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Neuro-Fuzzy Grid-tied PV system with Active Power Filter for Power Quality Enhancement

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ABSTRACT

Generally, electric power system operators have seen photovoltaic (PV) power systems as potential sources of problems due to intermittency and lack of controllability. However, the flexibility of power electronic inverters allows PV to provide grid-friendly features including volt-VAR control, ramp-rate control, high-frequency power curtailment, and event ride-through. Commercially available smart PV inverters can further provide frequency down-regulation by curtailing power, but they are unable to provide true frequency regulation through active power control (APC) because they are unable to increase power on command. A coordinated DC-link voltage control and deloading control for two-stage PV system to offer frequency support in an islanded microgrid without energy storage system (ESS) is implemented. ANFIS based PV inverter control is developed for very fast and accurate control of active power.

KEYWORDS— Photovoltaic (PV) system, Active power filter (APF), Fuzzy logic proportional–integrator and ANN Controller

INTRODUCTION

Power supply and power quality have been critical issues in power system recently. The grid-connected photovoltaic (PV) generator has nowadays become more popular because of its reliable performance and its ability to generate power from clean energy resources. The dc output voltage of PV arrays is connected to a dc/dc boost converter using a maximum power point tracking (MPPT) controller to maximize their produced energy. Then, that converter is linked to a dc/ac voltage source converter (VSC) to let the PV system push electric power to the ac utility. The local load of the PV system can specially be a non- linear load, such as computers, compact fluorescent lamps, and many other home appliances, that requires distorted currents. Development of a means to compensate the distribution system harmonics is equally urgent. In this case, PV generators should provide the utility with distorted compensation capability, which makes currents injected/absorbed by the utility to be sinusoidal. Therefore, the harmonic compensation function can be realized through flexible control of dc/ac VSC. Instantaneous power theory has successfully completed active power filter (APF) designing with good performance. However, the PV-APF combination has just been gradually developed for several years. This combination is capable of simultaneously compensating power factor, current imbalance, and current harmonics, and also of injecting the energy generated by PV with low total harmonic distortion (THD). Even when there is no energy available from PV, the combination can still operate to enhance the power quality of the utility. To the best of our knowledge, this idea was initiated in 1996 by Kim *et al.*. In this study, the PV system needs energy storage elements, which negatively increase the entire cost. Besides, the mathematical demonstration was not sufficiently provided. After that, the control techniques have been improved in some later efforts to develop PV inverters with real power injection and APF features. However, their research did not show consistent results obtained by their proposed theories, and they are applicable for a single-phase PV only. The most recent completely released paper in 2013 uses current references as the main functions of the dc/ac controller, which coincides with the basic ideas of this paper. By another manner in this paper, the proposed PV-APF controller utilizing power references shows some significant improvements in theory and a simple control topology. The PV-APF system helps the utility supply a unity power factor and pure sinusoidal currents to the local nonlinear loads by generating the oscillating and imaginary components. When there is an excess power, that PV unit will only inject average power to the utility. As a result, this system can be considered as a distributed APF, which is a better solution than adopting passive filters or centralized APFs.

To avoid the shortcomings, few adaptive reference current generation techniques have been implemented for grid-tied renewable energy systems. Considering the voltage distortion and unbalance grid conditions, pure sinusoidal signals injection into the utility grid is necessary. To bypass the cited work limitations, an adaptive hybrid control technique is employed based on the reference current generator, fundamental constituent extraction (FCE) of distorted grid voltages and dc-link bus controller. The multiple second-order generalized integrator frequency-locked loop (MSOGI-FLL) control scheme is executed to separate the FCs from three-phase load currents. Additionally, an MCCF is executed to take out the FCs from the extremely deformed grid voltages. Moreover, it is also used for grid synchronization. In addition, fuzzy tuned proportional–integral–differential (PID) adaptive dc-link voltage controller is absorbed in the suggested control scheme to keeping the balanced power between dc and ac sides by regulating the dc bus voltage constant.

Photovoltaic System:

Photovoltaic system is one of the energy source in renewable family, as compared to all DG systems it play a key role in the present power generation systems because of it freely available in environment and its durability. The PV system converts sun irradiance into electrical current with photon effect. This current is converted into electrical voltage with the help of solar electrical equivalent circuit [5] as shown in figure 2. And a DC-DC MPPT converter is used to extract maximum output from the solar system. The structure of solar system is shown in figure 1.

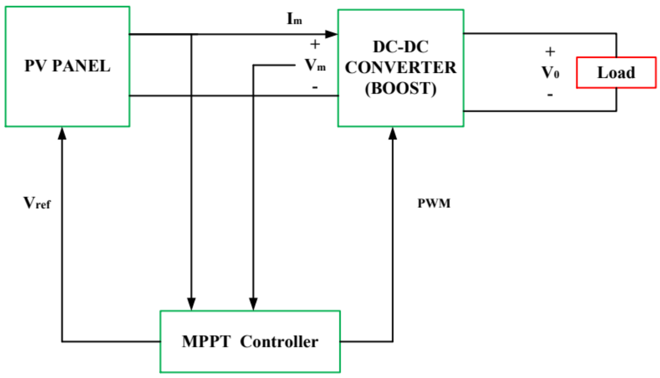

Figure 1: Structure of Solar Energy System

The expression for Photovoltaic system current

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_o[e^{(\frac{qV_D}{nKT})}] - (\frac{V_D}{R_s})$$

The structure of closed loop control diagram from dc-dc converter using MPPT technique is shown in figure 2 [6]. Here, the reference signal obtained from MPPT is compared with PV system voltage and applied to PWM converter to generate duty cycle required for dc-dc converter.

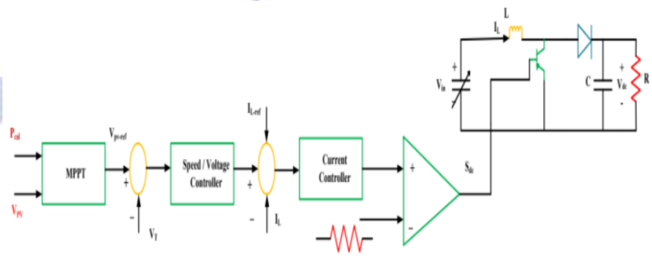

Figure 2: MPPT based PWM controller for DC-DC converter

PROPOSED SYSTEM:

The configuration of the three-phase grid-connected inverter for the grid-connected and islanding operations is shown in Figure 3. The power circuit contains a microsource such as photovoltaic panels and fuel cells represented by the dc source, a three-phase pulse width modulation (PWM) inverter, a three phase sensitive load connected to the output of the LCL filter, a static transfer switch (STS) for grid-on or grid-off control, and an LCL filter with a damping resistor. An LCL filter is used instead of an L filter, as it can provide higher high-frequency harmonic attenuation with the same inductance value. However, a system with an LCL filter has an inherent high-resonant peak at the resonant frequency of the LCL filter, which would make the current control system unstable. To avoid this stability problem, various active damping approaches for PI-based current control of a grid-connected inverter with an LCL filter are proposed by using additional feedback or by adjusting the ratio of the control frequency and resonance frequency of the LCL filter. Several active damping strategies for LCL filters are suggested.

In this paper, a passive damping method with a damping resistor is used as shown in Figure 3. The control system consists of a grid current control for grid-connected operation, and a load voltage control for islanding operation. The outputs of the d–q grid current controllers are connected to those of the d–q load voltage controllers, in order to prevent a sudden change of the outputs of both controllers at the mode transfer instant. In [2], the outputs of both the current and voltage controllers are connected together at a single-phase grid-connected inverter. However, because the outputs of both controllers are ac voltages, the phase between the two outputs should be matched.

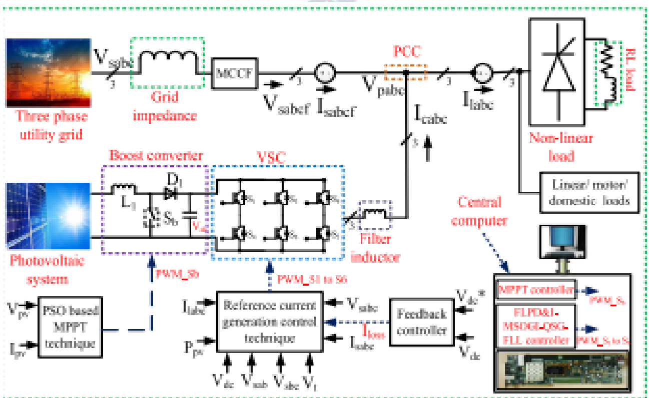

Figure 3: Proposed PV System using APC

CONTROL DIAGRAM:

The V_{PV}voltage controller regulates the PV voltage by sending the d-axis current command, *id*, as in [4]. The inverter's output current is controlled in the DC-AC controller block using sinusoidal pulse-width modulation (PWM) with independent proportional-integral (PI) control on the d-axis and q-axis currents in the rotating synchronous (dq) reference frame, as in [4]. Reactive power output can be controlled separately by regulating the q-axis current command *iq* in the voltage regulation block, but that is not the focus here.

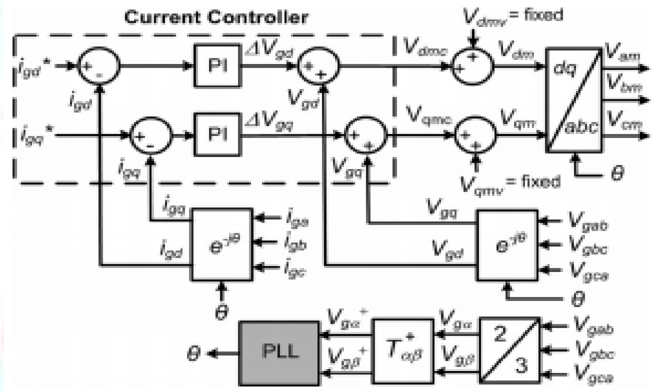

Figure 4: Control Structure for PV Inverter

ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM:

The ANFIS is one of the important controller in adaptive techniques. This section provides the information regarding the designing of neuro-fuzzy controller. These neural network controller consists of two inputs that are Δe and Δde and it has one output that is f ∈ {Δe, Δde}. Each input consists of 5 membership functions. Figure 7 shows the configuration of ANFIS for a mamdani type and it has two input and one output.

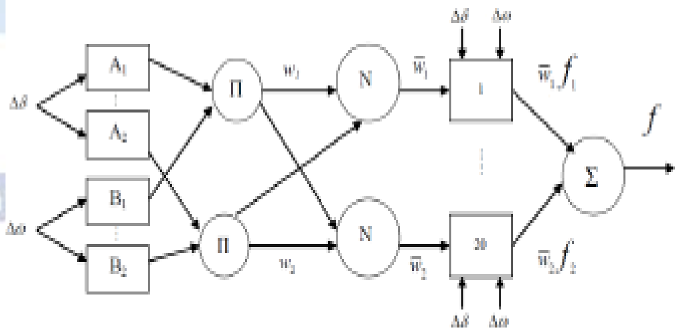

Fig 5: ANFIS architecture

According to Figure 5, it is a mamdani based fuzzy controller with two inputs and one output and the rules are formed according to if-then statements.

μAi and μBi are the membership functions of memberships with the fuzzy sets and these inputs are related with the operator logical AND. The hybrid learning algorithms are implemented for obtaining the values of system parameters. These learning algorithms is a function of linear and non-linear parameters. These explanations are implemented in Matlab/Simulink software.

Algorithm for Neuro Controller:

1. Assume the inputs and outputs in the normalized form with respect to their maximum values and these are in the range of 0-1.
2. Assure the No.of input stages given network.
3. Indicate the No.of hidden layers for the network.
4. Design the new feed forward network based on the system parameters 'transig' and 'poslin'.
5. Assume the learning rate be 0.02 for the given network.
6. Identify the number of iterations for the system.
7. Enter the goal.
8. Train the network based on the given input and outputs.
9. For the given network Generate simulation with a command 'genism'

Fuzzy Controller:

In control strategy based on PI controller is discussed. But in case of PI controller, it has high settling time and has large steady state error. In order to rectify this problem, this paper proposes the application of a fuzzy logic controller (FLC) shown in figure 6. Generally, the FLC is one of the most important software based technique in adaptive methods [15].

As compared with previous controllers, the FLC has low settling time, low steady state errors. The operation of fuzzy controller can be explained in four steps.

1. Fuzzification
2. Membership function
3. Rule-base formation
4. Defuzzification.

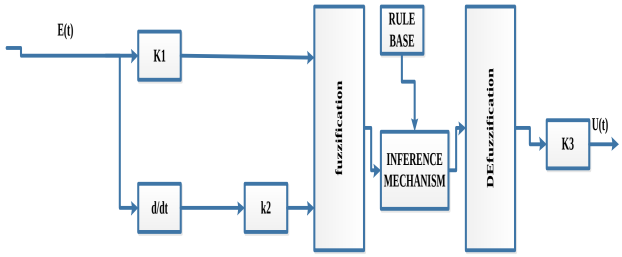

Fig 6: Configuration of Fuzzy Inference System

RESULTS AND DISCUSSIONS:

The model of the proposed control scenario is developed on MATLAB/Simulink platform. The proposed system is implemented on several conditions, such as steady state, dynamic load, load removed, grid voltage unbalanced, variable solar irradiation level, and distorted grid voltage conditions.

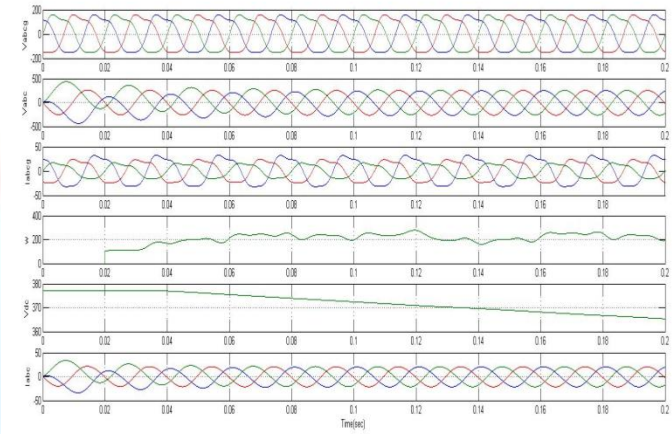

Figure 5: Simulation characteristics under polluted grid voltage condition

Figure 5 shows that the system is running under balanced supply voltage, load removed, and dynamic load conditions. From 0 to 0.08 s shows the grid balanced supply voltage condition. To examining the controller dynamic performance, phase "a" load is removed, which is shown in Figure 5 from 0.08 to 0.15 s. During 0.15–0.2 s, the proposed system is working under dynamic load condition.

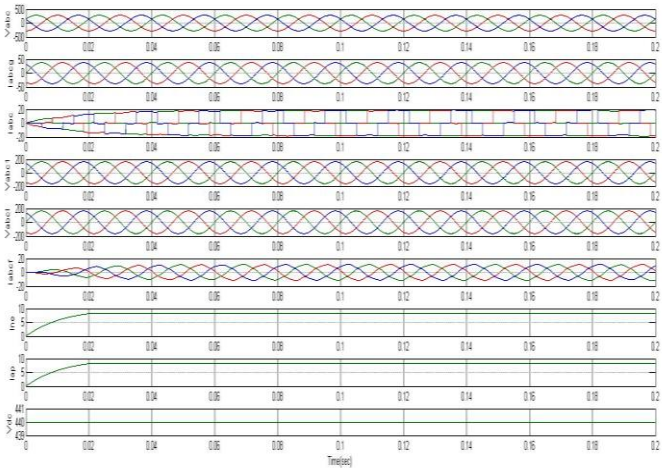

Figure 6: Simulation Results under Unbalanced Grid Voltages State Condition

To verify the potency of the hybrid control technique under grid transient conditions, the system is working under grid unstable voltages state. The grid and controller performance characteristics are included in Figure 6.

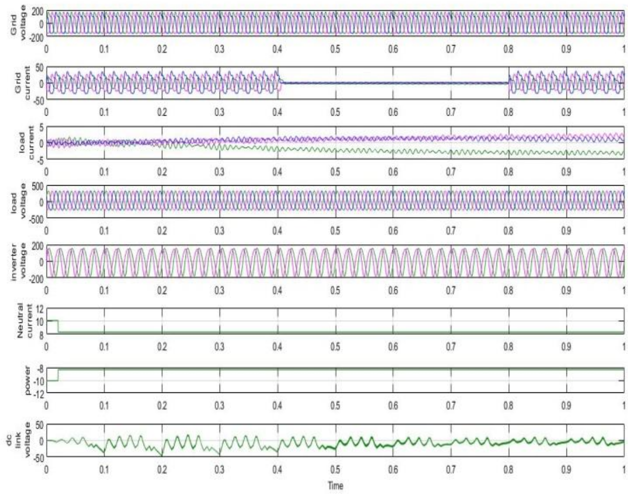

Figure 7: Simulation Results under Steady State, Load Removed, And Dynamic Load Conditions

Figure 7 shows the operation of the system under distorted grid voltages condition. In this condition, the MCCF is employed to take out the FCs from the extremely polluted grid voltages.

Table 1: Comparison of THD Values between PI and ANFIS Controller

S.NO	CONDITION OF THE SYSTEM	THD VALUE OF CURRENT WITH PI CONTROLLER	THD VALUE OF CURRENT WITH ANFIS CONTOLLER
1.	NON-LINEAR LOAD	5.03	2.83
2.	UNBALANCED LOAD	4.09	2.36
3.	IRRADIANCE	4.71	2.36

CONCLUSION:

Upon observing the negative consequences of harmonics presented into the transmission system, an APF with proposed FLPID-MCCF-MSOGI-FLL and ANFIS reference current generation scheme has been underlined in this article. To destroy the voltage and current harmonics in a grid-tied PV system, the APF along with adaptive current control technique is an optimal solution that results in a pollution-free power at the end users. The anfis reference current controller is used for APF to compute three-phase reference currents. The FLPID feedback controller is employed to maintain constant the voltage of the dc bus without any ripple at dc bus terminals. The MCCF is executed to eliminate the voltage harmonics from highly polluted grid voltages. The simulated outcomes of the proposed control strategy are found satisfactory and the THD of grid voltages and currents are maintained well within limits of IEEE-519 standard.

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