Enhanced Control Topology for Grid connected PV System under Distortions and Unbalance Conditions

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Abstract-In a distributed generation (DG) system, several renewable agents are connected to the low-voltage 3-phase utility grid through an inverter which is used as power condition and must guarantee the higher efficiency of the renewable agent. To attain this level of efficiency, a unitary power factor (PF) between the inverter currents and the utility grid voltages is necessary, and a synchronization algorithm is needed for the perfect synchronization between the renewable agent and the 3-phase utility grid. Within this context, In order to obtain a high efficiency of the system, a fuzzy logic controller with a Harmonic Compensator structure is designed for the control algorithm, whereas a Dual Second Order Generalized Integrator Frequency-Locked Loop (DSOGI-FLL) is used as the synchronization algorithm. When the 3-phase utility grid is affected by some disturbances such as voltage unbalances, frequency variations and harmonic distortions. Several simulations with a disturbed 3-phase utility grid using MATLAB/SIMULINK from The MathWorks, Inc. are shown here.

Keywords: Grid Synchronization, Dual Second Order Generalized Integrator Frequency-Locked Loop (DSOGI-FLL),Fuzzy controller,INC MPPT.

I. Introduction

With continuous fall in the prices of PV modules and concern in the green house gas emissions usage the PV generation has got more importance now days. Photovoltaic (PV) sources are extensively used in many applications as they have the advantages of being maintenance and environmental friendly. Grid connected photovoltaic (PV) system can reduce investment outlay because it does not need battery for storing energy. The efficiency, output energy quality and reliability will directly affect the performance and investment efficiency of the entire photovoltaic power generation system. In the framework of a Distributed Generation (DG) system, the connection of new, clean and infinite renewable sources to the utility grid, as an alternative to traditional ones for the collaborative effort towards the mitigation of the greenhouse effect , must be properly controlled according to the expected operating conditions of the primary energy as well as the utility grid normative.

In this paper a combined operation of both synchronization and control algorithms are proposed so as to validate its performance and to ensure the higher efficiency of the grid connected photovoltaic system when the 3-phase utility grid is affected by voltage unbalances, variations of its nominal frequency and low order harmonics. For this, the Dual Second Order Generalized Integrator Frequency-Locked Loop (DSOGI-FLL) proposed and it is used as the synchronization algorithm together with the Proportional Resonant

(PR) controller and a Harmonic Compensator (HC) structure and fuzzy controller are proposed.

II. GRID CONNCECTED PV SYSTEM

For grid-connected photovoltaic systems, it is necessary to control the power flow between the primary renewable energy source and the utility grid, as well as the power factor of the inverter-grid connection with high power quality. The global 3-phase grid-connected photovoltaic system can be divided into two subsystems, the power and the control subsystems.

a) Power subsystem

The power subsystem is formed by the PV Panels, the inverter, the LCL and the EMI filters. The LCL filter and the 3-phase utility grid are configured as a three wire system with two degrees of freedom.

The dc side of the inverter can be described as follows:

$$i_p = i_{clink} + i_{cc}$$

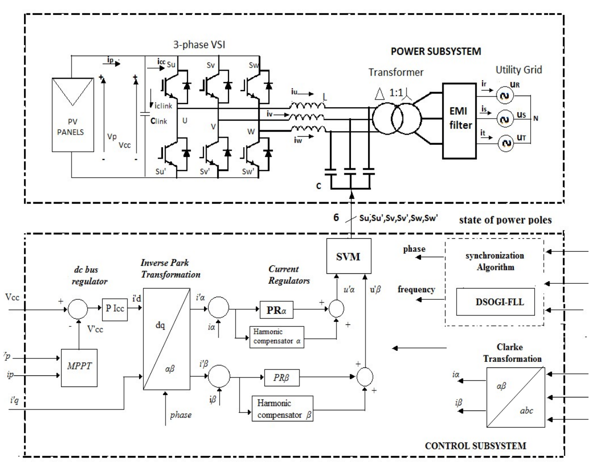

Fig.1.Block diagram ofpower and control Subsystms for a3-phase grid connected photovoltaic system

$$i_{cc} = s_u.i_u + s_v.i_v + s_w.i_w$$

$$i_{clink} = C_{link} \frac{dv_{cc}}{dt}$$

$$P_{PV} = i_p v_p$$

where v_p, i_p are the voltage and the output current of the PV Panels, respectively.

PPV is the available power for a specific irradiance and cell temperature.

v_{cc} is the dc bus voltage,.

i_{clink} is the current through the link capacitor link.

and

i_{cc} is the current delivered to the 3-phase VSI (which is a function of the line currents iu, iv, iw and the states of the power-poles su, sv, sw (1:‘on’, 0:‘off’, si-upper pole, si’-lower pole in the 3-phase VSI).

b) Control subsystem

The control subsystem is formed by the Maximum Power Point Tracking (MPPT) algorithm, the synchronization algorithm, and the outer voltage PI and the inner current PR regulators. The MPPT is an essential algorithm-module of a photovoltaic system for extracting the maximum available power of the PV Panels in order to increase the efficiency of the system .

III. Grid synchronization techniques:

Renewable sources of energy such as solar, wind, and geothermal have gained popularity due to the depletion of conventional energy sources. There are various methods of synchronization of grid. Based on the performance they are categorized as

A) Filtering algorithms:

The major task in synchronizing algorithm is to track the phase angle of the system. The phase angle of the grid voltage can be determined easily by filtering the grid voltages in α-β reference frame or d-q reference frame.

In in α-β reference frame the three phase voltages are transformed into in α-β components and filtering is applied to both α and β components. There are many types of filters discussed in various publications to get the phase angle .They are LPF filter, notch filter, space vector filters etc. However we know that when filters re introduced they produce the delay in the signals which is not acceptable especially in case of grid connected systems. A smaller cut-off frequency results in more distortion in the phase angle which in turn result in slower rate of convergence. The following figure shows a filtering type of synchronization using α-β reference frame.

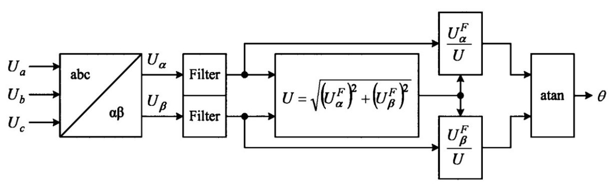

Fig. 1 Synchronization method using filtering on αβ frame.

Filtering techniques in d-q reference frame are easy to design because of the components of voltage are all DC. Even though we have many filtering techniques like LPF, notch and band-stop filters etc. the major disadvantage with the filtering techniques is their bad performance in case of frequency deviations or voltage unbalance conditions. The following diagram represents a filtering technique in d-q reference frame.

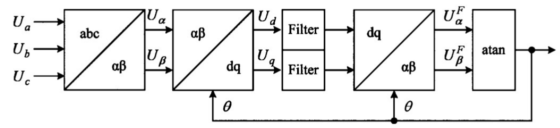

Fig. 2 Synchronization method using filtering on *dq* frame.

B) PLL-Based Techniques:

PLL based synchronization techniques consists of two major parts:

1.The transformation Module

2.PLL controller.

Transformation module will not have any dynamics but PLL controller determine the dynamics of the system. Therefore the band width of the filter determines the filtering performance and ots response .therefore the loop filter performance can influence the quality of locking and overall dynamics .however the performance of these filter is poor under unbalanced conditions. To handle the unbalanced situations there are many improvised techniques like decoupled double synchronous reference frame PLL,DSOGI-PLL etc.

The most basic and important condition for the synchronization poses an inverter that synchronizes with the grid which transfers maximum extracted power to the grid even when phase , frequency and amplitude of grid voltage varies.

Out of the many existing synchronization techniques ANF based techniques have slow adaptive process and used for harmonic detection and it is easy to implement and fast transient response. Also the FLL based synchronization is used for harmonic detection and elimination. And is also reliable for variations in frequency voltage and harmonics.

Here three improved and advanced grid synchronization systems are proposed: the dual second order generalized integrator PLL (DSOGI PLL). Its performance, computational cost, and reliability of the amplitude and phase detection of the positive sequence of the voltage, under unbalanced and distorted situations are expected to be somewhat improved here.

The operating principle of the DSOGI PLL for estimating the positive- and negative-sequence components of the grid voltage vectors is based on using the instantaneous symmetrical Component (ISC) method on the *αβ* stationary reference frame. The ISC method is implemented by the positive-sequence calculation block. To apply the ISC method, it is necessary to have a set of signals, $v_\alpha - v_\beta$, representing the input voltage vector on the *αβ* stationary reference frame together with another set of signals, $qv_\alpha - qv_\beta$, which are in quadrature and lagged with respect to $v_\alpha - v_\beta$. In the DSOGI PLL, the signals to be supplied to the ISC method are obtained by using a dual second order generalized integrator (DSOGI), which is an adaptive band pass filter based on the generalized integrator concept. At its output, the DSOGI provides four signals, namely, v'_α and v'_β which are filtered versions of *vα* and *vβ*, respectively, and qv'_α and qv'_β which are the in-quadrature versions of qv_α and qv_β. A conventional SRF PLL is applied on the estimated positive-sequence voltage vector, $v^+_{\alpha\beta}$ to make this synchronization system frequency adaptive. In particular, the $v^+_{\alpha\beta}$ voltage vector is translated to the rotating SRF, and the signal on the *q*-axis, v^+_q , is applied at the input of the loop controller. As a consequence, the fundamental grid frequency (ω') and the phase angle of the positive-sequence voltage vector (θ') are estimated by this loop. The estimated frequency for the fundamental grid component is fed back to adapt the center frequency ω' of the DSOGI.

IV. DSOGI-FLL Synchronization Algorithm

For the problem that conventional grid synchronization technology cannot implement a three-phase PV grid inverter reliable grid-connection and poor power quality under weak grid conditions, this paper proposes to use the synchronization method based on DSOGI-FLL, which can quickly and accurately synchronize the grid current and voltage. Compared to conventional zero detection synchronization method, the FLL method has a better dynamic performance and easier digital control implementation. The simulation results verify the effectiveness of DSOGI-FLL grid synchronization technique together with fuzzy controller adopted in three-phase PV grid-connected inverter under weak grid condition.

The synchronization algorithm plays a critical role in achieving a controllable power factor in the grid connection. Its primary objective is to accurately detect the phase of the 3-phase utility grid voltages with optimal dynamic response. However, real-world conditions introduce challenges, as the measured signals may be tainted by harmonics, voltage imbalances, and frequency fluctuations. Additionally, inherent inaccuracies in the sensors can introduce second-order harmonics.

The classical dq PLL method, implemented in the synchronous reference frame, is susceptible to disturbances caused by grid voltage imbalances. These imbalances, in turn, lead to the generation of undesirable second-order harmonics in the dc bus voltage. To mitigate this issue, a Positive Sequence Detector (PSD) block, leveraging the symmetrical component method or

Fortescue theorem, is introduced. This PSD+q PLL synchronization algorithm effectively isolates the positive sequence component of the 3-phase utility grid voltages. By doing so, it enhances the synchronization process, ensuring robust performance even in the presence of challenging grid conditions.

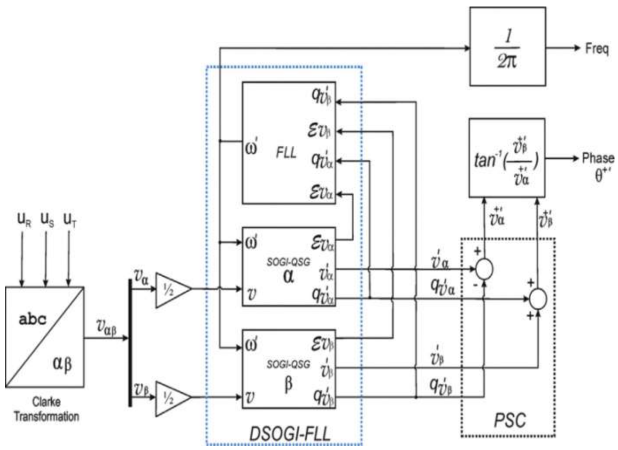

Fig.3.Block diagram of a DSOGI-FLL synchronization algorithm.

The algorithm's performance is contingent on the discrete S90 filter within the PSD block, rendering it susceptible to shifts in the nominal frequency of the utility grid. This sensitivity may result in a degradation of the power factor in the inverter-grid connection. To address this issue, a solution is presented for detecting variations in frequency and phase when voltage imbalances and frequency fluctuations occur in the 3-phase utility grid voltages.

The proposed approach involves the implementation of a Dual Second Order Generalized Integrator FLL (DSOGI-FLL) specifically tailored for the ab voltage components (vab) in the stationary reference frame. Within this framework, in-quadrature signals (90° shifted) for vab are derived through the utilization of two Second Order Generalized Integrators in conjunction with a Quadrature Signal Generation (SOGI-QSG) technique.

By incorporating the DSOGI-FLL and SOGI-QSG components, the algorithm enhances its robustness in the face of varying grid conditions, ultimately mitigating power factor degradation in the inverter-grid connection.

Simulation & results:

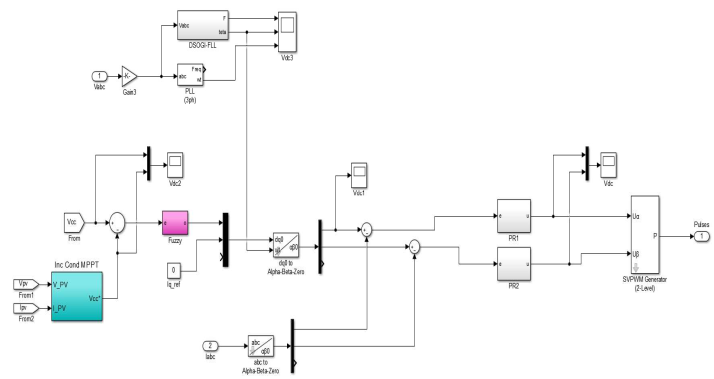

Fig.4.Simulink Model of Grid-connected PV System with fuzzy controller

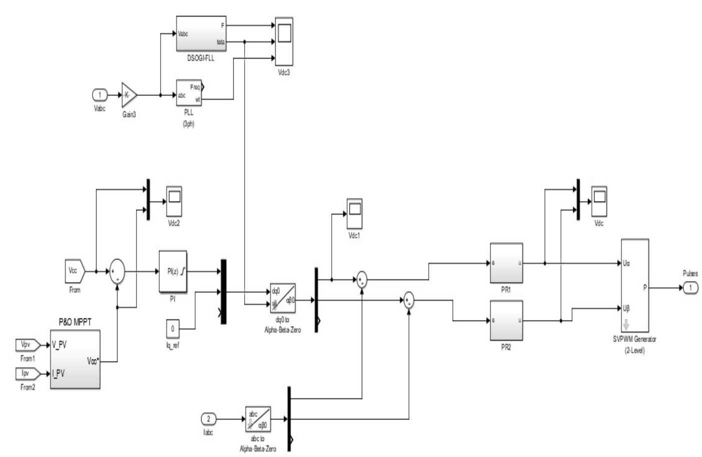

Fig.5.Simulink Model of the DSOGI- FLL synchronization Algorithm

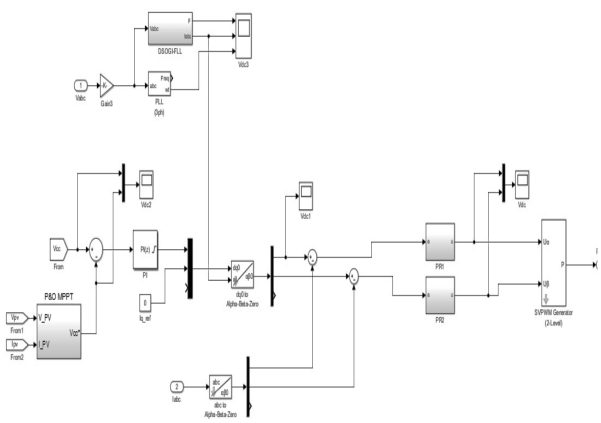

Fig.6.Simulink Model of the FLL structure

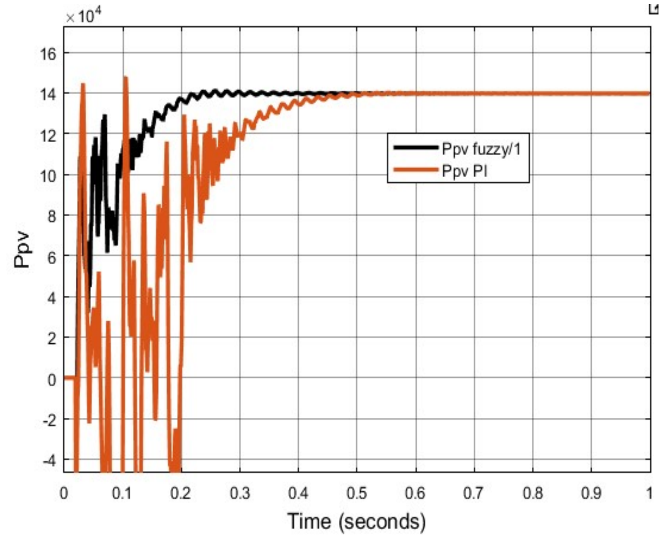

Fig.9.Power extraxted from both PI and Fuzzy controllers

Results

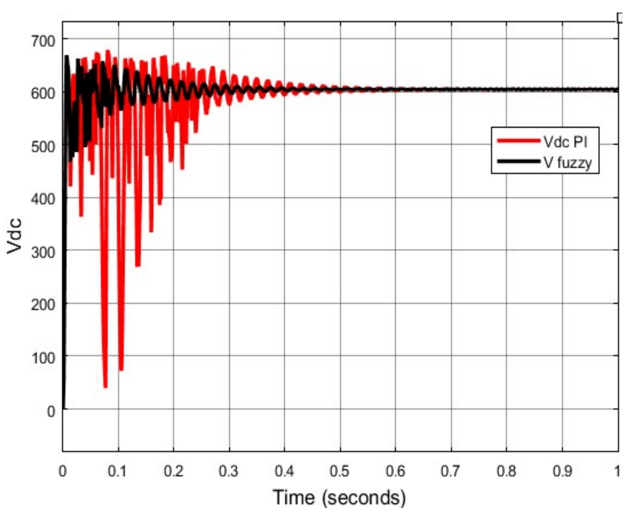

Fig.7. DC voltage extracted from PV

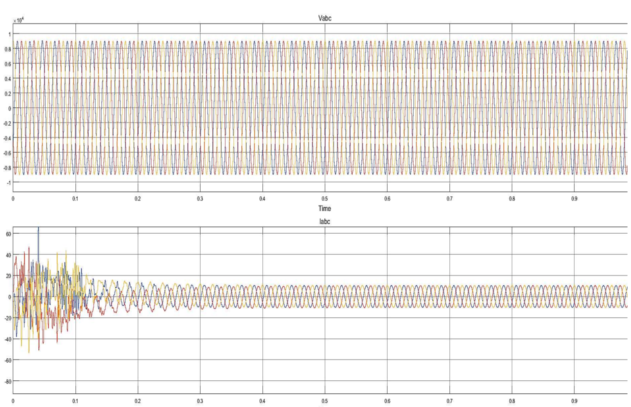

Fig.8. Voltage and current wave forms.

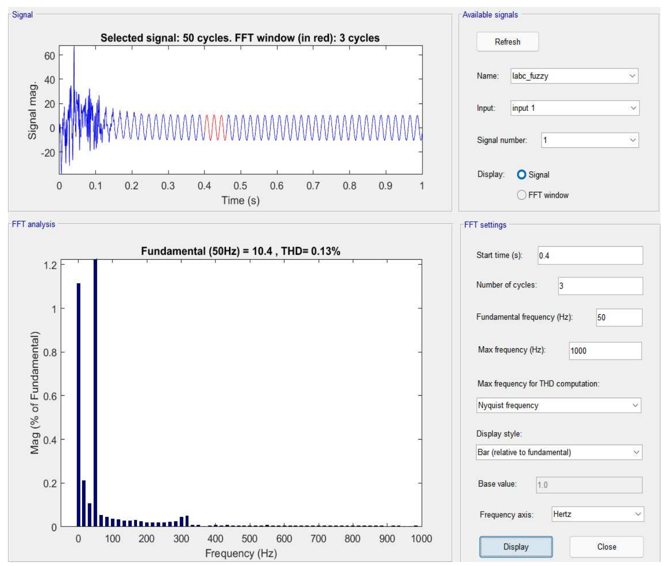

Fig.10. Total Harmonic Distortion with fuzzy controller in normal conditions.

Conclusion :

Here the dc voltage and power extarcted from PV is represented in the results. In which we can made the following conclusions:

1. The ripple content int the dc voltage is reduced.

2. The settling time by using fuzzy controller is reduced compared to traditional PI controller.
3. The percentage of peak overshoot is also reduced when compared with fuzzy controller.
4. The total harmonic Distortion is reduced.

Futher we can implement ANFIS to improve the performance of the PV system.

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