

POWER QUALITY IMPROVEMENT OF SINGLE STAGE GRID INTERFACED SECS USING AN FLC-BASED CONTROL STRATEGY

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Abstract: This study describes an enhanced generalized integrator (GI)-based control with a frequency locked loop for a multifunctional three phase single stage grid interfaced solar energy conversion system (SECS) for power quality (PQ) enhancement of the distribution network under abnormal grid circumstances. The maximum power point tracking (MPPT) approach based on perturb and observe (P&O) is used to acquire peak output from a solar photovoltaic (PV) array under variable meteorological conditions. This control method offers UPF operation, load balancing, harmonics reduction, and reactive power correction. When compared to a standard second order generalized integrator (SOGI) method, the enhanced generalized integrator control algorithm offers greater DC offset and harmonics rejection capabilities. To validate the control system, a fuzzy logic controller is implemented to improve the DC voltage and power quality. The results of the tests demonstrate that the system behaves satisfactorily under steady-state and dynamic operating conditions such as imbalanced load, solar irradiation fluctuation, voltage sag and swell, and distorted voltage grid. THDs (Total Harmonic Distortions) of grid voltages and currents are accomplished within the limits of grid code conformance with IEEE 519 and 1564 standards

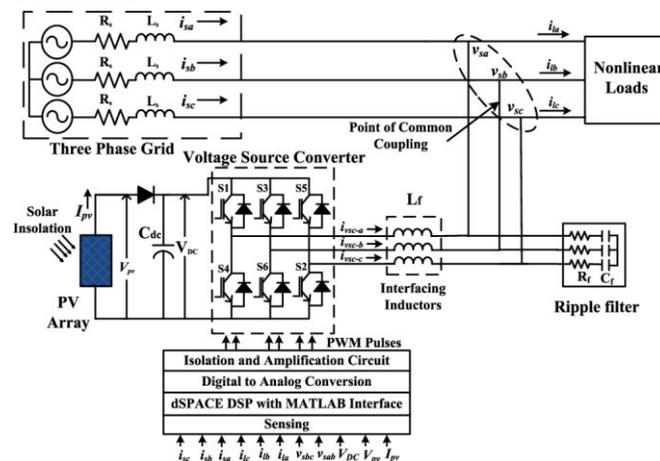
INTRODUCTION:

Nowadays, the usage of fossil fuels is responsible for environmental issues such as green-house gas, acid rain and deteriorates the ozone layer. The natural renewable energy resources such as geothermal energy, tidal energy, solar energy and wind energy etc. are the clean source of energy and less prone to large-scale failure of power generation of conventional methods due to distributed resources. It helps to improve environmental problems. The government has new policies, which provides incentives and subsidies for installation of renewable energy projects [1]. The growing importance has been manifested in solar PV

grid interfaced system, where energy storage device is waived off. For effective implementation of solar PV array, various techniques are described in [2-3]. To acquire crest energy from solar PV array under various environmental conditions, a maximum power point tracking (MPPT) algorithm is utilized. The comparative performance, convergence rate, sensing parameters, applications and cost are analyzed in [4-5] for different MPPT algorithms such as perturb and observe (P&O), fuzzy logic, neural network, incremental conductance, estimated perturb and observe (EPO) etc. The usage of nonlinear loads in energy conversion devices such as electric traction, healthcare equipment, illumination and non-conventional energy systems, has raised the concern of the researchers to maintain power quality (PQ) of the grid.

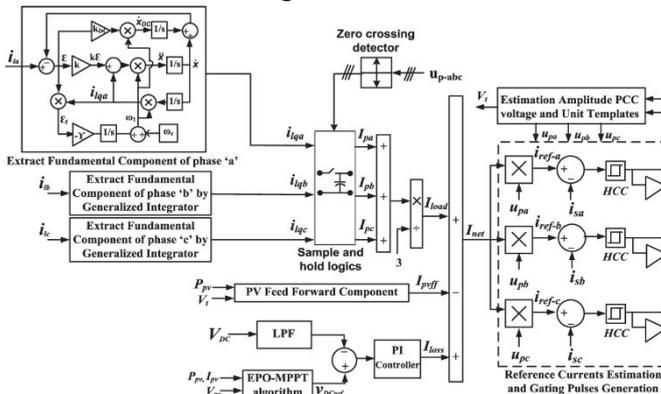
Schematic Diagram:

Figshows the single stage grid interfaced SECS for PQ improvement of the distribution network. This present system consists solar PV array, voltage source converter (VSC), ripple filter, DC link capacitor, interfacing inductor, diode bridge rectifier as load and three phase grid. The design procedure for three phase single stage grid tied SECS is given in the literature [8, 20]. The P&O MPPT algorithm is used to extract crest power from solar PV array under varying atmospheric conditions



CONTROL SCHEME:

Figdemonstrates the block diagram of the control scheme. The control scheme involves the MPPT algorithm and switching pulses generation for the VSC. The P&O technique is adopted to elicit peak power from solar PV array under diverse temperature and insolation. Figshows the control structure of generalized integrator to extract fundamental component. The PV feed-forward term is added into the control algorithm, which helps to reduce oscillations into the grid currents under variation in the solar power generation. The switching algorithm of VSC involves estimation of unit templates, PV feed-forward component, loss component and estimation of the amplitude of a fundamental load current component. The hysteresis current controller (HCC) is used to track reference grid currents.



MPPT Technique :

A P&O technique is utilised to acquire peak power from solar PV array under variable insolation conditions. The maximum power point (Vpv) is perturbed with fixed amount and next perturb is decided based on variation of solar PV array power (Ppv). For effective implementation of the P&O algorithm, changing rate of maximum power point (fMPPT) should not greater than inverse of settling time. The sensing of Ipv and Vpv is realised at higher frequency than updating of Vpv. The fMPPT may execute erroneous since the decision of perturb and observe is decided based on unsettled output as it may destabilize the system. The mathematical implementation of the P&O algorithm is given here.If dPpv/dVpv is higher than zero then it results positive perturb, otherwise it results into negative perturbation. Hence, it can be evident that a well-executed P&O algorithm denoted three levels.

B. Evaluation of Terminal Voltage

The line voltages (vsab and vsbc) are processed via

band pass filter (with tight tolerance value of cut-off frequency range $2 * \pi * 48$ rad/s to $2 * \pi * 52$ rad/s) to eliminate distortions and extract fundament frequency component. The phase voltages (vsa, vsb, and vsc) are estimated from sensed two-line voltages. The phase voltages are evaluated as [20],

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & 1 & 0 \\ -1 & 1 & 0 \\ -1 & -2 & 0 \end{bmatrix} \begin{bmatrix} v_{sab} \\ v_{sbc} \\ 0 \end{bmatrix} \tag{5}$$

The amplitude of terminal voltage (V_t) is evaluated as,

$$V_t = \sqrt{\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)} \tag{6}$$

Estimation of In-Phase Unit Templates

The in-phase unit templates (upa, upb and upc) are determined by taking division of phase voltages (vsa, vsb and vsc) and amplitude of terminal voltage (Vt). The in-phase unit templates are evaluated as [20],

$$u_{pa} = \frac{v_{sa}}{V_t}, u_{pb} = \frac{v_{sb}}{V_t}, u_{pc} = \frac{v_{sc}}{V_t} \tag{7}$$

Evaluation of Active Loss Component

The converter consumes some power as a loss from point of common coupling (PCC) during variation in DC link voltage. The active loss component (Iloss) is available at the output of PI (Proportional Integral) controller, which is used to maintain DC bus voltage. The Iloss is estimated as [20],

$$I_{loss} = (K_p + \frac{K_i}{s})(V_{DCref} - V_{DC}) \tag{8}$$

where, Kp and Ki are proportional and integral constants, which are utilised in the DC link PI voltage controller.

Evaluation of PV Feed-forward Component

The solar PV feed-forward term (Ipvff) is computed from PV power and amplitude of the terminal voltage. The oscillation into the grid currents (isabc) can arise due to deviation in loads at PCC and the solar PV power. A feed-forward term helps to minimize oscillations in isabc by adding feed-forward unit into control algorithm. This Ipvff is estimated as,

$$I_{pvff} = \frac{2P_{pv}}{3V_t} \tag{9}$$

Evaluation of Amplitude of Fundamental Load Component

The conventional generalized integrators provide low DC offset rejection capabilities as available in the literature [13, 15]. The amplitude extraction using conventional algorithms contain oscillations (2 times DC offset), which lead to oscillations in net weight of reference current component (Iload). The shifted quadrature component, leads to erroneous estimation of system frequency, which tracks erroneous fundamental load component. Therefore, a novel control scheme is required to provide good rejection towards DC offset and a fundamental load component without any attenuation. The internal structure of improved second order generalized integrator is shown in Fig. 2. The in-phase and quadrature of fundamental components of load current, are extracted as illustrated in Fig. 2. The fundamental frequency is obtained from improved frequency locked loop, which is demonstrated in Fig. 2. The fundamental frequency is provided to the improved generalized integrator. The gains k and kDC play a vital role to eliminate higher order harmonics and DC offset from the load current. The transfer function of improved SOGI is shown as,

$$\frac{i_{iq}(s)}{i(s)} = \frac{k\omega_1 s^2}{s^3 + (k+k_{DC})\omega_1 s^2 + \omega_1^2 s + k_{DC}\omega_1^3} \quad (10)$$

The fundamental component of the nonlinear load current is obtained as shown in Fig. 2. The ω_c is nominal frequency of the system. The amplitude of a fundamental load component of the nonlinear load current is obtained using the sample and hold (S&H) logics and zero crossing detector (ZCD). The configuration of the ZCD and S&H, are depicted in Fig. 2. The ZCD generates the triggered pulse when input template crosses the zero. The generated pulse is fed to the S&H logics. The S&H logics capture the sample of the input current at instant of the input triggered pulse. The S&H logics are maintained that sample value till next triggered pulse generated by ZCD.

Similarly, for phase ‘b’ and phase ‘c’, the amplitude of a fundamental component of the nonlinear load current, is obtained as shown in Fig. 2.

Stability of the Improved GI Algorithm

The dynamic behavior of improved GI algorithm can be represented by [21],

$$\dot{i}_n + \omega_1^2 i_n = k\omega_1 e \quad (11)$$

$$\dot{\omega}_1 = -\gamma i_n \omega_1 e \quad (12)$$

$$e = i_l - \dot{i}_n - i_{DC} \quad (13)$$

$$\dot{i}_{DC} = k_{DC}\omega_1(i_l - i_n - i_{DC}) \quad (14)$$

where, k is the damping coefficient and its value is higher than zero. γ is higher than zero, which determines adaptation speed. These terms are utilized to trade-off among noise sensitivity and adaptation speed. The estimated system frequency ω_1 reaches the steady-state gradually with respect to its states, when γ is very low value. For, mentioned input signal $i_l = I_p \sin \omega t$, where, ω is actual system frequency. The dynamic system realization by (11-14), has solitary period orbit with constant and true estimated frequency,

$$\text{Orbit} = \begin{pmatrix} \bar{i}_n \\ \dot{\bar{i}}_n \\ \bar{\omega} \end{pmatrix} = \begin{pmatrix} \frac{-I_p}{\omega} \cos(\omega_1 t + \phi_1) \\ I_p \sin(\omega_1 t + \phi_1) \\ \omega_1 \end{pmatrix} \quad (15)$$

The bar (-) represents above variables in (15) realize equilibrium conditions. The stability analysis of improved GI algorithm is represented using state-space representation as,

$$\begin{pmatrix} \dot{x} \\ \ddot{x} \\ \dot{x}_{DC} \end{pmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -\omega_1^2 & -k\omega_1 \\ -\omega_1 k_{DC} & 0 & -\omega_1 k_{DC} \end{bmatrix} \begin{bmatrix} x_{DC} \\ x \\ \dot{x} \end{bmatrix} + \begin{bmatrix} 0 \\ k\omega_1 \\ \omega_1 k_{DC} \end{bmatrix} i_l \quad (16)$$

$$\dot{\omega}_1 = -\gamma\omega_1 x(i_l - \dot{x} - x_{DC}) \quad (17)$$

In view of, a steady-state operating conditions of frequency locked loop, i.e, and then, (16) $\text{rew}=\omega_1$ and $w=0$ can be written as

$$\begin{pmatrix} \dot{x} \\ \ddot{x} \\ x_{DC} \end{pmatrix} = \begin{bmatrix} I_p \sin \omega_1 t \\ I_p \omega_1 \cos \omega_1 t \\ I_{DC} \end{bmatrix} \quad (18)$$

Even if frequency estimation by improved GI algorithm is locked deliberately at distinct value from the system frequency, still it’s would keep a stable orbit as,

$$\begin{pmatrix} \dot{x} \\ \ddot{x} \end{pmatrix} = I(\omega) \begin{bmatrix} \sin(\omega t + \varphi) \\ \omega \cos(\omega t + \varphi) \end{bmatrix} \tag{19}$$

where, $I(\omega) = I_p \frac{k\omega\omega_1}{\sqrt{(\omega_1^2 - \omega^2)^2 + k^2\omega^2\omega_1^2}}$ and

$$\varphi = \arctan\left(\frac{-k\omega\omega_1}{\omega_1^2 - \omega^2}\right)$$

From (19), it is manifested that improved GI algorithm keeps the subsequent steady-state alliance of and , when as , described as, $x \times 1 \text{ w}\#w1$

$$\ddot{x} = -\omega^2 x \tag{20}$$

Using (20), the steady-state error, (the subtraction between i and \dot{x}, x_{DC}) can be described as,

$$e = i_i - \dot{x} - x_{DC} = \frac{1}{k\omega_1} (\ddot{x} + \omega_1^2 x) \tag{21}$$

In steady-state condition, frequency error is expressed using (20) and (21) as,

$$e_f = x\omega_1 e = \frac{x^2}{k} (\omega_1^2 - \omega^2)$$

Therefore, (22) confirms that the signal e_f conveys information of the frequency error and hence used to estimate the system frequency.

Now, local stability analysis can be expressed by assuming that approximates to In this condition, the dynamics of improved GI algorithm, is represented as,

$$\dot{\omega}_1 = -\gamma e_f \tag{23}$$

$$\dot{\omega}_1 = -\gamma \frac{x^2}{k} (\omega_1^2 - \omega^2) \tag{24}$$

$$\dot{\omega}_1 = -2\gamma \frac{x^2}{k} (\omega - \omega_1)\omega_1 \tag{25}$$

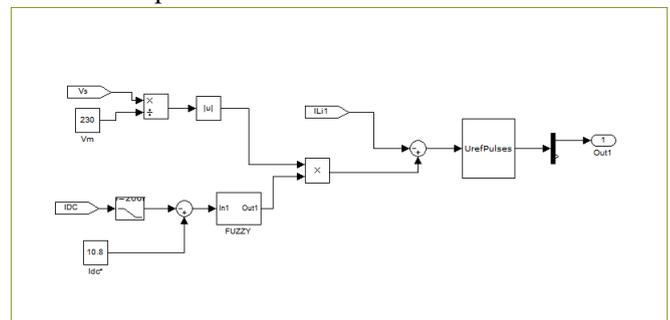
Define the frequency estimation error as and its derivative under constant system frequency is expressed by Therefore, the condition given by (26), permanently hold correct for positive value of evaluated system frequency, which is crucial for local stability.

$$\delta\dot{\delta} = -\frac{2\gamma}{k} x^2 \delta^2 \omega_1 \leq 0 \tag{26}$$

PROPOSED SYSTEM:

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give

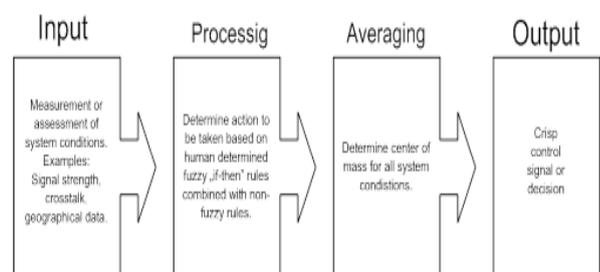
results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This paper contains a basic overview of the principles of fuzzy logic. Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. Undoubtedly, today’s advanced computer technology makes it possible; however, managing such systems is still too complex.



The fuzzy logic analysis and control methods shown in Figure can be described as:

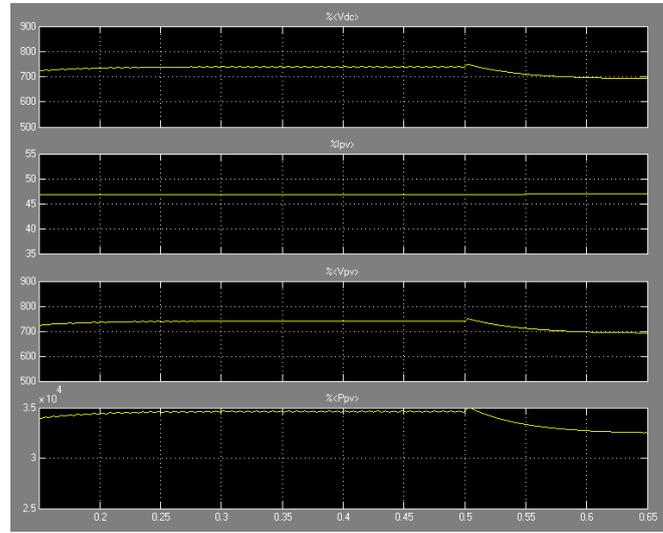
1. Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
2. Processing all received inputs according to human based, fuzzy "if-then" rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
3. Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value.

The following is Fuzzy Logic Control/Analysis Method diagram.

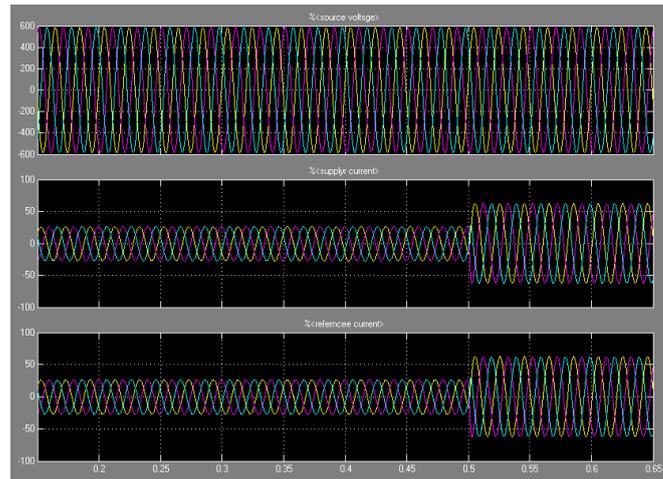


STIMULATION RESULTS:

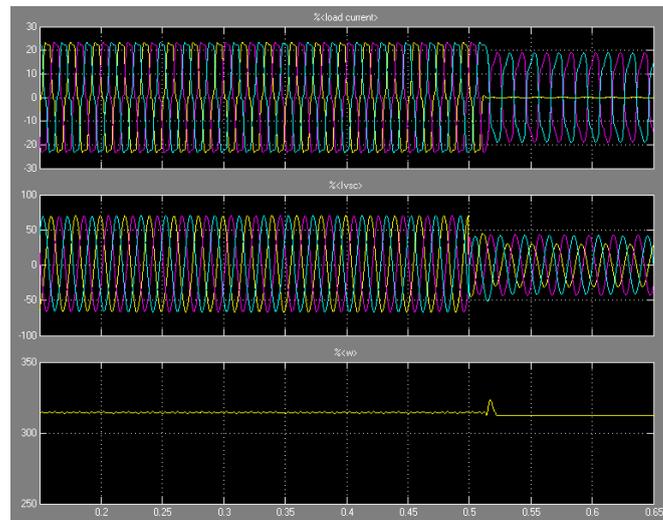
Fig Simulation results of system under load unbalancing (a) VDC, I_{pv} , V_{pv} , P_{pv} , P_s , Q_s (b) v_{sabc} , i_{sabc} , i_{ref} , i_{la} , i_{vsc} , ω



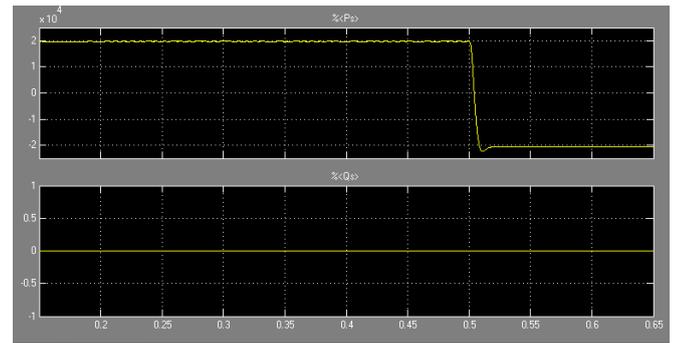
A



B



Active power & reactive power



Id&Iq

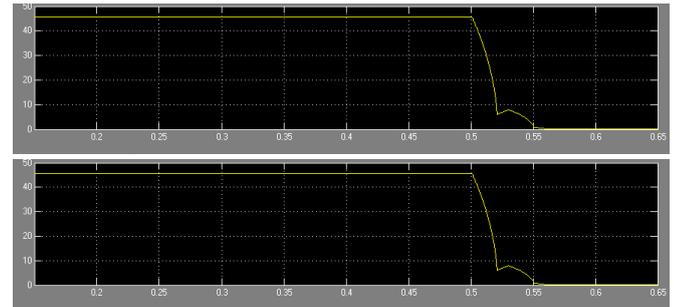
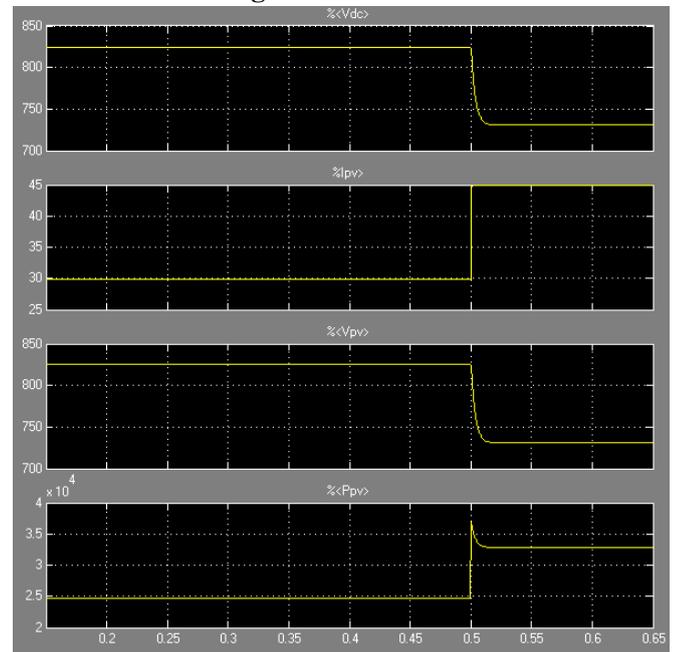
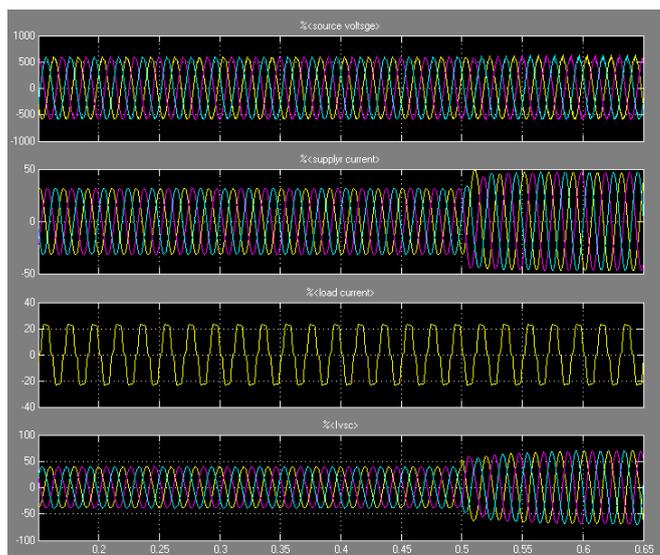


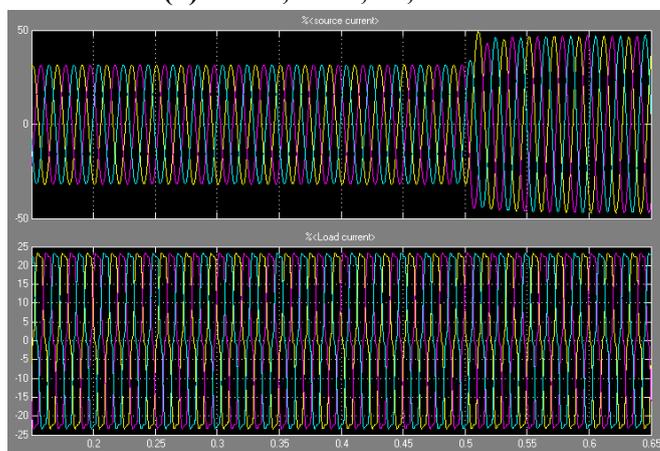
Fig Performance of system with and without feed-forward component (a) G , VDC , I_{pv} , P_{pv} (b) v_{sabc} , i_{sabc} , i_{la} , i_{vsc} (c) G , VDC , I_{pv} , P_{pv} (d) v_{sabc} , i_{sabc} , i_{la} , i_{vsc} (e) Comparative performance of proposed improved GI with CCF-SOGI-PLL algorithm.



(a) G , VDC , I_{pv} , P_{pv}



(b) vsabc, isabc, ila, ivsc



CONCLUSION:

A novel control technique for a single stage three phase grid interfaced solar energy conversion system has been presented. The suggested control strategy has fulfilled a variety of purposes for distribution system PQ improvement, including load balancing, power factor correction, reactive power compensation, and harmonics minimization. Even with voltage sag and swell, the control algorithm efficiently extracted the magnitude of the load basic component. The effectiveness of traditional SOGI and SOGI-Q algorithms in comparing frequency domain analysis of amplitude extraction performance of fundamental load current has been proven. The DC voltage regulation and power quality improvement is much better with Fuzzy logic controller compared with conventional PI controller. The simulation findings demonstrated effective performance under a variety of dynamic test circumstances, including voltage swell and voltage sag, reactive power, and temperature.

Unbalanced load and requirement the grid THDs Voltages-currents are obtained within limits set by Grid code conformity with IEEE-519 and 1564 standards.

REFERENCES:

- [1] Yoshihiro Yamamoto, "Feed-in tariffs combined with capital subsidies for promoting the adoption of residential photovoltaic systems," *Energy Policy*, vol. 111, pp. 312-320, 2017.
- [2] S. Shongwe and M. Hanif, "Comparative Analysis of Different Single- Diode PV Modeling Methods," *IEEE Journal of Photovoltaics*, vol. 5, no. 3, pp. 938-946, May 2015.
- [3] M. G. Villalva, J. R. Gazoli and E. R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," *IEEE Transactions Power Electronics*, vol. 24, no. 5, pp. 1198-1208, May 2009.
- [4] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," *IEEE Transactions Sustainable Energy*, vol. 4, no. 1, pp. 89-98, Jan. 2013.
- [5] Puneet Joshi and Sudha Arora, "Maximum power point tracking methodologies for solar PV systems – A review," *Renewable and Sustainable Energy Reviews*, vol. 70, pp.1154-1177, 2017.
- [6] H. Zhao, T. Jin, S. Wang and L. Sun, "A real-time selective harmonic elimination based on a transient-free inner closed-loop control for cascaded multilevel inverters," *IEEE Transactions Power Electronics*, vol. 31, no. 2, pp. 1000-1014, Feb. 2016.
- [7] K. K. Shyu, M. J. Yang, Y. M. Chen and Y. F. Lin, "Model reference adaptive control design for a shunt active-power-filter system," *IEEE Transactions Industrial Electronics*, vol. 55, no. 1, pp. 97-106, Jan. 2008.
- [8] R. Agarwal, I. Hussain and B. Singh, "LMF-based control algorithm for single stage three-phase grid integrated solar PV system," *IEEE Trans. Sustainable Energy*, vol. 7, no. 4, pp. 1379-1387, Oct. 2016.
- [9] S. A. George and F. M. Chacko, "Comparison of different control methods for an integrated system of MPPT powered PV module and STATCOM," in *Proc. IEEE International Conference on Renewable Energy and Sustainable Energy (ICRESE)*, Coimbatore, pp. 207-212, 2013.