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Harmonics Analysis of SPWM and SVPWM integrated UPQC Mitigating Harmonics and Improving Voltage Profile

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Abstract

In this paper a Unified Power Quality Controller is connected to a test system with harmonics and voltage variations creating sags and swells in source and load voltages. The UPQC is supported with PVA connected at the DC link injecting active and reactive powers to the grid. Individual controllers are modelled for shunt and series converters with feedback from the source and load voltages and currents. Both the converters work in synchronization to the source voltage with SRF controller using sinusoidal PWM technique. An MPPT is also used for magnitude generation of the reference current. For further improvement in the model the conventional sinusoidal PWM is replaced with space vector PWM reducing the harmonic content in the source voltages and currents. The design is modelled in MATLAB Simulink environment with graphs generated with respect to time.

Keywords: Power Quality, shunt compensator, series compensator, UPQC, Solar PV, MPPT SVPWM.

1. Introduction

1.1 Introduction to Electrical Power Quality

Electric power quality can be described as the degree to which the voltage, frequency and waveform of a power supply system match to established specifications. A good power quality can be stated as a steady supply voltage that remains within the prescribed range, a steady ac frequency that is close to the rated value and smooth voltage curve waveform preferably a sinusoidal wave. In other words, it can also be stated as the compatibility between output of an electric outlet and the plugged-in load. In absence of proper power, an electrical device tends to malfunction, prematurely fail or not at all operate. While "power quality" is a suitable term but actually it is the quality of the voltage rather than power or electric current that is actually described by it. The power quality may be expressed as a set of values of parameters, such as:

- Continuity of service irrespective of voltage sag/swell
- Voltage magnitude variations
- Transient currents and voltages
- Harmonics in the waveforms

Compatibility is the major term associated with power quality and the problems associated with it usually have two solutions: i.e., either to clean up the power or to make the equipment stronger.

1.2. Series Compensation

The method of connecting a capacitor in series with the transmission line so as to improve the system voltage is termed as series compensation. In other words, the impedance of the system is improved in series compensation by inserting reactive power in series with the transmission line. It also improves the power transfer capability of the line. It is typically used in extra high voltage line and ultra-high voltage line.

1.3. Unified Power Quality Conditioner

A Unified Power Quality Conditioner (UPQC) is a device that is very much in similar in construction to a Unified Power Flow Conditioner (UPFC). The UPQC utilizes two voltage source inverters that are connected to energy storage capacitor. One of these is connected in series and the other is connected in shunt with the ac system. The UPQC is one of the most powerful custom power devices, which can mitigate both voltage and current related problems simultaneously. The UPQC is a combination of back-to-back connected series and shunt APFs to a common dc link voltage. The series APF compensate all voltage harmonics and shunt APF cancels current-based distortions. And improve power factor by compensating reactive component of load current. In this paper, the improved synchronous-reference-frame with SPWM based control method for the UPQC system is optimized without using transformer voltage, load, and filter current measurement, so that the numbers of the current

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measurements are reduced and the system performance is improved. In the figure 1.3 configuration of UPQC is depicted. The main purpose of the series active filter is harmonic isolation between a sub transmission system and a distribution system. In addition, the series active filter has the capability of voltage flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The main purpose of the shunt active filter is to absorb current harmonics, compensate for reactive power and negative sequence current, and regulate the dc link voltage between both active Filters.

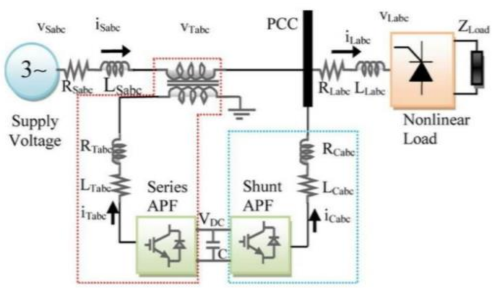

Fig. 1 UPQC Model

2. Proposed Methodology

2.1 Description of proposed System

The structure of the PV-UPQC is shown in Fig.2. The PV-UPQC is designed for a three-phase system. The PVUPQC consists of shunt and series compensator connected with a common DC-bus. The shunt compensator is connected at the load side. The solar PV array is directly integrated to the DC-link of UPQC through a reverse blocking diode. The series compensator operates in voltage control mode and compensates for the grid voltage sags/swells. The shunt and series compensators are integrated to the grid through interfacing inductors. A series injection transformer is used to inject voltage generated by the series compensator into the grid. Ripple filters are used to filter harmonics generated due to switching action of converters. The load used is a nonlinear load consisting of a bridge rectifier with a voltage-fed load.

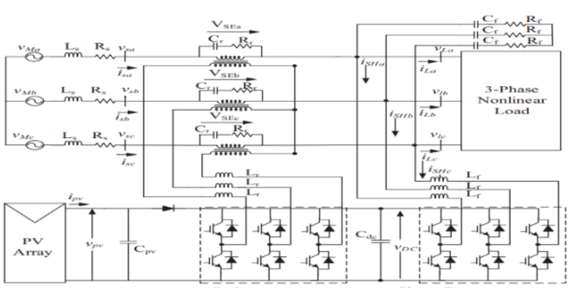

Fig. 2. Proposed System of Photovoltaic Array with Unified Power Quality Conditioner

Design of PV-UPQC the design procedure for PV-UPQC begins with the proper sizing of PV array, DC-link capacitor, DC-Link voltage level etc. The shunt compensator is sized such that it handles the peak power output from PV array apart from compensating for the load current reactive power and current harmonics. As the PV array is directly integrated to the DC-link of UPQC, the PV array is sized such that the MPP voltage is same as desired DC link voltage. The rating is such that, under nominal conditions, the PV array supplies the load active power and also feeds power into the grid. The detailed PV array specifications are given in Appendix A. The other designed components are the interfacing inductors of series and shunt compensators and series injection transformer of the series compensator. The design of PV-UPQC is elaborated as follows.

1.Voltage Magnitude of DC-Link: The magnitude of DClink voltage Vdc depends on the depth of modulation used and per-phase voltage of the system. The DC-link voltage magnitude should more than double the peak of per-phase voltage of the three-phase system [8] and is given as

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \qquad \text{...........................2.1}$$

where depth of modulation (m) is taken as 1 and VLL is the grid line voltage. For a line voltage of 415 V, the required minimum value DC-bus voltage is 677.7 V. The DC-bus voltage is set at 700 V(approx), which is same as the MPPT operating voltage of PV array at STC conditions.

2. operating voltage of PV array at STC conditions. 2) DC-Bus Capacitor Rating: The DC-link capacitor is sized based upon power requirement as well as DC-bus voltage level. The energy balance equation for the DC-bus capacitor is given as follows

$$C_{dc} = \frac{3kaV_{ph}I_{sh}t}{0.5 \times (V_{dc}^2 - V_{dc1}^2)} \qquad \text{...2.2}$$

$$= \frac{3 \times 0.1 \times 1.5 \times 239.6 \times 34.5 \times 0.03}{0.5 \times (700^2 - 677.79^2)}$$

$$= 9.3mF$$

required value of DC-bus voltage,a is the overloading factor, Vph is per-phase voltage, t is the minimum time required for attaining steady value after a disturbance, Ish is per-phase current of shunt compensator, k factor considers variation in energy during dynamics.

2.2 Space Vector Pulse Width Modulation (SVPWM)

The space vector pulse width modulation method is an advanced, computation intensive PWM method, which is an excellent feature and is possibly the best among all the PWM techniques for variable frequency drive applications. It has been found wide spread application in recent years, because of its superior performance characteristics.

2.3 Advantages of SVPWM

Space vector PWM is considered a better technique of PWM implementation owing to its associated advantages mentioned below:

- Better fundamental output voltage.
- Improved harmonic spectrum.
- Easier implementation in Digital Signal Processor and Microcontrollers.
- Conventional techniques involve look up tables for achieving this optimum switching Sequence

3. Simulation Results & Analysis

3.1 Description 1(fig. 3) Unified power quality conditioner UPQC system with PVA

The below is the simulation model of proposed UPQC system with PVA connected at DC link supporting the grid system by injecting active and reactive power to the grid.

It also consists of shunt capacitor and series capacitor as an integral part of this system which are discussed in the coming section.

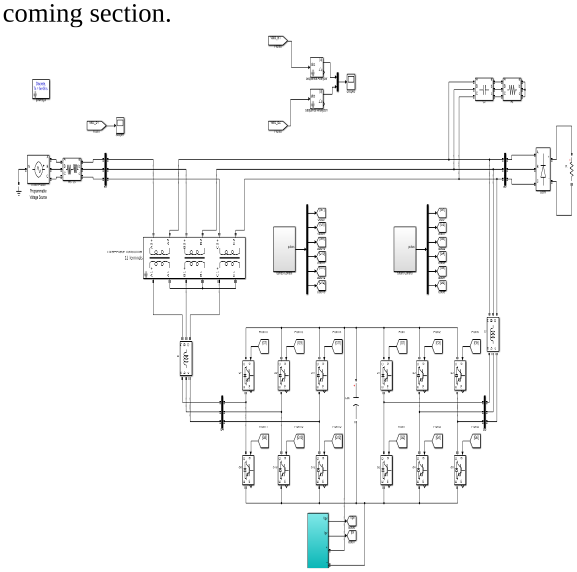

Fig.3. Proposed PVA-UPQC system

A. Description 2 (Fig. 4): Shunt Controller

The below, fig. 2, shows the simulation model of the shunt compensator. As the name suggests it compensates for load power quality like load current harmonics and load reactive power. It also extracts power from the solar PV array in case of PV-UPQC by making use of MPPT algorithm.

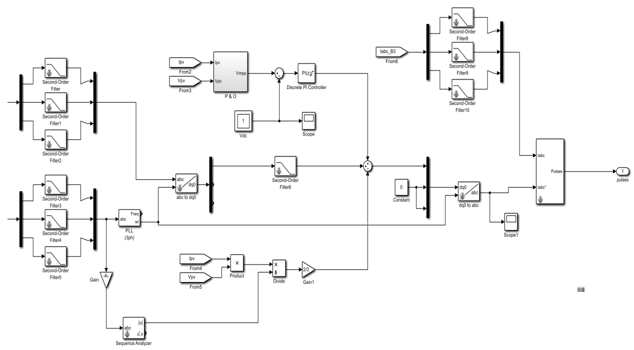

Fig. 4 Shunt controller modelling

Description 3 (Fig. 5): Series Compensator

The below, Fig.3. shows the simulation model of the series controller. Its main function is to protect the load from grid side power quality issues such as voltage sag or voltage swell. It is done by injecting appropriate voltage in phase with the grid voltage. This injected voltage is obtained by comparison accordingly with the reference voltage by making use of the feedback technique. The reference voltage for the sin PWM pulse generation is generated using Parks transformation.

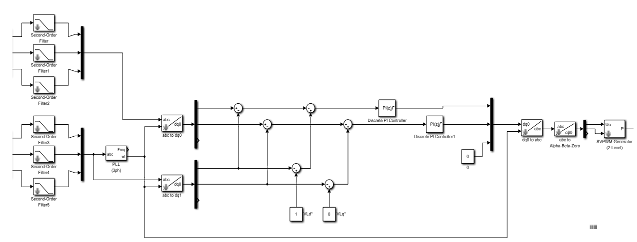

Fig. 5 Series controller modelling

C. Description 4 (Fig. 6): Internal model of PVA

The below, Fig.6 is the mathematical modelling of PVA connected at the DC link of UPQC.The solar PV array is directly integrated to the DC-link of UPQC with the help of a reverse blocking diode. The PV array not only supplies the load active power but also feeds power into the grid.

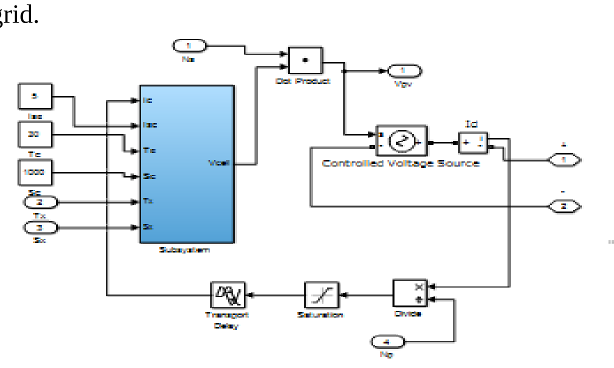

Fig. 6 PVA internal modelling

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Case 1. System analysis with PVA-UPQC

In contradiction to above discussed system, when the system is connected with a PVA-UPQC the following graph (Fig. 9) is obtained while comparing the source and the load voltages for sag and swell condition. We can infer from the graph that the source voltage is varying and the load voltage remains constant at 0.97pu. Fig. 10 depicts the source current with reduced harmonics generating sin waveforms when the grid system is connected with PVA-UPQC.

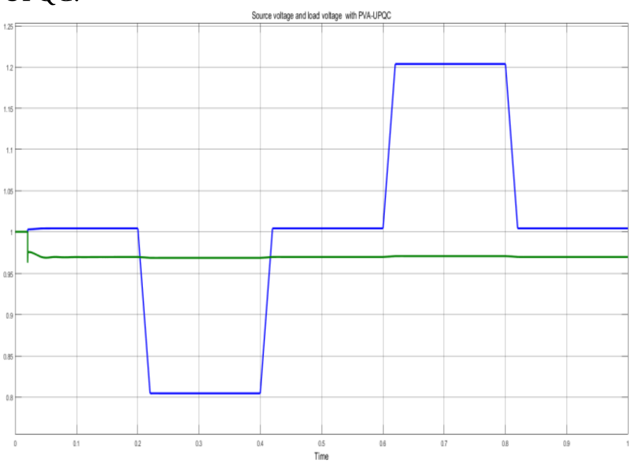

Fig. 7 Source voltage (blue) and load voltage (green) magnitudes with PVA-UPQC

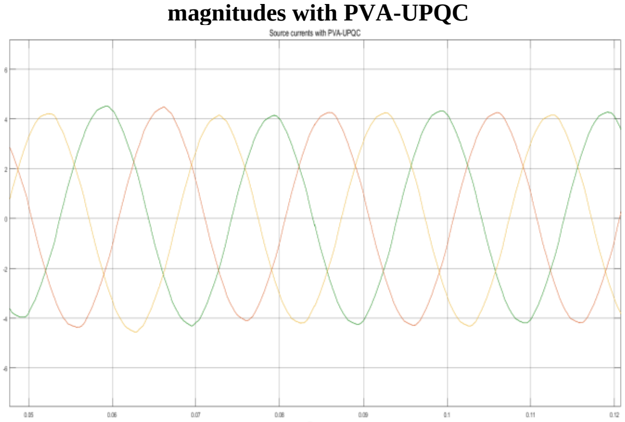

Fig. 8 Source currents with PVA-UPQC

3.2 FFT Analysis

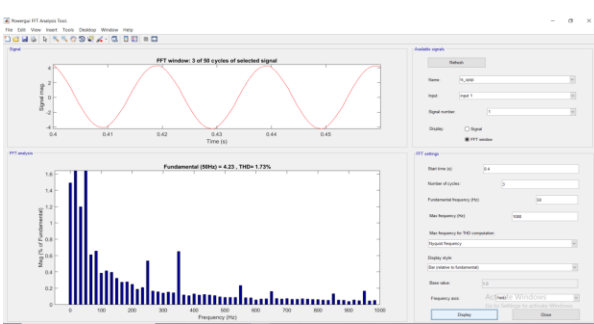

Fig.9 THD of source current with PVA-UPQC controlled by sinusoidal PWM technique

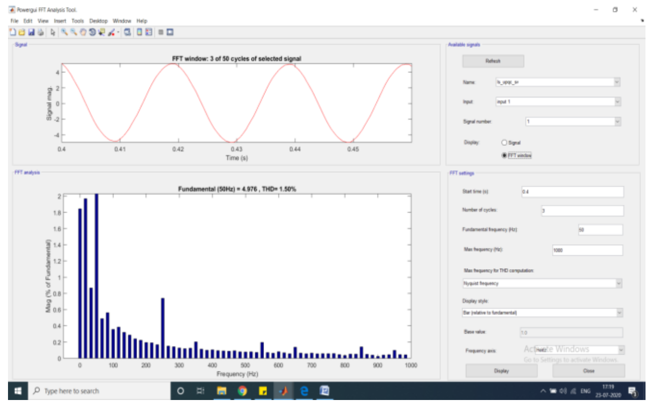

Fig. 10 THD of source current with PVA-UPQC controlled by space vector PWM technique

4. Conclusion

The series converter supports the load voltage with injecting the deficit voltage into the load side maintaining the voltage magnitude. Even the THD of the source current is maintained at very low value of 1.73% reduced from 27.14%, when PVA-UPQC is connected to the grid system. The harmonics are reduced further to lesser value of 1.5% when the series controller is updated with space vector PWM technique. With the above simulation results generated by powergui toolbox the grid system improves the voltage profile and reduce harmonics in the system when it is connected with PVA integrated UPQC.

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