IMPROVING THE PERFORMANCE OF A SOLAR PV INTEGRATED UPQC-S BY USING POWER CONTROL THEORY

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Abstract— The quality of electric power is greatly affected by the proliferation of non-linear loads in electrical energy processing applications like switched mode power supplies, electric motor drives, battery chargers, etc. The custom power devices like UPQC has gained more importance in power quality arena as it gives the best solution for all power quality issues. This project proposes a modified p-q theory based control of solar photovoltaic (PV) array integrated unified power quality conditioner (PV-UPQC-S). The system incorporates clean energy generation along with power quality improvement thus increasing functionality of the system. The fundamental frequency positive sequence (FFPS) components of voltages at the point of common coupling (PCC) are extracted using generalized cascaded delay signal cancellation (GCDSC) technique which are then used in p-q theory based control to estimate reference signals for the PV-UPQC-S. This modification in p-q theory enables its application for PV-UPQC-S control in conditions of distorted PCC voltages. The series voltage source converter (VSC) of PVUPQC-S operates such that it shares a part of the reactive power of the load even under nominal grid conditions. This increases the utilization of the series VSC while reducing the rating of shunt VSC. The PV array is integrated at the DC-bus of the UPQC, provides a part of active load power thus reducing demand on the supply system. The dynamic performance of modified p-q theory based PV-UPQC-S is verified by simulating the system in Matlab-Simulink with combination of linear and nonlinear loads. The simulation results are presented to show the effectiveness of the PV-UPQC-S and here obtained an acceptable THD for source current and kept load voltage at its nominal value.

Index Terms— power quality, UPQC-S, solar MPPT, GCDSC, p-q theory, series compensation, shunt compensation.

I. INTRODUCTION

Power quality as set of parameters defining the properties of power quality as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (frequency, magnitude, waveform and symmetry). Custom Power devices also called as power quality compensator employ power electronic or static controllers in medium or low voltage distribution systems for the purpose of supplying a level of power quality that is needed by electric power customers that are sensitive to root mean square (RMS) voltage variations and voltage transients. CP devices include static switches, power converters, injection transformers, master control modules and/or energy storage modules that have the ability to perform current interruption and voltage regulation functions in a distribution system to improve power quality.

In control of PV-UPQC-S, p-q theory based technique is ideal as this technique inherently calculates load active and reactive powers which are necessary in particularly in reactive power sharing of series VSC. Though the classical p-q theory involves only simple calculations, it does not produce accurate results under conditions of voltage distortions or unbalance. This drawback can be overcome by using fundamental frequency positive sequence (FFPS) voltages for estimating the reference currents using p-q theory. Modified p-q theory using phase locked loop (PLL) has been proposed. Various other methods to extract fundamental frequency positive sequence voltages are using notch filters, second order generalized integrators (SOGI), generalized cascaded delay signal cancellation (GCDSC) based methods etc. Techniques based on adaptive notch filters use a number of filter blocks for each harmonic component and have a slower response time which results in a settling time of a few cycles. The performance of SOGI based techniques deteriorates greatly with minor deviations from their tuned frequencies. The techniques based on GCDSC have improved harmonic attenuation characteristics. The proposed modified p-q theory based PV-UPQC-S is simulated using Matlab-Simulink and its dynamic performance is tested under conditions of irradiation variation, voltage sags/swells, distortions, load unbalance etc.

II. POWER CIRCUIT TOPOLOGIES OF UPQC
UPQC is a combination of a shunt (Active Power Filter) and a series compensator (Dynamic Voltage Restorer) connected together via a common DC link capacitor, which facilitates the sharing of the active power. Each compensator consists of IGBT inverters, which can be operated in current or voltage controlled mode. Depending upon the location of the shunt compensator with respect to series compensator, UPQC model can be named as right shunt-UPQC or left shunt-UPQC. Typically the active power generated in one unit is consumed in the other unit maintaining the energy balance overall characteristics of the right shunt-UPQC are superior to those of the left shunt-UPQC.

![Block diagram of UPQC](image)

**Fig:1. Block diagram of UPQC**

UPQC can be used for medium voltage and low voltage applications. In case of low voltage applications, it is not convenient to install a UPQC, since DVR spends most of its time in standby mode. UPQC is generally designed as 3-phase 3-wire (3P3W) systems. 3-phase 4-wire (3P4W) system is also realized from (3P3W) system where the neutral of series transformer used in series part UPQC is considered as the fourth wire for 3P4W system. There are also single-phase UPQC systems. Various topologies such as multilevel topology, single-phase UPQC with two half-bridge converters, H bridge topology and single-phase UPQC with three legs are examined for UPQC applications. A new topology consists of the DC/DC converter and the super capacitor is presented. The series and parallel units do not have a common DC link. Advanced renewable generation based distributed power generation system is developed. UPQC is connected between two independent feeders to regulate the bus voltage of one of the feeders while regulating the voltage across a sensitive load in the other feeder. A new configuration, named multi converter unified power quality conditioner (MC-UPQC), for simultaneous compensation of voltage and current in adjacent feeders has been proposed. Compared to a conventional UPQC, MC-UPQC topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell and interruption in two-feeder systems. The protection of a UPQC against voltage surges and short circuit conditions to prevent its malfunction or destruction is discussed. The power circuit of UPQC generally consists of common energy storage unit, DC/AC converter, LC filter and injection transformer.

**III. SYSTEM MODELING**

The topology of a PV-UPQC-S is presented in Fig. 2. The major parts of the system are a series VSC and shunt VSC connected back to back through a common DC-bus. The VSCs are connected to PCC using interfacing inductors. Ripple filters are used to filter out switching harmonics of the VSCs. The series VSC injects voltage through a series injection transformer. The PV array is connected directly at the DC-bus of UPQC through a reverse blocking diode. The phasor diagram of the PV-UPQC-S with a linear reactive load is presented in Fig. 3. The subscript ‘1’ represents condition when reactive power is shared by shunt VSC only whereas the subscript ‘2’ refers to condition when the series VSC shares a part of reactive load power. The PCC voltage ($V_{SI1}$) and load voltage ($V_{L1}$) are in phase when series VSC is not injecting any voltage. The load current before series compensation is ($I_{L1}$) and the load angle is ($\phi$). The shunt VSC also injects real power obtained from PV array which is represented by ($IPV$). The remaining part of the load real power is obtained from the grid ($IS1$). The shunt VSC current ($ISH1$) before series VSC injection is phasor sum of PV array current and load reactive current.

![Structure of PV-UPQC-S](image)

**Fig. 2. Structure of PV-UPQC-S**

When a part of reactive power of the load is to be shared by series VSC, then series VSC injects voltage ($V_{SE}$) such that load voltage is shifted to ($V_{L2}$). This results in shifting of load current to ($I_{L2}$). However, as the active current drawn from the grid is to remain same ($IS1 = IS2 = IS$), the shunt VSC current reduces to ($ISH2$). It can be observed that due to power angle ($\delta$), the part of reactive burden of shunt VSC is shared by the series VSC thus increasing the utilization of series VSC.
For a given reactive power sharing by series VSC, the magnitude of series VSC voltage $V_{SE}$ is lesser under sag condition as compared to swell condition. This is because the grid current $I_S$ is higher under sag condition as compared to swell condition for a constant load. Based on these observations, in order to prevent excessive VA rating of series VSC, the control implemented is such that, it compensates for reactive power under sag and nominal conditions. The PV array is designed such that it supplies around 30% of load active power. This is because as more load active power is supplied by the PV array, there is less current drawn from the grid which reduces the reactive power sharing capability of series VSC for a fixed voltage rating of series VSC.

There are four control blocks involved in the control of PV-UPQC-S. These are GC-DSC block, load power calculation block, shunt VSC and series VSC control block.

The mathematical implementation of DSC operator is presented in Fig. 4(a). As it can be observed from the figure, in discrete form, the delay is implemented by $z^{-M}$ where $M$ is delay samples corresponding to a delay factor of $N$. When the harmonic content of PCC voltage is unknown, it is often recommended to cascade five delay signal operator blocks with delay factors $N = 2, 4, 8, 16, 32$. This system of cascaded blocks is known as GCDSC block as represented in Fig. 4(b).

The system can be made frequency adaptive, by using GCDSC block as a pre-filtering scheme as in case of GCDSCL. When the GDSC is designed for a frequency of 50Hz, a signal of 49Hz is attenuated by 0.065% and phase error of 3.43° as it can be obtained. Since the normal grid fundamental frequency variation is from 49.3 to 50.2 Hz, this variation causes only negligible magnitude and phase error. Hence, frequency adaptation can be avoided to prevent unnecessary complexity in the system.

This block calculates the instantaneous active and reactive load powers using p-q theory. The block diagram of load power calculation is shown in Fig. 5. The load voltages ($v_{La}, v_{Lb}, v_{Lc}$) and load currents ($i_{La}, i_{Lb}, i_{Lc}$) are converted into $\alpha - \beta$ domain load voltages ($v_{L\alpha}, v_{L\beta}$) and load currents ($i_{L\alpha}, i_{L\beta}$) using power invariant Clarke transform. The instantaneous active and reactive powers, $p_L$ and $q_L$ are passed through low-pass filter (LPF) to obtain fundamental active and reactive powers $PL$ and $QL$.

**IV. SIMULATION RESULTS**

The dynamic behavior PV-UPQC-S under dynamic conditions is simulated in Matlab/Simulink software using Sim Power Systems blockset. The dynamic performance is evaluated at different conditions such as fluctuation in PCC voltages, irradiation variation and load unbalance conditions. The load used is a combination of linear and nonlinear loads.

**CASE-A: PV-UPQC-S PERFORMANCE UNDER LOAD UNBALANCE CONDITION**
The PV-UPQC-S performance during load unbalance condition is presented in Fig. 6. The signals shown are PCC voltages ($v_s$), load voltages ($v_L$), DC-bus voltage ($V_{dc}$), grid currents ($i_s$), load currents ($i_L$), shunt VSC currents ($i_{SH}$), PV array power ($P_{pv}$). At 0.51 s the phase ‘b’ of load is disconnected thus resulting in an unbalanced nonlinear load. It can be observed that the shunt VSC of PV-UPQC-S maintains the grid currents balanced at unity power factor. The DC-bus voltage settles within 0.04 s to its regulated value of 700 V after a slight overshoot of 20 V.

**CASE-B: PV-UPQC-S BEHAVIOR DURING IRRADIATION CHANGE**
The PV-UPQC-S performance during change in irradiation is presented in Fig. 7. The signals shown are PCC voltages ($v_{s}$), load voltages ($v_{L}$), DC-bus voltage ($V_{dc}$), grid currents ($i_{s}$), load currents ($i_{L}$) of phase ‘a’, shunt VSC currents ($i_{SH}$) of phase ‘a’, PV array power ($P_{pv}$), series VSC voltages ($v_{SE}$) and power angle ($\delta$). From 0.95 s to 1 s the solar irradiation is varied from 1000 $W/m^2$ to 500 $W/m^2$. As it can be observed from Fig. 5.4, the power angle and series VSC voltages are higher at higher PV power as compared to lower PV power. This is due the fact that, as the PV array power supplies a part of load real power demand, the grid current drawn is lower. Hence, to compensate the same reactive power, the load angle and series VSC voltage is higher as compared to case when the PV array power is lesser.

**CASE-C: PV-UPQC-S PERFORMANCE DURING PCC VOLTAGE DISTURBANCES**

(a) PCC voltage
The PV-UPQC-S behavior under PCC voltage disturbance is presented in Fig. 8. The solar irradiation (G) is kept constant at 1000 $W/m^2$. The signals shown are PCC voltage of phase 'a' ($v_s$), load voltages ($v_L$), DC-bus voltage ($V_{dc}$), grid currents ($i_s$), load current ($i_L$), shunt VSC current ($i_{SH}$), PV array power ($P_{pv}$), power angle ($\delta$), series VSC voltages ($v_{SE}$). Only signals of one phase are shown in case of certain signals for clarity in representation. At 0.65 s, there is a voltage sag of 0.3 pu along with harmonic distortion and at 0.75 s there is voltage swell of 0.3 pu along with harmonic distortion. It can be seen that load voltage is sinusoidal and reference value despite the distortions in PCC voltage. Under nominal conditions, as seen from $\delta$ and $v_{SE}$ the series VSC still operates to share a part of reactive power of the load. Under swell conditions, the series VSC compensates only swell and no reactive power sharing is done, which is shown by $\delta$ being zero under voltage swell. After PCC voltage swell, there is a slight delay of 2 cycles for series VSC to calculate necessary power angles. This is due to low pass filters using in $PL$ and $QL$ calculation.
The proportional-resonant (PR) controller is one of the most popular controllers used for grid-connected inverters to regulate the current injected into the grid. In this chapter, the PR current controller is designed and implemented for three-phase inverters, in the stationary reference frame and in the natural reference frame. For inverters, the controller deals with sinusoidal signals, which makes it difficult to design the controller with the correct gain that is able to regulate the performance at the fundamental frequency and also to reject harmonic disturbances.

The simulation results are presented to show the effectiveness of the PV-UPQC-S and here obtained an acceptable THD for source current and kept load voltage at its nominal value.

### V. CONCLUSION

The dynamic performance of modified p-q theory based PV-UPQC-S has been analyzed in detail. A GCDSC block has been used to extract FFPS component of distorted PCC voltages which is then utilized in control of using p-q theory PV-UPQC-S. The modified p-q theory enables the PV-UPQCS to work under conditions of distorted PCC voltages. The series VSC shares a part of reactive power of the load under nominal conditions thus increasing utilization of series VSC and also reducing the loading on the shunt VSC. The dynamic performance of PV-UPQC-S is shown under scenarios of sudden change in irradiation and fluctuations in PCC voltage such as voltage sags/swells. The proposed system can work under multiple disturbances such as irradiation variation and PCC voltage disturbances occurring simultaneously. The PVUPQC - S system combines concept of clean energy generation along with power quality improvement thus increasing its utility.

### REFERENCES


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