Journal of Science and Technology
ISSN: 2456-5660 Volume 5, Issue 5, Sep-October 2020

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2020.v5.i5.pp140-148*

Performance Analysis of Three-Phase Solar PV Integrated UPQC Using Space Vector Technique

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To Cite this Article
J Sandhya and N. Sirisha, "Performance Analysis of Three-Phase Solar PV Integrated UPQC Using Space Vector Technique", Journal of Science and Technology, Vol. 05, Issue 05, Sep-October 2020, pp140-148

Article Info
Received: 28-05-2020 Revised: 02-09-2020 Accepted: 05-09-2020 Published: 08-09-2020

Abstract: *Due to the increase of load demand in future, the generation must also increase. The use of traditional resources such as coal, diesel fuels etc., causes global warming which is leading us to shift to renewable energy resources. Renewable energy resources may in include solar, wind, tidal as the source for production. These are used in small quantities as Distribution Generators (DG) at different locations in a bus system. As the generation of these sources is less when connected to grid, we call them as micro-grids. These micro grids generally use these DGs to distribute power to loads, and involve power electronic elements to control the generation. It induces energy into the system but also create a problem of harmonic distortions and voltage sags.*

To eliminate these sags and harmonics in the micro grid system caused by the power electronic devices employed by the renewable sources, we induce a UPQC (Unified Power Quality Conditioner) system. The UPQC system eliminates the harmonics in the systems and restores the voltage of the micro-grid system. We introduce a new topology called instantaneous reactive power (IRP) theory in the UPQC control to operate in a more efficient way, by utilizing RES (Renewable Energy Sources) at the DC-link. The RES support the UPQC system by injecting the active power generated by the resources through DC-link.
Keywords*: Photo voltaic, Micro grid, UPQC*

I. Introduction

The concept of micro grid has offered consumers with increased reliability and reduction in total energy losses, and has become a promising alternative for traditional power distribution system . One area of study for the connection of a micro grid to the distribution grid is the impact of power quality (PQ) problems on the overall power system performance. These PQ problems include voltage and frequency deviations in the grid voltage and harmonics in the grid voltage and load currents. To overcome the aforementioned PQ problems, several power-conditioning equipment such as active filters, uninterruptible power supplies, dynamic voltage restorers and unified PQ conditioners are usually employed by consumers to protect their loads and systems against PQ disturbances in the distribution network. However, these devices are usually installed at the consumer sides and the PQ problems that they are capable to handle are usually limited. This paper proposes a flexible ac distribution system device for the micro grid that is realized using a combination of series and shunt voltage source inverters (VSIs). The proposed device is installed at the point of common coupling (PCC) of the distribution grid that the micro grid and other electrical loads are connected to. The proposed source for the dc-link voltage of the flexible ac distribution system device consists of a photovoltaic (PV) array and a battery to store the excess energy generated by the PV array and to provide power during sunless hours. The device is equipped with the capability to improve the PQ and reliability of the micro grid. Furthermore, during islanded operation of the micro grid, the device can provide real and reactive power to the micro grid. The proposed controller is based on a newly developed model predictive control (MPC) algorithm to track periodic reference signals for fast sampling linear time-invariant (LTI) systems that are subject to input constraints. This control methodology controls the input signals of the VSIs and decomposes the control problem into steady-state and transient subproblems which are optimized separately. In this way, the computational times can be greatly reduced.

In what follows, this paper provides a comprehensive solution for the operation of the flexible ac distribution system device for a microgrid based on a multi-input–multi-output (MIMO) state-space model. The device will accomplish the following tasks simultaneously:

1) Compensating for harmonics in the grid voltage and load currents;
2) Real and reactive power control for load sharing during peak periods and power factor correction at the grid side;
3) Maintaining PQ despite slight voltage and frequency variations in the grid voltage; and
4) Momentarily dispatching real and reactive power to the micro grid when it becomes islanded.

II. SYSTEM DESCRIPTION

The configuration of the micro grid considered in this paper for implementation of the flexible ac distribution system device is shown in Fig. 1. The proposed micro grid consists of three radial feeders (1, 2 and 3) where feeders 1 and 3 are each connected to a distributed generation (DG) unit consisting of a micro generator, a three-phase VSI, and a three-phase LC filter. Feeder 2, however, is connected to an electrical load.

The flexible ac distribution system device is operated in two modes:

1) PQ compensation and
2) Emergency operation.

During grid-connected operation, the micro grid is connected to the distribution grid at the PCC. In this mode, the two DG units are controlled to provide local power and voltage support for loads 1–3 and hence reduce the burden of generation and delivery of power directly from the utility grid. The flexible ac distribution system device functions to compensate for any harmonics in the currents drawn by the nonlinear loads in the micro grid so that the harmonics will not propagate to the rest of the electrical loads that are connected to the PCC. The device also functions to compensate for harmonics in the grid voltage that are caused by other nonlinear loads that are connected at the PCC. The energization of large loads and rapid changes in the load demand may also result in voltage and frequency variations in the grid voltage. Therefore, the device is also equipped with the capability to handle such voltage and frequency variations. When a fault occurs on the upstream network of the grid, the CBs operate to disconnect the micro grid from the grid. The DG units are now the sole power sources left to regulate the loads. In the case when the generation capacity of the micro generators is unable to meet the total load demand, the flexible ac distribution system device transits to operate in the emergency mode and functions to momentarily provide for the shortage in real and reactive power.

III. UNIFIED POWER FLOW CONTROLLER

In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. Therefore, the UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance [2]. The UPQC consisting of the combination of a series active power filter (APF) and shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link [3]. The shunt APF is usually connected across the loads to compensate for all current-related problems such as the reactive power compensation, power factor improvement, current harmonic, compensation, and load unbalance compensation (3,4)whereas the series APF is connected in a series with the line through series transformers. It acts as controlled voltage source and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc.

The proposed control technique has been evaluated and tested under non-ideal mains voltage and unbalanced load conditions using MATLAB/SIMULINK software. The proposed method is also validated through experimental study. The following diagram shows the generalized UPQC system The UPQC consists of two voltage source inverters Connected back to back with each of them sharing a common dc link. Fig-2 shows the control diagram of UPQC system. One inverter work as a variable voltage source is called series APF, and the other as a variable current source in called shunt APF.

a) Series APF: The main aim of the series APF is harmonic isolation between load and Supply; it has the capability of voltage flicker/ imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer PCC.

b) Shunt APF: The shunt APF is used to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc link voltage between both APFs.

IV. SYSTEM CONFIGURATION

The structure of the PV-UPQC is shown in Fig.1. 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.

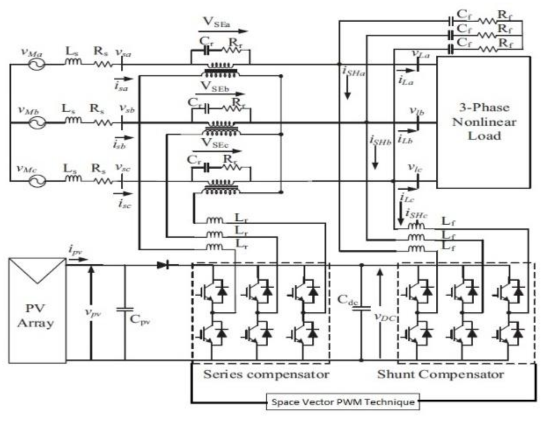


Fig. 1. Main Circuit Configuration

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. The PV-UPQC is designed

to compensate for a sag/swell of 0.3 pu i.e 71.88 V. Hence, the required voltage to be injection is only 71.88 V which results in low modulation index for the series compensator when the DC-link voltage is 700V. In order to operate the series compensator with minimum harmonics, one keeps modulation index of the series compensator near to unity.

The main subsystems of PV-UPQC are the shunt compensator and the series compensator. The shunt compensator compensates for the load power quality problems such as load current harmonics and load reactive power. In case of PVUPQC, the shunt compensator performs the additional function of supplying power from the solar PV array. The shunt compensator extracts power from the PV-array by using a maximum power point tracking (MPPT) algorithm. The series

compensator protects the load from the grid side power quality problems such as voltage sags/swells by injecting appropriate voltage in phase with the grid voltage.

A) Control of Shunt Compensator

The shunt compensator extracts the maximum power from the solar PV-array by operating it at its maximum power point. The maximum power point tracking (MPPT) algorithm generates the reference voltage for the DC-link of PV-UPQC. Some of the commonly used MPPT algorithms [28] are Perturb and Observe (P& O) algorithm, incremental conductance algorithm (INC). In this work, (P& O) algorithm is used for implementing MPPT. The DC-link voltage is maintained at the generated reference by using a PI-controller. To perform the load current compensation, the shunt compensator extracts the active fundamental component of the load current. For this work, the shunt compensator is controlled by extracting fundamental active component of load current using SRF technique.. The load currents are converted to d-q-0 domain using the phase and frequency information obtained from PLL. The PLL input is the PCC voltage.

B) Control of Series Compensator

The control strategy for the series compensator is presage compensation, in-phase compensation and energy optimal compensation. A detailed description of various compensation strategies used for control of series compensator is reported in [29], [30] In this work, the series compensator injects voltage in same phase as that of grid voltage, which results in minimum injection voltage by the series compensator. The control structure of the series compensator is shown in Fig.3. The fundamental component of PCC voltage is extracted using a PLL which is used for generating the reference axis in dq- 0 domain. The reference load voltage is generated using the phase and frequency information of PCC voltage obtained using PLL. The PCC voltages and load voltages are converted into d-q-0 domain. As the reference load voltage is to be in phase with the PCC voltage, the peak load reference voltage is the d-axis component value of load reference voltage. The q-axis component is kept at zero. The difference between the load reference voltage and PCC voltage gives the reference voltage for the series compensator. The difference between load voltage and PCC voltage gives the actual series compensator voltages. The difference between reference and actual series compensator voltages is passed to PI controllers to generate appropriate reference signals. These signals are converted to abc domain and passed through pulse width modulation (PWM) voltage controller to generate appropriate gating signals for the series compensator.

V. SIMULATION RESULTS

The basic system without UPQC is shown in Fig.2 is

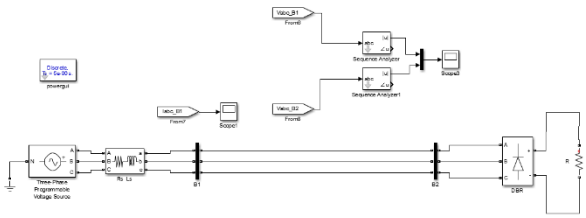


Fig. 2. Test system without UPQC

The source and load voltage magnitudes of test system without UPQC is in Fig. 3.

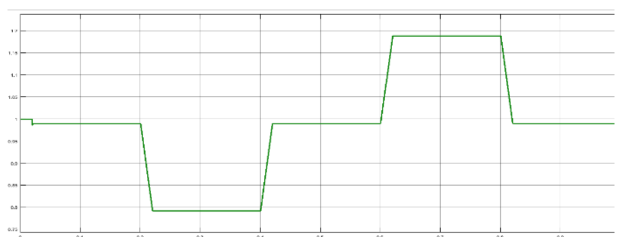


Fig. 3. Source and load voltage magnitudes without UPQC

The theree phase source currents wave form without PVA UPQC is shown below in Fig.4:

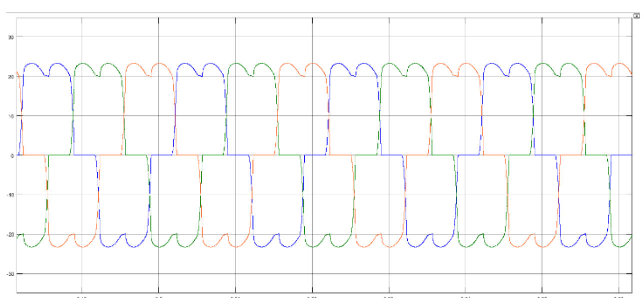
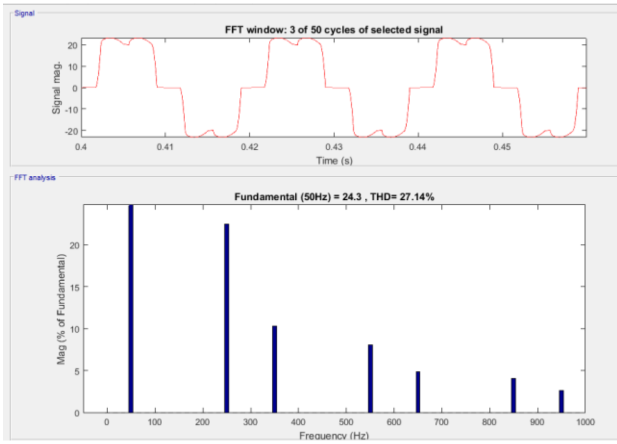


Fig. 4. Source currents without PVA UPQC

Due to the absence of UPQC, the THD is high of 27.14%



1. THD of source current without PVA-UPQC

Now, the test systme is configured with a UPQC and it is represented in Fig. 6.

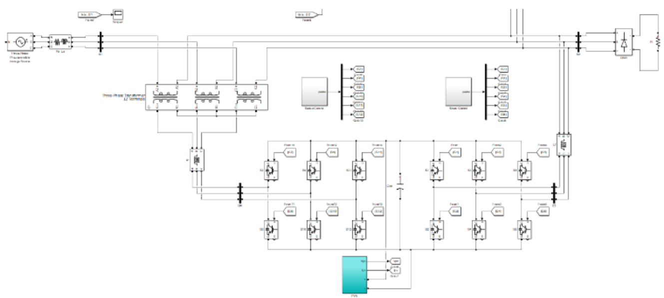


Fig. 5. Test system with PVA-UPQC

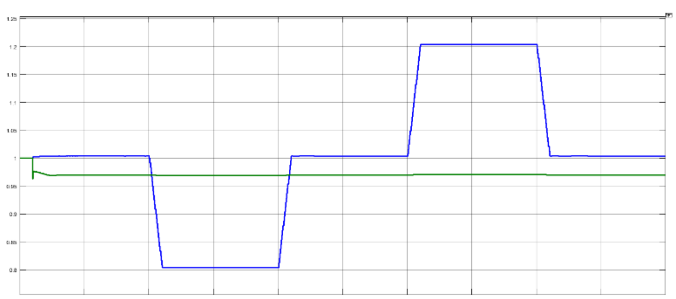


Fig. 6. Source and load voltage magnitudes with PVA-UPQC

The current waveform is pure sinusoidal wave shape and it is represented in Fig. 8.

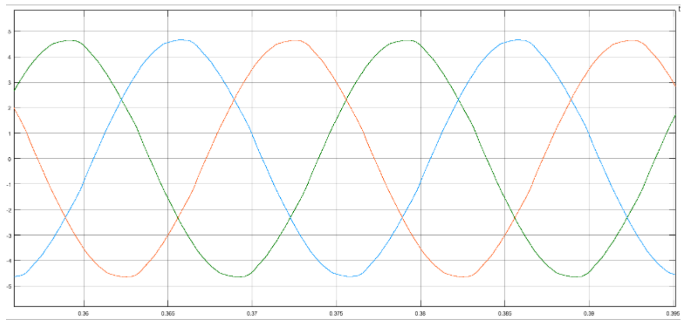


Fig. 7. Source current with PVA-UPQC

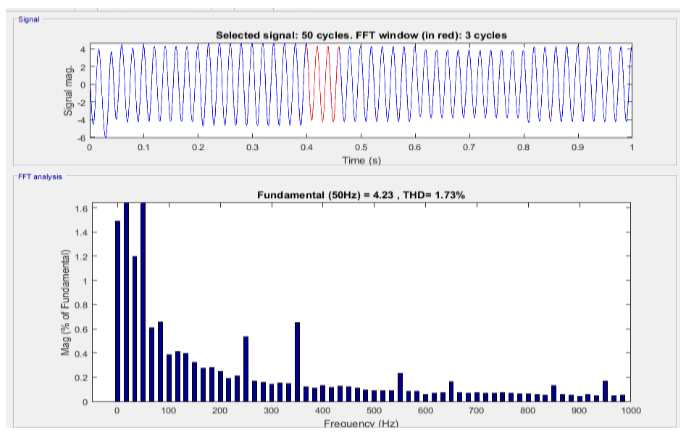


Fig. 8. THD of source current with PVA-UPQC

The configuration is modeled as PVA UPQC using SV modulation technique for lesser THD.

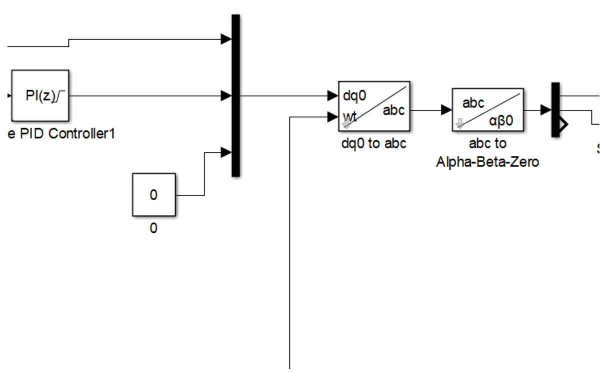


Fig. 9. PVA-UPQC updated with space vector PWM

The space vector technique for the shunt and series VSIs respectively improvise the THD of the grid current from 27% to a value of 1.76% and with space vector the value is 1.5%. The voltages and the currents of the micro grid system are improvised with injection of active and reactive powers from the UPQC system. It is shown in Fig. 11.

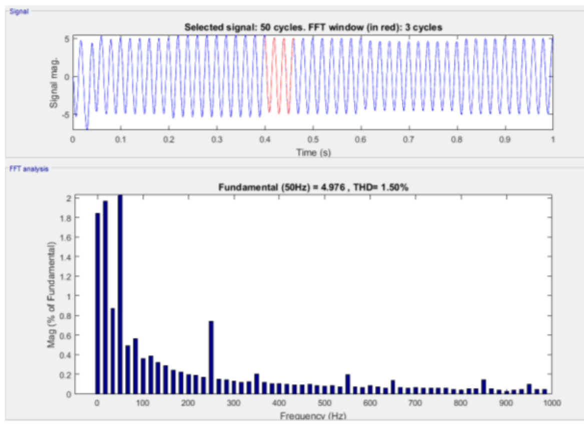


Fig. 10. THD of source current with PVA-UPQC using space vector PWM

VI. COMPARISION OF SYSTEM CONFIGURATION

In this, the Total Harmonic Distortion (THD) is very much reduced by using the UPQC device and effective with Space Vector Modulation Technique is used. The other power quality issues of voltage and currents parameters are improved.

S. No.	**Configuration of PV system**	**Power Quality Issue**	**THD (%)**
1	Without UPQC	More fluctuations	27.14
2	With UPQC	Almost same as rated	1.73
3	With UPQC using SV PWM		1.50

VII.CONCLUSION

Finally with all the graphical representation and output analysis of the grid and micro system, implementation of UPQC FACTs device in a renewable grid system will improve the quality of the system. The IRP method along with the space vector for the shunt and series VSIs respectively improvise the THD of the grid current from 27% to a value of 1.76% and with space vector the value is 1.5%. The voltages and the currents of the micro grid system are improvised with injection of active and reactive powers from the UPQC system.

VIII. FUTURE SCOPE

The PV system source connected at the DC link can be replaced with wind farms or any other renewable sources like battery, fuel cell, super capacitor etc. Better adaptive controller can be integrated into the shunt and series controllers for better results further improving the voltage and current profiles. SV PWM is difficult to design, high cost and limited to some kind of converters only so we can replace with simplified PWM technique that can suitable for any converter and results in reduction in THD.

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