Technical Review of Confederated Three-Phase Photovoltaic and Unified Power Quality Conditioner

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Abstract— The rooftop installed photovoltaic (PV) system has gained much popularity due to great potential to supply clean energy with minimum impact on environment. The PV energy sources has discontinuous nature which leads to voltage quality problems as well as the advancement of semiconductor tends to increase the level of current harmonic distortion. Power quality issues at load side is most common problem which creates huge unbalance on transmission and generation side of the system. As the problems related to power quality is going to take newer dimensions power quality improvement technique of Unified Power Quality Conditioner (UPQC) can be used. Dynamic model of Confederated Three-Phase PV-UPQC analysis is stimulated in MATLAB-Simulink software. The MATLAB stimulation results reveal that the designed unified power quality conditioner with photovoltaic array effectively mitigate the current and voltage harmonics.

Key words: Unified Power Quality Conditioner (UPQC), Three-Phase Photovoltaic

I. Introduction

Photovoltaic system has become major source of energy fulfilling global energy needs. In domestic purposes medium size PV grid has been used. Increase in harmonic distortion and power electronic loads penetration have been increased with the development of power electronics. The line current deviates from the sinusoidal waves at the input of the diode bridge and these non- linear current results into voltage distortion. Therefore, to solve these power quality problems a system can be designed to increase PV system utilization.

Active filter is used to mitigate these issues on utility side. Active filters have time dependent harmonics. Filters are sized and shaped in accordance of how much harmonic current and voltage is needed to be filtered. Electronic controller is used which injects harmonic current on the system at 180 degree out of phase to the system harmonics. They are cost effective and a free of power factor displacement problem. The Unified power quality conditioner has simple current and voltage control implementation. It also provides immunity against ambient harmonic load.

In UPQC, shunt active filter is used to mitigate current harmonics while the series active power filter has been used to reduce the voltage interruptions. Integrating the photovoltaic array along with UPQC has an advantage of pollution free energy generation along with surety of high levels power quality. Synchronous Reference Frame (SRF) is used as control technique with hysteresis based current control to obtain switching signals in the shunt compensator while Phase Locked Loop (PLL) is used for series active power filter.

In recent years, harmonic pollution has become a huge problem in distribution system, due to non- linear loads used in industrial and domestic applications. Therefore, use of active filters helps us to have better and improved power quality. Three phase PV-UPQC system and power qualities related to it have been studied with possible optimal solution to design unified power quality conditioner. Moreover, the effectiveness of the control method of the photovoltaic and unified power quality conditioner with three phase system by utilising supply voltage has been investigated.

II. PV-UPQC System Configuration and Design

A. General Introduction

As the problems related to power quality is going to take newer dimensions power quality improvement technique of Unified Power Quality Conditioner is used in the proposed paper. The energy supply from PV is transferred to the Unified Power Quality Conditioner (UPQC) for conditioning. Active Power Filter gives promising solution to compensate the adverse effects of harmonics and reactive power compensation by suitable control strategies.

B. Designing of PV-UPQC System

The main components of the unified power quality conditioner are series and shunt compensators where active power filters are used significantly. The shunt compensators assist in improving the power quality by removing the current harmonics interruptions. While the series compensator, provide protection by removing voltage interruptions. The unified power quality conditioner eventually creates an environment of less total harmonic distortion and better efficiency.

In UPQC, shunt active filter is used to mitigate current harmonics while the series active power filter has been used to reduce the voltage interruptions. Integrating the photovoltaic array along with UPQC has an advantage of pollution free energy generation along with surety of high levels power quality. Synchronous Reference Frame (SRF) is used as control technique with hysteresis based current control to obtain switching signals in the shunt compensator while Phase Locked Loop (PLL) is used for series active power filter as shown in Fig.1. It shows the three-phase photovoltaic and unified power quality conditioner.

1) Active shunt Filter

Active filters are used as best solution to attenuate problems such as line loss reactive power, resonance problem, heating up of the hardware, unstable system which are caused by harmonics. These filters are designed and sized depending upon how much harmonic current is to be filtered.

The filter consists of voltage source inverter with a special electronic controller which injects harmonic current on to the system 180º out of phase to the system harmonics. This results in harmonic cancelling effect which makes the system distortion less. It is cost effective and requires simple current control implementation methods. In active filters protection is easy as it does not require expensive and complex insolation and switchgear. A suitable controller is required to extract load harmonic current in an efficient manner.

2) Voltage Source Inverter

The DC voltage always has one polarity. The power reversal is possible by reversing the dc current polarity. Voltage source inverter (VSI) is preferred over current source inverter as it is economical and have better performance results. IGBTs have parallel reverse diode which makes it suitable for VSI as DC current flows in either direction in VSI (bidirectional). The DC side of the inverter has capacitor in support as voltage is unipolar there. The capacitor handles the charging and discharging current with the switching sequence of converter valves.

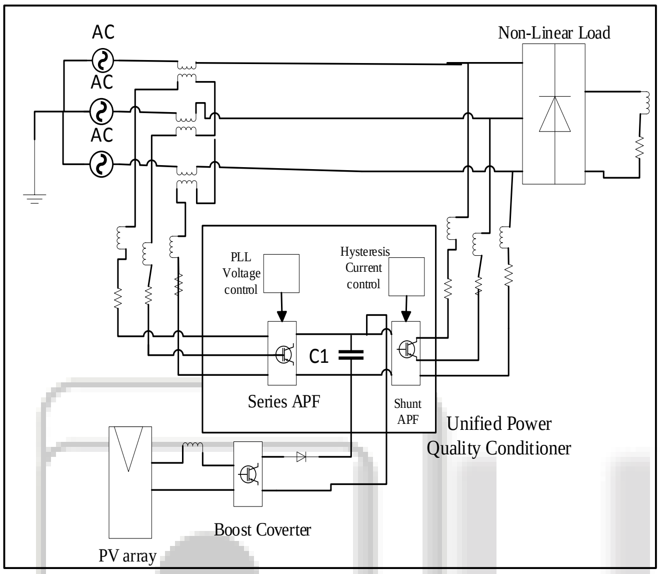

Fig. 1: PV-UPQC system

III. CURRENT REFERENCE GENERATION TECHNIQUE

Selection of reference generation scheme is one of the important methods as it determines the performance of active power filter. The amplitude and phase information must be included by the current reference template for desired current compensation while the voltage across the DC bus remain constant. This scheme works adequately under steady state and transient conditions

A. Synchronous Reference frame Method

The real currents are successfully transformed into a synchronous reference frame. The synchronous frame is synchronized with the ac mains voltage while rotating at the same frequency. One of the most important characteristics of this method is that the real load currents are used for the derivation of the reference current without considering the source voltage. The compensation of the robustness and performance of the system increases and another specific advantage is that the reference signals is not affected by voltage unbalance.

B. Proposed Structure for Current Harmonics Compensation

1) Estimation of Reference Current

The instantaneous currents can be written as

$$I_{s(1)} = i_{i(t)-}i_{c(t)} \quad (3.1)$$

Source voltage is given by

$$V_s(t) = V_m \sin \omega t$$

If non-linear current is applied, then the load current can be given as

$$I_{l(t)} = \sum (i_n \sin(nwt + \phi n))$$

$$= I_{i(x)} \sin(nwt + \phi n) + \sum n = 2 \sin(nwt + \phi n) \quad (3.2)$$

The instantaneous load power can be given as

$$P_i(t) = V_s(t) * I_i(t)$$

$$= P_{f(t)} + P_{r(t)} + P_{h(t)} \quad (3.3)$$

The fundamental power drawn by the load is

$$P_{f(t)} = V_m I_1 \sin 2wt * \cos \phi 1 = V_{s(t)} * i_{s(t)} \quad (3.4)$$

From the source current supplied by the source, after compensation is

$$I_{s(t)} = P_{f(t)} / V_{s(t)} = I_{1} \cos \phi 1 \sin wt = I_{sm} \sin wt$$

Where

$$I_{sm} = I_1 \cos \phi 1 \quad (3.5)$$

There are also some switching losses in the PWM converter, and hence the utility must supply a small overload for the capacitor leakage and converter switching losses in addition to the real power.

The total peak current supplied by the source is therefore given by

$$I_{sp} = I_{sm} + I_{s1} \quad (3.6)$$

The (t) will be in phase with the utility voltage and will be purely sinusoidal if the active filter presents the total reactive and harmonic power. The compensating current provided by the active filter at this time is as follows:

$$I_{c(t)} = I_{l(t)} + I_{s(t)} \quad (3.7)$$

Hence, for accurate and instantaneous compensation of reactive power and harmonics it is essential to estimate the fundamental component of the load current as the reference current.

C. Basic Compensation Principle

The non-linear load injects significant current harmonics to the power system creating non-linear load current. At point of common coupling, the active power filter feeds current harmonics exactly at opposite phase. This results in mitigation of harmonics by the compensating current. The role of control algorithms is to produce compensating current and it works appropriately to generate the reference current signal and the generating gate pulse.

IV. CURRENT CONTROL TECHNIQUE

The better selection of best current control strategy is significant for the performance of active power filter. The capability of tracking slope variations in the current reference is essential for current control done by rectifiers to compensate distortion which makes the process critical. Therefore, the active power filter application, the choice of the current regulator with its implementation is important for the achievement of satisfactory results.

A. Hysteresis Current Control Method

The hysteresis current control is method of generating the required triggering pulses which are used to control the voltage source inverter. The output current is then generated from the filter which follows the path as traced by reference current waveform. The generated triggering pulses are compared with error signal of the hysteresis band. The hysteresis current control is the easiest control method to implement in the real time.

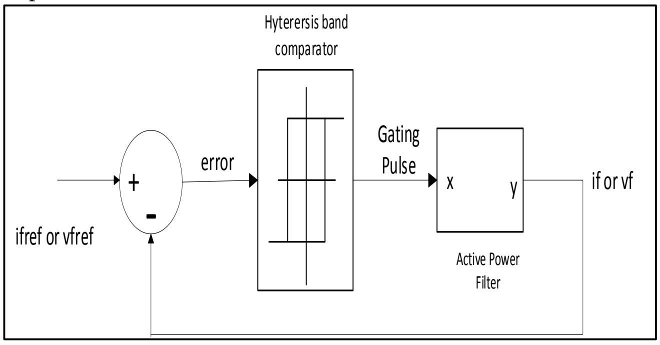

Fig. 2: Hysteresis Current Control

Fig.2 illustrates the ramping of the current between the two limits where the upper hysteresis limit is the sum of the reference current and the maximum error or the difference between the upper limit and the reference current.

Symbol	Quantity
ω	Angular Frequency
$I_{c(t)}$	Compensating Current provided by active filter
$P_{f(t)}$	Fundamental Power by the load
$I_{s(t)}$	Instantaneous Current
I_{abc}	Load Current of Shunt Active Power Filter
V_{load}	Load Voltage of Series Active Power Filter

Table 1: List of Figures

B. Synchronous Reference Frame Theory

The synchronous reference frame theory or d-q theory is based on the concept of time-domain reference signal estimation techniques. It supports the active power filter system in the steady-state and the transient state as well as in real-time scenarios. Another magnificent attractive quality of this controller is the simplified calculations.

The reference frame transformation is formulated from a three-phase a-b-c stationary system to the direct axis(d) and the quadratic axis(q) rotating coordinate system.

The d-q transformation output signals depend on the load current (fundamental and harmonic components) and the performance of the Phase Locked Loop (PLL). The rotational speed(rad/sec) is provided by PLL circuit and ωt is set as fundamental frequency component.

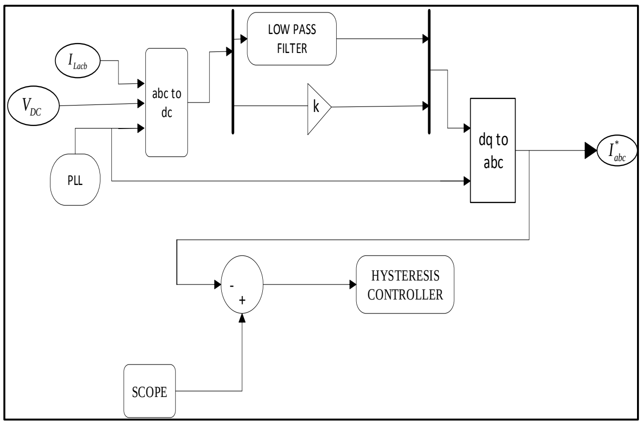

Fig. 3: Synchronous d-q-0 reference frame-based compensation algorithm

The basic structure involves direct(d-q) and inverse (d-q)-1 park transformation is shown in Fig. 3.

The PLL circuit provides the vectorized at 50 Hz frequency followed by sin θ and cos θ for synchronization. The low pass filter filters the harmonics and it is a second order Butterworth filter, whose cut off frequency is selected to be 25 Hz for eliminating higher order harmonics.

C. Control Scheme of Series Active Power

The control strategies used in the presented model is the synchronous reference frame with the Phase Locked Loop (PLL) controller. The control scheme of series active filter is based on a-b-c to d-q transformation method. The reference voltage with the actual voltage are converted to dq0 from a-b-c coordinates and both are simultaneously compared in the provided dq0 reference frame. After the required comparison conversion is done to fit in a-b-c reference frame. The Phased Locked Loop (PLL) generates the θ which is used effectively in the Park's transformation and inverse Park's transformation. The switching pulses are generated. The PLL controller, thus compares the selected output voltage (V_C^*) with the sensed series APF output voltage (V_C).The ideal output waveform is generated by the proposed technique as the output is generated by PWM (Pulse Width Modulator) with minimum harmonic distortion and maximum fundamental useful voltage.

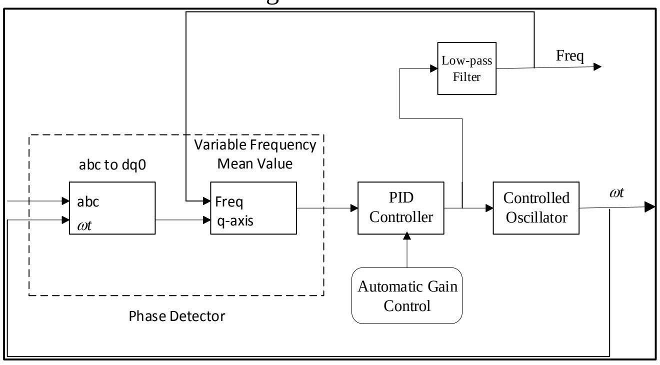

Fig. 4: Internal Diagram of PLL Controller

The Fig.4. shows the Proportional-Integral-Derivative (PID) controller is used in combination with optional automatic gain control (AGC) Automatic gain control helps in maintaining the phase difference to 0 which follow up on a controlled oscillator. PID output is utilized as the mean value which is the converted frequency (hertz) from the angular velocity.

V. THREE – PHASE PV CONFEDERATED UPQC SYSTEM IN MATLAB

A model of Unified Power Quality Conditioner (UPQC) is developed with three phase voltage sources with Photovoltaic (PV) Array integrated on its DC-link in MATLAB. The UPQC is based on series active power filter and shunt power filter. The Phase Locked loop (PLL) controller are used in series active power filter and the hysteresis controller is used in shunt active power filter.

Synchronous Reference Frame (SRF) Theory is applied to applied to generate the reference currents required to compensate the load current harmonics and reactive power compensation. While SRF theory with PLL Controller is used for removal voltage harmonics. The compensation effectiveness of an active power filter depends on its ability to have minimum error and the delay time. The reference signal calculated is used to compensate the distorted load current as shown in Fig.5.

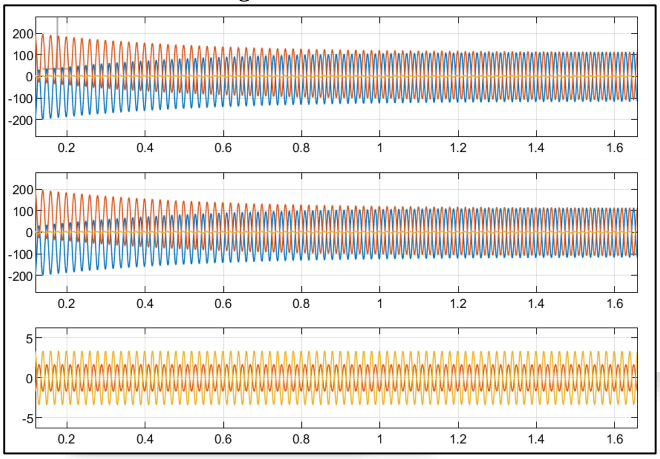

Fig. 5: (a) Source Current (b) Distorted Input Current (c) Improved Current

The series compensator eliminates voltage sag and voltage swell by injected favourable voltage in opposite phase with the grid voltage disturbance as illustrated in Fig. 6. and thereby, balancing the fluctuating voltage in the system under dynamic conditions. The system is observed to be stable under dynamic conditions of voltage fluctuations.

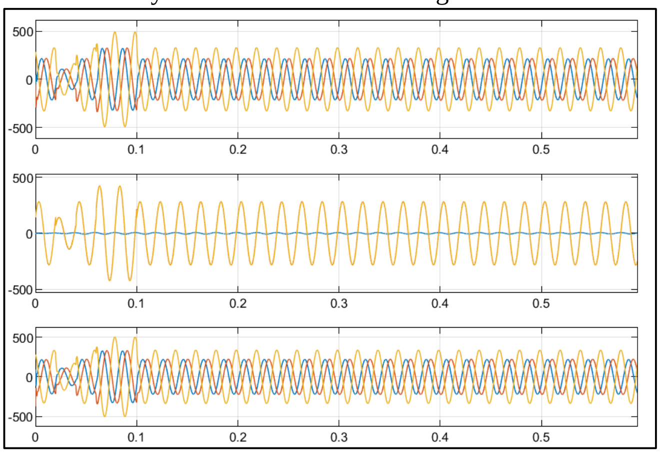

Fig. 6: (a) Three-phase Input Voltage (b) Compensating Voltage (c) Load Voltage

The load current is reduced to an effective percentage of 0.04% and while voltage THD is reduced to 0.29% in FET Analysis of the dynamic model of Three-Phase confederated PV-UPQC as described in Fig.7 and Fig.8 respectively.

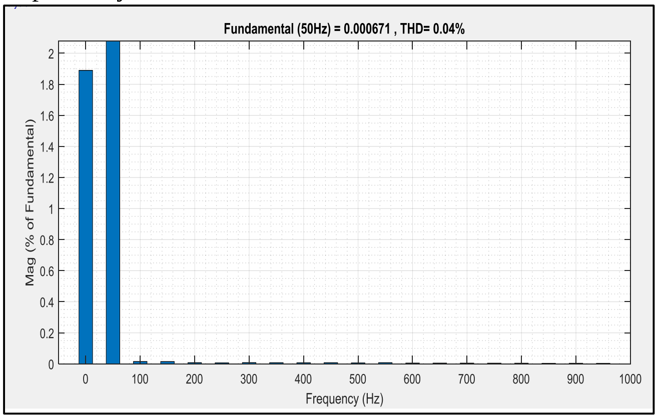

Fig. 7: FET analysis of load current where THD is 0.04 %

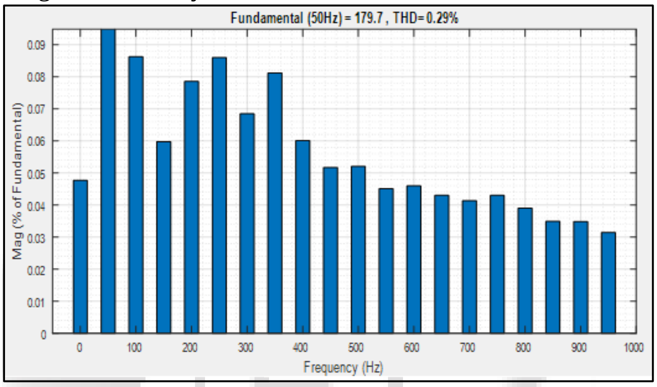

Fig. 8: FET analysis of load current where THD is 0.29%

VI. CONCLUSION

A model of Unified Power Quality Conditioner which is based on shunt and series active filter is grid connected PV system has been developed in MATLAB Simulink and stimulated to verify the results. It has been observed in stimulation results that UPQC improves power quality of the system due to elimination of Current Harmonics and reactive current with reduction in voltage harmonics. This makes the load current sinusoidal and in phase with the source voltage.

APPENDIX

Experimental Parameters

Snubber Resistance of Active Filter Rs (Ohms)	2e5
Snubber Resistance of Boost Converter Rs (Ohms)	1e5
Minimum Frequency of PLL used in series active filter controller (Hz)	45
Inductance connected after three-phase voltage source (H)	4e-3
Load Resistance (Ohms)	100
Load Inductance (H)	20e-3
Resistance of Active Filter Ron (Ohms)	1e-3
Loop filter proportional gain of 3-phase discrete PLL used in Hysteresis Controller	200

Loop filter integral gain of 3-phase discrete PLL used in Hysteresis Controller	2000
Sample time of 3-phase discrete PLL used in Hysteresis Controller	-1
Cut-off frequency of Low pass Filter used in Hysteresis Controller of Shunt Active Filter (Hz)	25
Switch off point of Relay used in Hysteresis Controller	-0.1
Output when on of Relay used in Hysteresis Controller	1

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REFERENCES

[1] S. Devassy, and B. Singh, "Design and Performance Analysis of Tree-Phase Solar PV Integrated UPQC." IEEE Trans on Industry Applications, Vol 54, pp. 73-81. 2018.
[2] T. Esram, and P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques." IEEE Transactions on Energy Conversion, Vol. 22, pp. 439-449. 2007.
[3] H. Fujita, and H. Akagi, "The unified power quality conditioner: the integration of series – and shunt – active filters." IEEE Trans Power Electron, Vol. 13, pp. 315-332. 1998.
[4] V. Khadkikar, and A. Chandra, "UPQC-S: A Novel Concept of Simultaneous Voltage Sag/Swell and Load Reactive Power Compensations Utilizing Series Inverter of UPQC."IEEE Transactions on Power Electronics, Vol. 26, pp. 2414 – 2425. 2011.
[5] Rauf, A.M., and Khadkikar, V. "Integrated photovoltaic and dynamic voltage restorer system configuration." IEEE Transactions on Sustainable Energy, Vol 6, pp. 400–410. 2015.
[6] W., Zhaoan, Y. Jun, and Q. Guanyuan, "DC-side voltage control of shunt active power filter." IEEE Trans. Power Electronics, Vol. 4, pp. 48–50. 1996.
[7] P.K. Ray, and S.K. Dash, "Design and Modeling of Single-Phase PV-UPQC Scheme for Power Quality Improvement Utilizing a Novel Notch Filter-Based Control Algorithm: An Experimental Approach." Arabian Journal for Science and Engineering, Vol. 43, pp. 3083–3102. 2018.