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UPQC Based Power Quality Enhancement for PV System in Single Phase Distribution Network

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Abstract: In order to get rid of voltage imbalances and voltage harmonics, a single-phase unified power quality conditioner (PV-UPQC) is discussed in this paper as a means of integrating photovoltaic systems into the grid. The current UPQC's DC-link voltage is insufficient to maintain a constant voltage. The proposed work combines the PV panel and UPQC. The boost converter runs the PV array in maximum power point tracking mode, which maximises power output. Matlab-Simulink is used to model the behaviour of PV-UPQC with nonlinear loads in the presence of varying irradiance and grid voltage fluctuations. To regulate photovoltaic (PV)-connected UPQC series and shunt inverters, a PLL-based control method is proposed. In addition to correcting for voltage and current fluctuations, the proposed controller can also detect phases and perfectly synchronise grids. The effectiveness and efficiency of PV-UPQC are studied through computer modelling.

Key words: PV-UPQC, Fixed voltage level, MPPT, Voltage imbalance

Introduction

Power electronics in high-end consumer electronics are the root of voltage and current quality issues. The world also needs to switch to renewable energy sources like wind and solar as conventional energy runs out quickly [5]. Large and small-scale solar and wind energy-based systems have been increasingly installed at the distribution level. During the process of grid integration, power electronic converters are crucial for feeding the grid with electricity produced by renewable energy systems [6-11]. As a result, grid-integrated systems have begun to experience issues with current and voltage quality. This sensitive equipment's abnormal behaviour may be noticed or even result in damage if the voltage quality is poor. Power electronics devices, on the other hand, are employed to deal with power quality issues. Power quality issues can be avoided with the right regulation of these power electronics devices. Highly regarded are power conditioners that employ active power filters, which can take the form of either a shunt active power filter, a series active power filter, or a hybrid active power filter [12-19].

But these power conditioners are used independently to fix voltage and current issues [20]. The UPQCs use a DC-link capacitance to connect a pair of active power filters in series and shunt to improve power quality. UPQC is able to address multiple voltage and current quality issues concurrently due to its hybrid design. Single-phase systems still require attention, even though most system studies are based on the three-phase system with UPQC installed as power conditioners [21-27]. Single-phase systems are more vulnerable to power quality problems like current harmonics, voltage dips, voltage spikes, and voltage unbalance. There has also been research into various active filtering solutions for PV grid-connected systems, with a focus on current quality concerns. In the literature, many different PV grid integration topologies are reported [28-33]. However, single-phase UPQC grid-connected photovoltaic systems have not been reported as of yet. Therefore, the primary focus of this paper is on PV-1UPQC power quality compensation [34-41].

With UPQC-S, you can inject either active or reactive power into the grid. PV-UPQC has a distinct benefit over the other UPQC topologies. It can keep working even if there are problems with voltage, current, or the presence of a fault. Several controller options are available for grid-connected PV systems that include active conditioners. The scope of those regulators is limited to the correction of immediate defects in quality. Single-phase UPQC is used to interface the PV system with the grid, which gets rid of voltage quality and current quality issues [42-49]. In the current setup, UPQC performance is directly tied to the effectiveness of the control algorithm. Instantaneous reactive power theory and synchronous detection algorithms are two examples of widely used controllers. Both the shunt and series inverters of UPQC are controlled by a scheme that generates unit vector templates. Despite its usefulness in conventional power systems, very few publications have detailed the use of such controllers in photovoltaic (PV)-connected grids or PV-connected uninterruptible power supply (UPQC) systems. For the common three-phase setup, a synchronous reference frame controller is typically used. Its use in controlling the inverters of PV-tied UPQC in a single-phase system is unknown [50-57].

The detection of phase and frequency is significantly more important in a grid-connected PV system that is synchronised with the grid. Thus, numerous phase detection mechanisms, often represented as phase-locked loops, are implemented. A Better PLL For typical systems, synchronous reference frames are already in place. When the grid voltage is severely distorted, detecting phase becomes extremely challenging. A significant number of zero crossings are observed to result from the presence of highly distorted elements in the grid. The voltage profile, energy losses of distribution feeders, maintenance costs, and peak-hour loading of transformer tap changers can all be improved by adding PV systems to a power grid. Overloading of the feeders, harmonic pollution, high investment costs, low efficiency, and low reliability are just some of the issues that prevent PV systems from becoming as widely adopted as other renewable technologies. Furthermore, power fluctuations and voltage flicker brought on by variations in solar irradiation can have unfavourable effects on power systems with a high penetration of PV systems [58-64]. Maximum Power Point Tracking (MPPT) is one such control method that can be used to increase the effectiveness of PV systems. Both the voltage and current from the PV array need to be regulated by the controller. This could add unnecessary complexity to the design of the PV system, increasing the likelihood of failure during the pursuit of maximum power in adverse climatic conditions [65-71].

UPQC And Solar Panel

In recent years, "power quality" (PQ) has become an increasingly popular topic of discussion. Most devices and prototypes based on power electronics are now feasible on a commercial platform, thanks to developments in semiconductor device technology. Thanks to advancements in power electronics, numerous types of equipment for generating clean electricity and improving power grid management are now within reach. Some of them include UPQC. The combination of series-active and shunt-active filters is the topic of this paper. The primary function of a UPQC is to mitigate power quality issues like harmonics, negative-sequence current, reactive power, and flickering or imbalanced supply voltage [72-79]. In other words, the UPQC can be installed on power distribution systems or industrial power systems to immediately enhance power quality. Therefore, the UPQC is anticipated to be among the most effective solutions for high-capacity loads that are vulnerable to supply voltage flicker or imbalance. Dual active filters, one in series and one in shunt, make up this device. The active filter in series isolates the load terminal voltage from any fluctuations or imbalances in the supply voltage. Since the shunt-active filter controls the voltage across the dc link, the dc capacitor needs to be significantly smaller [80-85].

When it comes to solving the issue of poor power quality, the General UPQC Unified Power Quality Conditioner (UPQC) is an effective tool. Below is a diagram depicting the UPQC in its most basic form. When installed in a power grid or an industrial power system, the UPQC can immediately begin enhancing power quality. As a result, the UPQC is anticipated to be among the most potent answers to the problem of large capacity loads that are vulnerable to supply voltage flicker or imbalance [86-91]. When everything is balanced perfectly, the PCC voltage is the basic positive sequence sinusoidal voltage from the power source. All of the currents coming from the various sources are sinusoidal currents with phase angles that are in phase with the fundamental voltage. In other words, the series UPQC function equates the load to a resistance. Two active filters serve distinct purposes because the UPQC is a hybrid of series and shunt active filters. The voltage-based distortion is muted and isolated by the series active filter. Shunt active filters eliminate distortion caused by current. It boosts the power factor while compensating for the load's reactive current. The most well-known approach to controlling the voltage and current is based on the instantaneous active and reactive power theory (the pq theory) proposed in, and the most widely used approach today is the dq0 method, which was derived from the pq theory [92-99].

The DC voltage regulator:

Since UPQC adjusts for active power and switch losses, etc., in the compensation process, the DC side voltage will shift. The output voltage of the series active filter will not be equal to the compensation value if the DC voltage is not the same as the rating value. There will be an error in the payment [100]. The shunt active filter operates similarly. A constant voltage is maintained with the help of a control signal generated by the DC voltage regulator. As a result, more power is needed to run the shunt active filter. Research into the control of continuous voltage at the limits of storage capacity revealed the need for a trade-off between filtering and speed. To guarantee the best possible filtering at the lowest possible cost, the studied regulator, the proportional integrator (PI), is the best choice [101-105].

Solar Panel

The photovoltaic effect describes the process by which solar panels (also called photovoltaic cells or PV panels) convert light energy into electrical energy. A solar cell can be thought of as a diode with a P-N junction. The term "photoelectric cell" is used to describe devices whose electrical properties change when exposed to light; solar cells fall into this category. Solar panels are made up of many different kinds of solar cells assembled into modules. Open-circuit voltages of about 0.5 to 0.6 volts can be generated by the most common single-junction silicon solar panels. This isn't excessive on its own, but keep in mind the size of these solar cells. Renewable energy production is greatly increased when combined with a large solar panel [106-109].

Working Principle of Solar Panels:

Light photons can easily enter the p-n junction because the p-type layer is so thin. Photons of light supply the junction with enough energy to create numerous electron-hole pairs. The junction's thermal equilibrium is disrupted by the incoming light [110-112]. In the depletion regions, free electrons can easily flow to the n-type side of the junction. The reduction's hole population may also tend to migrate quickly into the P-type region of the junction. The barrier potential of the junction prevents any further movement once the newly created free electrons have moved toward the n-type. Also, any newly formed holes that travel to the P-type side will encounter the same barrier potential at the forward junction and be unable to pass through. The P.N. junction acts like a miniature battery as the density of electrons on one side, the n-type of the junction, and the density of pores on the other, the p-type of the junction, increases [113-119].

Construction of Solar Panels:

The solar cell's buildup is depicted in the diagram below. An anti-reflective cover glass forms the topmost layer of this cell. Sunlight can't damage semiconductors thanks to this glass. Under the glass of this cell is a small grid pattern with thin metal stripes. glass, metal strips, and anti-reflective coatings can be used to create the outer layer of these cells. The middle layer of the cells is where the photovoltaic effect occurs, making it the most crucial part of the cells. It has a p-type semiconductor layer and an n-type semiconductor layer. These cells have a double-layered base [120-127]. The P-type semiconductor is supported by a metallic grid, and an electric current is generated in the upper layers by a rear metallic electrode. Although their constructions differ slightly from a standard P-N junction diode, solar cells are essentially junction diodes. Over a relatively thick n-type semiconductor, a very thin layer of p-type semiconductors is grown. The p-type semiconductor layer is then covered with finer electrodes. Light can easily pass through these electrodes and reach the thin P-type layer [128-131].

Working of Solar Panels:

When sunlight hits a solar panel, it is converted into usable energy. Semiconductor materials, found in each solar panel's individual cells, combine the best features of insulators and metals. In this way, the power of the sun is harnessed [132-137]. When sunlight strikes the panel, it is absorbed by a semiconductor, where the photon energies are transformed into electron energies and flow outward through the material in the form of an electric current. When a solar cell is exposed to sunlight, a flood of photons is absorbed by the P-silicon area. The photon's energy causes the electron-hole pair to dissociate. An electric field at a p-n junction causes an electron to hop from one type of atom's orbital to the other. To boost this electric field even further, the diode is inverted. This causes the current to begin flowing in the solar cell circuits. When all the solar cells in a panel are operating at full capacity, we get a lot of power [138-141]. In solar power plants, high voltage outputs are achieved by connecting a large number of solar panels together. When there is no sunlight, the solar panels' combined output is converted into electricity and stored in a lithium-ion battery for use later (Fig. 1).

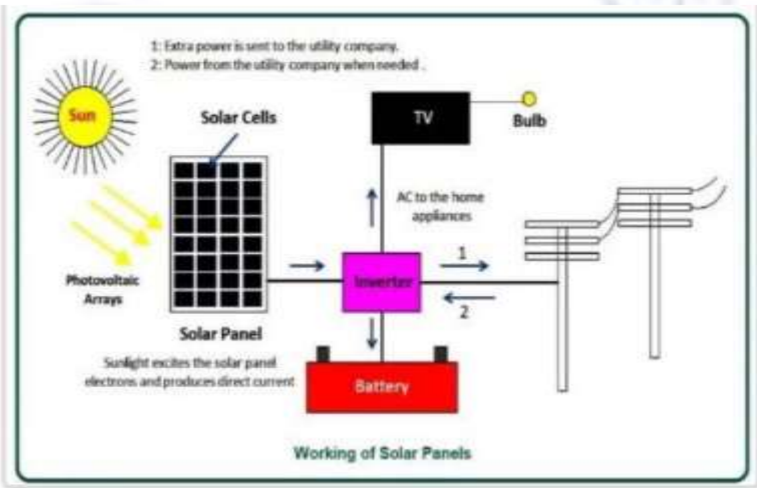

Figure 1: Working of Solar Panels (https://www.mechanicalbooster.com/2017/12/solar-power-plant.html)

The solar panel is the main component of photovoltaic systems. Multiple solar cells work together to form a solar panel. We counted around 35 individual solar cells in a single panel. Although the energy output of a single solar cell is negligible, we were able to charge a 12-volt battery using the combined power of 35 solar panels [142-145].

Solar Cell: P-type and N-type silicon semiconductors are used to create this energy-producing module. It's the nerve centre of photovoltaic farms.

Battery: It is a power plant constructed from P-type and N-type semiconductor silicon. It is the engine that drives solar power plants.

D.C. to A.C. Converter (Inverter): Direct current from solar panels must be changed to alternating current before it can power homes or the grid.

Literature Survey

According to Shirbhate and Jawale [1], fluctuations in the load connected to the system and environmental factors like solar radiation can cause issues with power quality. Voltage fluctuations, voltage distortion, and harmonics on the L.T. line are caused by the source and load at the power conversion centre (PCC).

Power quality issues are discussed, and active filter solutions are provided, by Hari et al. [2]. Power engineers have become interested in developing dynamic and adjustable solutions to power quality issues as it becomes clear that traditional power quality mitigation equipment is insufficient for a growing number of applications. Because of this, specialised power devices have emerged (CPDs). UPQC control schemes and algorithms for power quality improvement and the implementation of a flexible control strategy to improve UPQC performance were the focus of this study.

According to Salman et al. [3], the maximum power point shifts as a result of the solar insolation level and temperature influencing the current-voltage characteristics of the solar cells (MPP). The perturb and observe (P&O) technique is used because it produces the best results among the various MPPT methods. As can be seen from the results, the designed MPPT controller is superior to traditional charge controllers in terms of PV panel efficiency.

The Unified Power Quality Conditioner (UPQC) was identified by Ye et al. [4] as the most promising strategy to enhance microgrid power quality (PQ). The high manufacturing cost, however, presents a significant barrier to widespread adoption of the UPQC method. examines how compensation impacts the optimal UPQC system size. The basic ratings of the shunt converter, series converter, and series transformer are all determined by the size of the UPQC system, so optimising that size is a priority. To realise the implementation of the designed UPQC system under the various compensating conditions, a data-driven control (DDC)-based controller is developed using the variable phase angle control (PAC) method.

System Analysis

Power quality for sensitive end-users can be improved with the help of a single-phase unified power quality conditioner (UPQC). However, a significant low-frequency dc-link voltage ripple will be produced by the inherent instantaneous power difference between a parallel and series converter, reducing the compensation performance of UPQC. This article examines the mechanism by which ripple voltage is generated in a dc link and how this affects the voltage and current used for compensation. A strategy for controlling the single-phase UPQC is proposed with the aim of dampening the impact. It is proposed to implement a specific order harmonic compensation in the inner-current loop of the parallel converter in order to reduce the grid current harmonics, and a notch filter is implemented in the outer voltage loop to prevent the voltage ripple from entering the control loop. To reduce the impact of voltage ripple on the series converter's compensation performance, dc-link voltage feedback is used. The control circuit is split in two: one half is used to regulate the series active filter, which fixes the voltage issue, and the other half regulates the shunt active filter, which fixes the current issue. The unit vector template is used to establish fundamental frequency synchronisation for both control circuits. The shunt filter's control scheme is analogous to that of the series APF. However, in this case, the DC link reference voltage error is calculated and then PI control is used to generate the reference current. By using a PI controller, the DC-link voltage can be held steady. The reference current is calculated by multiplying the PI controller output by the unit vector template.

Proposed System

In this study, we evaluate the efficiency of a single-phase PV-UPQC in a range of irradiance and grid voltage imbalance conditions. The DC link of PV-UPQC is connected to the solar PV array via a boost DC-DC converter. To get the most juice out of a PV array, a boost converter will do a maximum power tracking operation. Load reactive power and harmonics are cancelled out by the shunt compensator connected on the load side, as shown in Fig. 2. In addition, the active power from the PV array is injected by the shunt compensator, which maintains the DC link voltage. The harmonics, voltage imbalance, etc., of the grid voltage are all smoothed out by the series compensator. Three-phase three-wire and three-phase four-wire inverters are both available in PV-UPQC. The series inverter is located between the power source and the PCC, while the shunt inverter is connected to the PCC via the shunt transformer. Both the shunt and series inverters function as current and voltage sources, respectively.

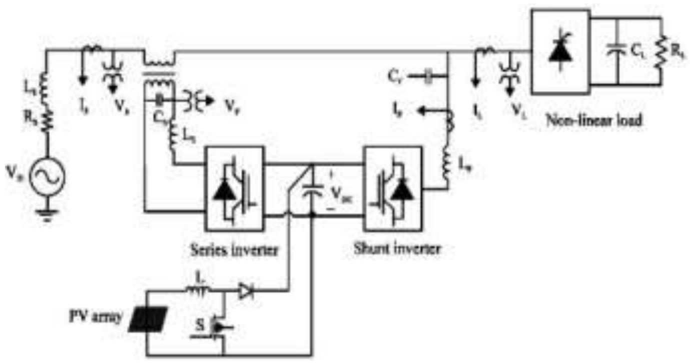

Figure 2: Block Diagram of Proposed System

Because it lacks sources, PV-UPQC can only correct current harmonics, reactive power, voltage distortions, and load flow, but not voltage interruptions. In Fig. 3, we see the typical PV system architecture, which consists of a PV array, DC/DC converters, and DC/AC converters all working together. We develop and implement a landing-mode-based control strategy for two coupled systems. Power is provided to the load jointly by the source and PV in the interconnected mode, and solely by PV in the landing mode. The system reverts to its normally interconnected state once the voltage disruption is fixed. The MPPT method enhances the UPQC's functionality (P&O).

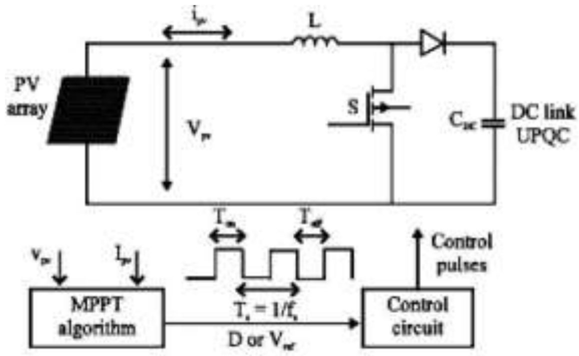

Figure 3: Schematic Block Diagram of MPPT Of PV Array

MPPT Technique

Maximum Power Point Tracking, or MPPT for short, is an algorithm typically found in charge controllers designed to draw the most possible power from photovoltaic (PV) modules under a given set of conditions. Maximum power point refers to the voltage at which the PV module produces the most energy (or peak power voltage). Solar cell efficiency, maximum power, and ambient temperature all play a role in how much energy can be generated from the sun. The average solar panel is only able to convert 40% of the solar irradiance into usable electricity. Maximum power point tracking is used to maximise the solar panel's output. The Maximum Power Transfer theorem states that an electrical circuit's output power is highest when the source impedance (Thevenin impedance) is equal to the load impedance. Therefore, following the maximum power point becomes a problem of impedance matching. On the input side, we've got a solar panel wired up to a boost converter to boost the voltage so it can power things like a motor load. The source impedance and the load impedance can be matched by adjusting the boost converter's duty cycle (Fig. 4).

The simplest technique is known as "perturb and observe" (P&O). Because we only need a single sensor—a voltage sensor—to measure the power from the PV array, our system is cheap and simple to set up. While this algorithm's time complexity is low, it continues to cause perturbations in both directions even as it approaches the MPP. An appropriate error limit or wait function, both of which increase the time complexity of the algorithm, may be used at this point because the algorithm is very close to the MPP. Perturbing the PV panel's operating voltage by a small amount and monitoring the resulting change in power P is what the Perturb & Observe algorithm calls "perturbing in the direction of MPP" (fig.5).

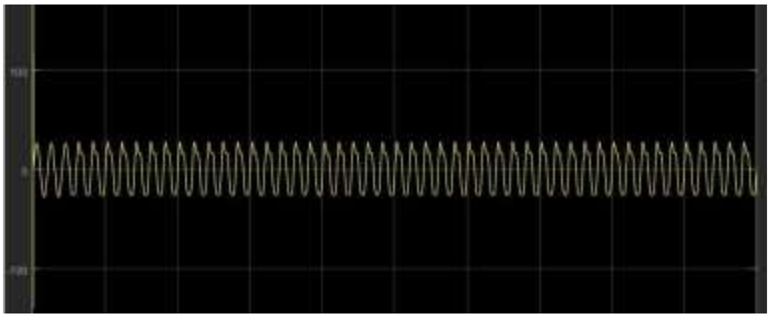

Figure 4: Grid Voltage

Figure 5: PV Output Voltage And PWM

Conclusion

The outcomes of an analysis of UPQC and PV working together are detailed in this project. The proposed system includes a PV array, a DC/DC converter, and voltage compensators for voltage dips, surges, interruptions, reactive power, and harmonics in both landing and interconnected modes. The proposed system has the potential to compensate for voltage interruptions using UPQC by connecting PV to a DC link, and it can reduce the cost of a PV interface inverter connected to the grid as a result. The P and O method is used to find the PV array's maximum power point in this proposed system. Using MATLAB/SIMULINK, we analyse the functioning of this proposed system, and the results of our simulations verify the correct operation of the system.

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