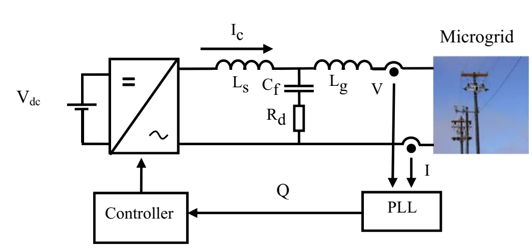

Fig. 2. Typical grid-inverter connection structure.