# A Universal Active Filter Design Based on Discrete Adaptive Filter Control

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***Abstract-*** Whenever a photovoltaic system is properly interfaced with power grid, there are many power quality issues that need to be taken care-off. So, additional power control equipment needs to be interfaced with PV-Array, especially FACTS devices which are efficient modes to control power. In this study, Universal Active Power Filter and Compensator (UAPF&C) is used as power flow controller for PV-Array systems. The system under study is composed of series and shunt inverters connected back to back by a DC-link to which PV-array is synced. It compensates the voltage and current issues in inter-connected mode and islanding mode by injecting active power to grid. This system is tested in simulation environment for proofs of its ability to reduce the amount of power impurities.

Keywords**-** *Universal Active Power Filter and Compensator (UAPF&C), PV (photovoltaic) Array, Power Quality*

## I. INTRODUCTION

There has been an ever increasing focus on installation of renewable energy sources such as solar photovoltaic and wind energy systems with the grid [1]. This has been facilitated due to development of reliable and efficient power electronics, improved efficiency of PV panels and decreasing costs of manufacturing. However, with the increasing penetration of renewable energy sources which are intermittent sources of energy, fluctuations in voltage at the point of common coupling (PCC) has also increased. This is particularly common in low voltage distribution systems. Another major issue faced in modern distribution systems is the extensive use of non-linear power electronic systems which draw highly distorted currents. These distorted currents may cause voltage distortion at PCC depending upon the magnitude of current and grid impedance [2]. These loads also cause losses in feeders and distribution transformers. Moreover, these loads themselves are sensitive to PCC voltage dip/rise which causes frequent tripping and increased maintenance costs. Hence, the major requirement of modern distribution system is the integration of renewable energy systems along with power quality improvement. Recently, there has been increasing focus on multi-functional renewable energy systems which can provide both clean energy as well as compensate the power quality issues arising from load side and PCC side. A solar photovoltaic integrated distribution static compensator has been shown in [3]. This system has dual role of generation of power from renewable sources along with compensation of load current harmonics generated due to nonlinear loads. A single phase multi-functional solar energy conversion system has been proposed in [4]. This system combined clean energy generation and active filtering functionality for a single phase distribution system. A variable DC-link voltage grid interfaced converter for three phase supply systems has been proposed in [5]. This system apart from combining clean energy generation and active filtering has an adjustable DC-link voltage. The DC-link voltage is adjusted based on voltage at point of common coupling which leads to improved efficiency and good harmonic compensation of load current.

## II. UNIVERSAL ACTIVE POWER FILTER AND COMPENSATOR (UAPF&C)

UAPF system has two shunt and series voltage source inverters which are as 3-phase 3-wire or 3-phase 4-wire. Shunt inverter is connected to point of common coupling (PCC) by shunt transformer and series inverter stands between source and coupling point by series transformer. Shunt inverter operates as current source and series inverter operates as volt-age source. UAPF is designed for compensation of current harmonics, to compensate reactive power levels, voltage alterations and can recompense voltage disruption because of having PV-array as a source. The controlling design of proposed system is composed of three following parts:

- Shunt inverter control
- Series inverter control
- DC/DC converter

Controlling strategy is designed and applied for two interconnected and islanding modes. In inter-connected mode, source and PV provide the load power together while in islanding mode; PV transfers the power to the load lonely. By removing voltage interruption, system returns to interconnected mode.

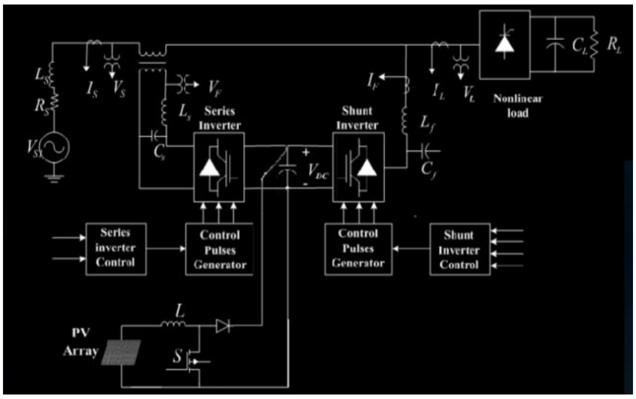

Fig 1- Configuration of UAPF with PV

(i) Shunt inverter control:
Shunt inverter undertakes two main duties:

1. Compensating both current harmonics generated by non-linear load and reactive power
2. Injecting active power generated by PV system.

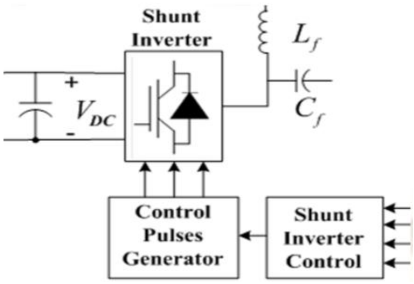

Fig- shunt inverter control

Shunt inverter control estimates compensation current for current harmonics and reactive Power when PV is out of the grid. The power loss caused by inverter operation should be considered in this calculation. It has the ability of stabilizing DC-link voltage during shunt inverter operation to compensate voltage distortions. The stabilization is maintained by DC-link capacitor voltage controlling loop in which P.I. controller is applied.

## III. SYSTEM DESIGN AND SIMULATION

a) Shunt inverter control- Interconnected mode:

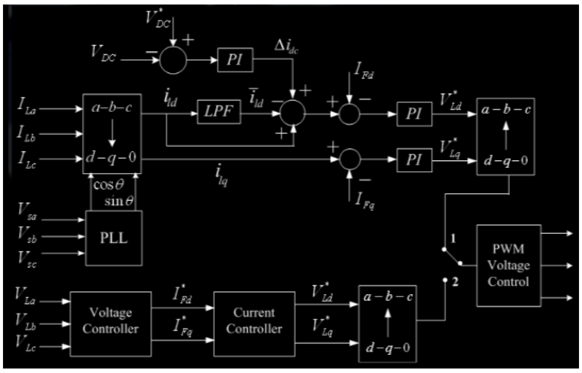

Fig 2- Shunt inverter control- Interconnected mode

The control diagram for simulation in this mode is shown above for UAPF&C shunt voltage source inverter controlling block diagram to which Synchronous reference frame theory then is applied by extracting the sensitive load currents as $I_{LA}$, $I_{LB}$, $I_{LC}$. When unbalance condition occurs in each phase, the stationary values are changed as +ve, −ve & '0' sequences. So, exact analysis is difficult to achieve. So the measured load currents applying synchronous reference frame conversion method (dq0) or parks transformation are transferred to dq0 frame using sinusoidal functions, i.e., frequency and phase angle of the converted load currents are determined. This function is obtained by PLL by taking source side voltages $V_{SA}$, $V_{SB}$, $V_{SC}$ as reference, which provides to maintain the synchronism with supply voltage and current.

The direct & quadrature axis currents are:

$$I_{ldq0} = T_{abc}^{dq0} I_{abc}$$
$$I_d = i_a \cos 0 + i_b \cos 120 + i_c \cos 240$$
$$I_q = i_a \sin 0 + i_b \sin 120 + i_c \sin 240$$
$$T_{abc}^{dq0} = \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix}$$

The reference currents will transfer to ABC frame by reverse converting the Synchronous reference frame. Resulted reference currents will be compared with shunt inverter Output currents ($I_{fa}$, $I_{fb}$, $I_{fc}$) in a PWM current controller and required controlling pulses are generated. Applying these signals to shunt inverter power switches gate, required compensation current is generated by inverter.

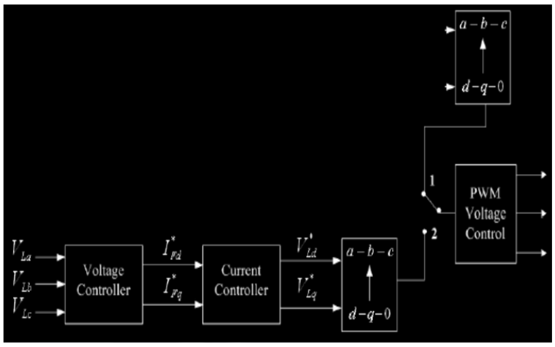

Fig 3- Shunt inverter control- Islanding Mode

b) Shunt inverter control- Islanding Mode:

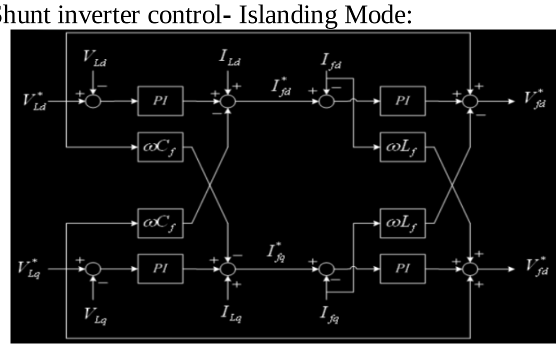

Fig 4– Controlling of shunt inverter in islanding mode

Shunt inverter control should inject active power of PV system to control when PV is operating. If the voltage interruption occurs at load, that exceeds a threshold value, the inverter operation will switch from interconnected mode to islanding mode. PV system provides required active power to stabilize load voltage. In this case, shunt inverter controls output voltage and current in order to inject to load using PI controller. This reduces steady state error and maintains constant power. In voltage control current is considered as leading (capacitive load) and corresponding d-q currents are obtained as output as shown below:

$$I_{fd}^{*} = K_{PI}\,(V_{ld}^{*} - V_{ld}) - \omega C_f V_{lq} + I_{ld}$$
$$I_{fq}^{*} = K_{PI}\,(V_{lq}^{*} - V_{lq}) - \omega C_f V_{ld} + I_{lq}$$

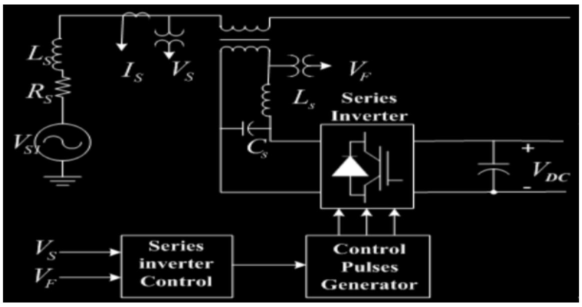


Fig 5– series inverter block diagram

c) Series inverter controlling

The duty of the series inverter is to compensate the voltage disturbance in the source side, grid which is due to the fault in the distribution line. Series inverter control calculates the voltage reference values which are injected to grid by series inverter. In order to control series inverter of UAPF, load sinusoidal voltage controlling strategy is shown in figure above. Here, series inverter would be controlled in a way that it compensates the whole distortions and helps the voltage of load voltage stay balanced in sinusoidal 3-phase. In order to reach this aim synchronous reference frame theory is applied. In this method only d-axis component is being controlled i.e., active power component. By compensating the active power component, reactive power component will be compensated automatically. In this method the desired value of load phase voltage is replaced in d and q-axis. The load voltage should be kept sinusoidal with constant amplitude even if the voltage on system side is disturbed.

$$V_{idq0}^{*} = T_{abc}^{dq0} V_{labc}^{*}$$
$$= \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \begin{bmatrix} V_m \cos(\omega t + \theta) \\ V_m \cos(\omega t + \theta - 120) \\ V_m \cos(\omega t + \theta + 120) \end{bmatrix}$$

$$V_{idq0}^{*} = \begin{bmatrix} V_m \\ 0 \\ 0 \end{bmatrix}$$

d) PV-Array

A solar cell basically is a p-n semi-conductor junction which is made of several poly-crystalline silicon cells. At junction electrons from the sides mix and form a barrier, making it hard for electrons on the N-side to cross to the P-side. Eventually equilibrium is reached, and an electric field separates the sides. The P&O algorithm is used to trace the MPPT of PV system, where it reads the value of current and voltage from PV-array module. Power is calculated from the measured voltage and current.

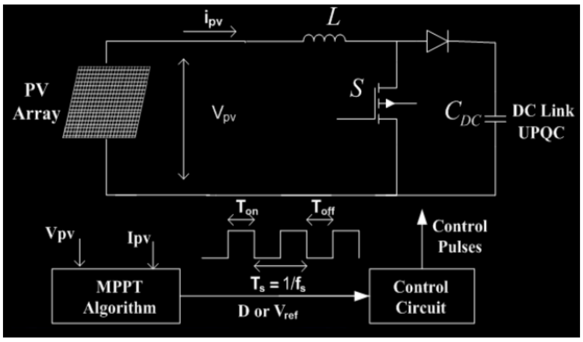


Fig 6- Circuit of PV-array

## IV. RESULTS AND DISCUSSION

In simulation, power system is modelled as a 3-wired 3-phase system by an RC load with uncontrolled diode rectifier. The PV model applied in simulation whose parameters are regulated for normal condition (25°c temp & sun radiation) Circuit parameters used in simulation are located in Table 1. The maximum simulation time is regulated on 600msec. Shunt inverter starts to operate at 100msec and series inverter starts at 200msec.

Table 1 – PV Array grid parameters

| Grid Parameters | Values |
|---|---|
| Source Ph. voltage (RMS) | 220v/50Hz |
| DC link voltage | 600 V |
| Shunt Inverter Rating | 45 kVA |
| Series inverter rating | 15 kVA |
| Shunt inverter Inductance ($L_f$) | 3 mH |
| Shunt inverter Capacitance ($C_f$) | 10 uF |
| Switching Frequency | 20KHz |
| Series Inverter Inductance(Ls) | 3 mH |
| Series Inverter Capacitance(Cs) | 15 uF |
| Series Inverter Resistance(Rs) | 12 Ohm |
| PV Array Rating | 40 kW |

Active and reactive powers consumed by load are shown in figure below. Simulated load consumes 17 kW active power and 8kVAr reactive power. In this simulation, it is assumed that the PV array is inter-connected to grid and outages after 0.45s of operation. The current, injected by shunt inverter is shown in figure below. As it is shown in figure below, at the presence of PV, shunt branch injects a high current to grid, a part of which is consumed to feed the load and else is injected to grid. During PV outages, the shunt branch undertakes the duty of compensating current harmonics and current's reactive power.

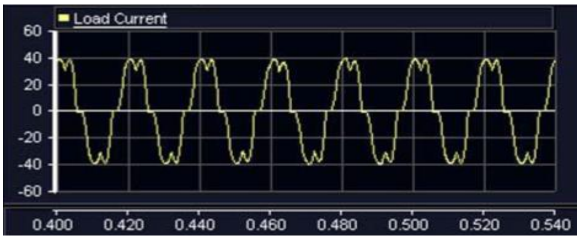

Fig 7- Nonlinear load's current

Fig 8- source current and voltage

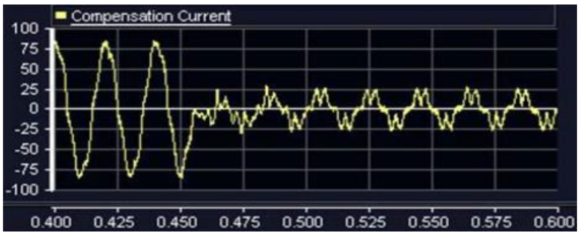

Fig 9- Current of shunt inverter injected to grid

At 0.45sec, PV outage occurs, source current returns to sinusoidal mode after passing the transient state. It can understood that, before PV outage, voltage has 180° phase difference with its current and PV injects current to source in addition to providing load. After PV outage, V, I are in same phase and UAPF compensates current harmonics and power factor. The total harmonic distortions (THD) of source and load currents got reduced from 22% to 3%.

In figure below, active and reactive powers injected by shunt inverter are shown. When PV outage occurs, injected reactive power doesn't vary, while injected active power decreases to a negative value from 37.5kW. Shunt inverter is not able to inject active power after PV outage and required active power of series inverter is provided through shunt inverter from the grid.

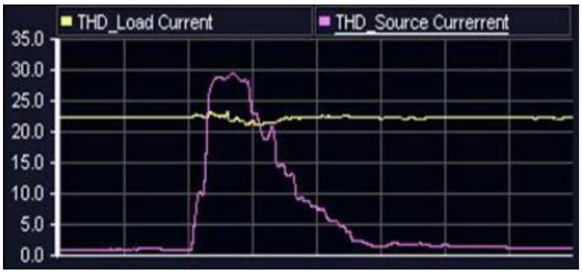

Fig 10- Load and source current THD

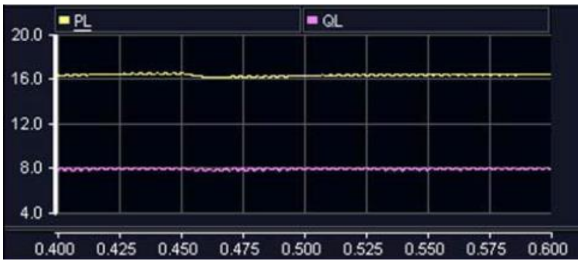

Fig 11- Active and reactive power by Non-linear load

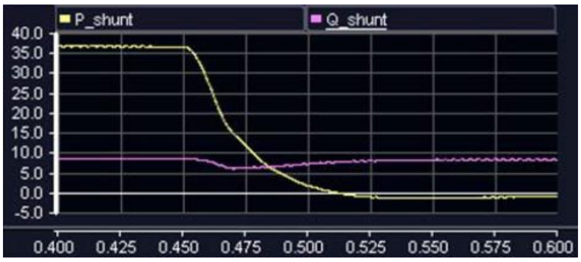

Fig 12- Active and reactive power injected by shunt inverter

## V. CONCLUSION

The results of analyzing combined operation of UAPF and PV system is studied. The system is composed of series and shunt inverters, PV array and DC/DC converter which can compensate the voltage and current quality issues and harmonics in both islanding and interconnected modes. The advantages of the system is reducing the expense of PV interface inverter connection to grid because of applying UAPF&C shunt inverter and also is the ability of compensating the voltage interruption using UAPF&C because of connecting PV to DC link.

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