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# "Design and performance Analysis of Three Phase Solar PV Integrated UPQC Using Artificial Neural Network: A Review"

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***Abstract:*** *This paper deals with the Artificial Neural Network based design and performance analysis of a three-phase solar photovoltaic integrated unified power quality conditioner (PV-UPQC).The PV-UPQC consists of a shunt and series-connected voltage compensators connected back-to-back with common dc-link. The shunt compensator are performs the dual function of extracting power from PV array apart from compensating for load current harmonics. An improved synchronous arrangement management supported moving average filter is employed for extraction of load active current part for improved performance of the PV-UPQC. The series compensator compensates for the grid aspect power quality issues like grid voltage sags/swells. The compensator injects voltage in-phase/out of section with purpose of common coupling (PCC) voltage throughout sag and swells conditions.*

***Index Terms:*** *Shunt Compensator, Series Compensator, Power Quality, UPQC, Solar PV,MPPT.*

## I. Introduction

As solar energy is abundantly available in most parts of world, it has become the most economical source of renewable energy. Moreover, it is an energy source which has no greenhouse effect. Hence, solar photovoltaic (PV) arrays are now the most clean renewable energy and with recent advances in solar panel manufacturing, the efficiency of the panels are increasing. With the advancement in semiconductor technology, there is an increased penetration of power electronic loads .These loads such as computer power supplies, adjustable speed drives, switched mode power supplies etc. have very good efficiency, however, they draw nonlinear currents. These nonlinear currents cause voltage distortion at point of common coupling particularly in distribution systems.

There is also increasing emphasis on clean energy generation through installation of rooftop PV systems in small apartments as well as in commercial buildings. However, due to the intermittent nature of the PV energy sources, an increased penetration of such systems, particularly in weak distribution systems leads to voltage quality problems like voltage sags and swells, which eventually instability in the grid. These voltage quality problems also lead to frequent false tripping of power electronic systems, malfunctioning and false triggering of electronic systems and increased heating of capacitor banks etc. Power quality issues at both load side and grid side are major problems faced by modern distribution systems. Developing an intelligent system with Artificial Neural Networks (ANN) to track the Maximum Power Point (MPP) of a PV Array is being proposed. A PV array has non-linear output characteristics due to the insolation, temperature variations and the optimum operating point needs to be tracked in order to draw maximum power from the system.

A three-phase single-stage solar photovoltaic interfaced unified power quality conditioner (PV-UPQC) was provided with the design, configuration and control. The PV-UPQC is used to maintain the quality of power under different fluctuations of current and voltage. The PV-UPQC is made up of a shunt and series linked voltage compensators connected with standard DC-link back to back. In addition to compensating for load current harmonics, the shunt compensator performs the dual task of extracting power from the PV set. An improved synchronous frame control based on the moving average filter is used to remove the active current load element to enhance the PV-UPQC output. The compensator series addresses the problems of grid side power performance such as grid voltage sags / swells. The compensator injects in-phase / out - of-phase voltage with common coupling point (PCC) voltage, respectively, during the sag and swell conditions. Also under investigation is the complex behavior of PV-UPQC under irradiance transition.In this project the design and performance analysis of a three phase PV-UPQC are presented. The main advantages of the proposed system are as follows:

- Integration of clean energy generation and power quality improvement.
- Simultaneous voltage and current quality improvement.

• Stable under various dynamic conditions of voltage sags/swells, load unbalance and irradiation variation. The performance of the proposed system is analyzed extensively under both dynamic and steady state conditions using Matlab-Simulink software.

## II. Problem Formulation

A) Existing System

Work is under way at the moment. In the case of UPQC, rapid detection of the disturbance signal with high accuracy, fast processing of the reference signal and high dynamic controller response are the primary requirements for desired compensation. Under parameter variations nonlinearity load disturbance, unbalance load, harmonics, etc. the modern controller fails to perform satisfactorily.

B) Proposed System

In the case of UPQC, rapid identification of the disturbance signal with high accuracy, quick processing of the reference signal, and high dynamic controller response are the primary criteria for required compensation. Under variations in parameters, the conventional controller does not perform satisfactorily nonlinearity load disturbance, etc. The Artificial Neural Network (ANN)-based controllers provide fast dynamic response to the traditional controller problem while retaining the converter system's stability over large operating range. The artificial neural network (ANN) is based on machine learning approach that models human brain and contain the number of artificial neuron to perform the specific task in the network. The ANN is made up of interconnecting artificial neurons. It is essentially a cluster of suitably interconnected nonlinear elements of very simple form that possess the ability to learn and adapt. It resembles the brain in two aspects:
1) The knowledge is acquired by the network through the learning process and
2) Interneuron connection strengths are used to store the knowledge.

c)Objectives:

The primary objectives of this study can be summarized as follows:
The main objective of the project is to mitigate the harmonics caused by nonlinear load and maintains the THD of grid current under limits.
1) Study of three-phase solar PV integrated UPQC:- The section includes the detail study of PV-UPQC.
2) Design of Control Structure of Shunt Compensator: - This section includes the detail study of Control Structure of shunt Compensator.
3) Design of Control Structure of Series Compensator: - This section includes the detail study of Control Structure of series Compensator.
4) Design of Artificial Neural Network Controller :- This section includes the detail study of Control Structure of ANN Controller.
5) Design of System Configuration PV-UPQC :- The section deals with simulation process three-phase solar PV integrated UPQC.

## III. System Configuration And Design

The PV-UPQC structure is shown in Fig.1. A three-phase system is designed for the PV-UPQC. The PVUPQC is a shunt and series compensator that is connected to a common DC bus. The shunt compensator on the side of the load is connected. Through a reverse blocking diode, the solar PV array is directly inserted into the UPQC DC-link. The compensator series operates in voltage control mode and compensates for the sags / swells of the grid voltage. Through interfacing inductors, the shunt and series compensators are built into the system. Using a series injection transformer, the series compensator injects voltage into grid.Ripple filters are used to filter harmonics produced as a resultof converter switching action. The load used i s a nonlinear load consisting of a voltagefed bridge.

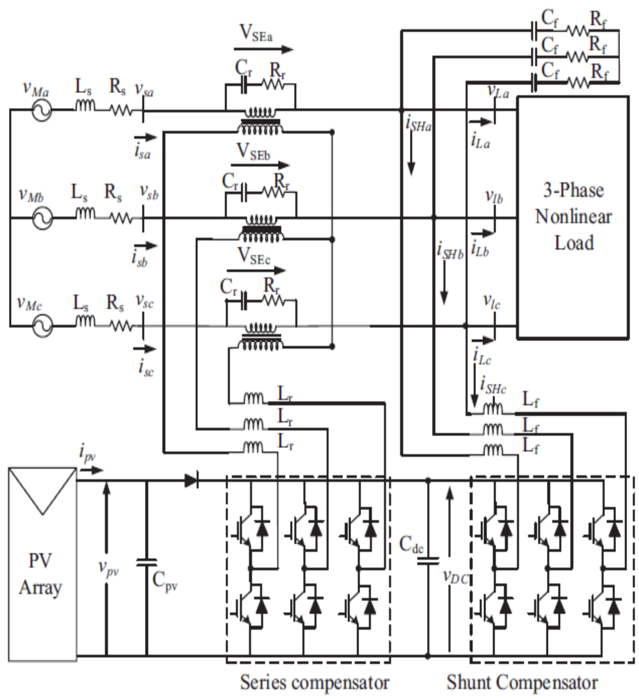


**Fig.** System configuration of PV-UPQC.

*A. Design of PV-UPQC*

The PV-UPQC design procedure begins with proper PV array size, DC-link condenser, DC-Link voltage rate, etc. The shunt compensator is designed to accommodate the peak power output from the PV range apart from compensating the reactive power of the load current and the harmonics of the present. As the PV array is directly integrated into UPQC's DC-link, the PV array is sized to match the desired DC link voltage with the MPP voltage. The rating is such that the PV array provides the active load power and power into the grid under nominal conditions. The detailed specifications for the PV range are given in Appendix A. The other built components are series and shunt interfacing inductors series injection components of series compensator. Thedesign of PV-UPQC is elaborated as follows.

1. DC-Link voltage magnitude

DC link voltage magnitude Vdc depends on the modulation depth used and the system's per-phase voltage. The magnitude of the DC-link voltageshould more than double the per-phase voltage peak of the three phase system[8] and is given as Vdc=22VLL / almost3m(1) where the modulation depth (m) is taken as 1 and VLL is the grid line voltage. The required minimum value of DC-bus voltage is 677.7 V for a line voltage of 415 V. DC-bus voltage is set at 700 V(approx.), which is the same as PV array operating voltage MPPT under STC conditions.

2.DC-Bus Capacitor Rating

The size of the DC-link capacitor is based on the power requirement and the DC-bus voltage. The energy balance equation for the DC-bus condenser is given as follows[ 8], Cdc=3kaVphIsht/0.5 (Vdc 2— Vdc 21)= 30.11.5239.634.50.0.03/0.5= 9.3mF (7002 — 677.792) Where Vdc is the average DC-bus voltage, Vdc1 is the lowest necessary value of the DC-bus voltage, a is the overloading variable, Vph is the per-phase voltage, t is the minimum time required to achieve a steady value after a disruption, Ish is the shunt compensator's per-phase current, k factor takes into account energy variability throughout dynamics. The minimum required voltage of DC-link is Vdc1= 677.69 V as obtained from (2), Vdc= 700 V, Vph= 239.60 V, Ish= 57.5 A, t= 30 ms, a= 1.2, and the value of Cdc is obtained as 9.3 mF for dynamic energy change= 10%, k= 0.1.

3. Shunt Compensator Interface Inductor

The shunt compensator interface rating depends on the ripple current, the frequency of switching and the voltage of the DC-link. The expression for the interfacing inductor is as, Lf=√3mVdc/12afshIcr,pp =√3×1×700/12×1.2×10000×6.9 = 800μH ≈ 1mH where m is depth of modulation, a is pu value of maximum overload, fshis the switching frequency, Icr,pp is the inductor ripple current which is taken as 20% of rms phase current of shunt compensator. Here, the value of m=1, a=1.2, fsh=10kHz, Vdc=700V, is 800 µH. The selected value is approximately 1mH.

4.Series Injection Transformer

The PV-UPQC is designed to compensate for a sag / swell of 0.3 pu i.e. 71.88 V. The required injection voltage is therefore only 71.88 V, resulting in a low modulation index for the series compensator when the DC-link voltage is700V. To operate the series compensator with minimal harmonics, one keeps the series compensator modulation index close to unity. Therefore a series transformer with a turn ratio is used, KSE= VVVSC / VSE= 3.33 (4) the value obtained for KSE is 3.33. The selected value is 3. The injection transformer series rating as,SSE=3VSEISEsag=37246=10kVA.(5) The current in the VSC series is the same as the grid current. The supp ly current under 0.3 pu is 46 A and is therefore 10 kVA for the injection transformer.

5. Series Compensator interfacing inductor

The score of the series compensator interfacing inductor depends on the swelling current, the switching frequency and the voltage of the DC link. Its value is expressed as, Lr =√3 × mVdcKSE/ 12afseIr =√3 × 1 × 700 × 3/ 12 × 1.2 × 10000 × 7.1 = 3.6mH where m is the depth of modulation, a is the pu value of maximum overload, fse is the switching frequency, Ir is the inductor current ripple, which is taken to be 20% of grid current. In this case, m=1, a=1,5, fse=10 kHz, Vdc=700 V and 20 percent ripple current, the selected value is 3.6 mH.

## IV. Control Of PV-UPQC

The shunt compensator and the series compensator are the central subsystems of PV-UPQC. The shunt compensator compensates for the problems of load power quality such as harmonics of load current and reactive load power. The shunt compensator performs the additional power supply feature from the solar PV array in the case of PVUPQC. The shunt compensator uses a maximum power point tracking (MPPT) algorithm to extract power from the PV array. The series compensator protects the load from problems of grid side power quality such as voltage sags/swells by injecting suitable voltage in the grid voltage phase.

A. Shunt Compensator Control

By running it at its maximum power level, the shunt compensator extracts the maximum power from the solar PV array. The PV-UPQC DC-link is generated by the maximum power point tracking (MPPT) algorithm. Some of the widely used MPPT algorithms[28] are Perturb and Observe (P&O) algorithms, incremental algorithms of conductance (INC). The (P&O) algorithm is used in this work to implement MPPT. The voltage of the DC-link is maintained by using a PI controller at the created reference. The shunt compensator extracts the active basic component of the load current to perform the load current compensation.The shunt compensator is controlled for this work by using SRF technique to extract the fundamental active component of the load current. The shunt compensator control structure is shown in Fig. 2. Using phase and frequency information obtained from PLL, the load currents are translated to d-q-0 domain. The input of PLL is the voltage of the PCC. The load current d-component (ILd) is filtered to remove the DC component (ILdf), which is the basic component in the reference frame of abc. A moving average filter (MAF) is used to remove the DC portion without degrading the dynamic output.The moving average filter transfer function is given as, MAF(s)=1-e-Tws / Tws(7), where Tw is the moving average filter's window length. Due to the double harmonic portion being the lowest harmonic present in the d-axis current, Tw is held at half the fundamental time period. The MAF has multiple window length unit DC gain and zero gain integer. The PV array's equivalent current component is given as, Ipvg=23PpvVs(8) where Ppv is the PV array power and Vs is the PCC voltage magnitude. The reference grid current in d-axis is givenasI∗sd= ILdf+Iloss-Ipvg (9) I∗sd is converted to abc domain reference grid currents. The reference grid current in d-axis is given as *I∗sd=ILdf+Iloss-Ipvg*(9) *I∗sd*is converted to abc domain reference grid currents. The reference grid currents are compared with the sense d grid currents in a hysteresis current controller to generate the gating pulses for the shunt converter.

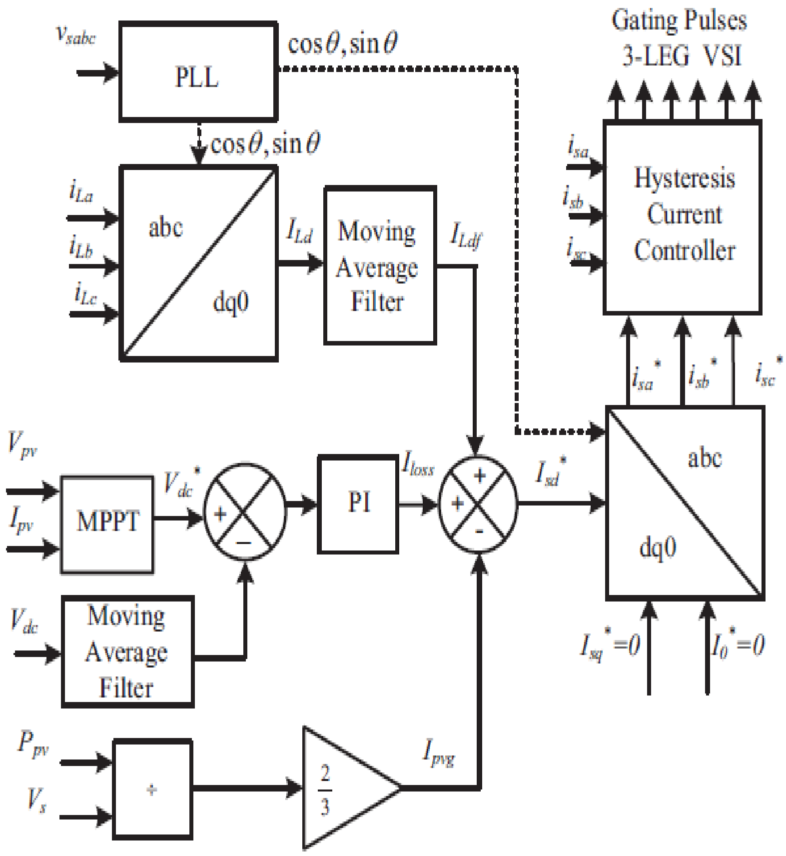


**Fig.** Control Structure of Shunt Compensator

B. Series Compensator Control

The series compensator control strategy consists of pre-compensation, in-phase compensation and optimal energy compensation. A detailed description of the various compensation techniques used for series compensator control is stated in[ 29],[ 30] In this study, the series compensator injects voltage in the same cycle as the grid voltage, resulting in the series compensator's minimum injection voltage.The basic component of PCC voltage is extracted using a PLL that is used in the dq-0 domain to generate the reference axis.The load voltage of reference is generated using the PCC voltage phase and frequency information obtained using PLL. The voltages and voltages of the PCC are converted to the domain d-q-0. The peak load reference voltage is the d-axis part value of the load reference voltage, since the reference load voltage is to be in accordance with the PCC voltage. The element of the q-axis remains at zero. The difference between load voltage and PCC voltage gives the actual countervailing voltages of the series. To produce correct reference signals, the difference between reference and actual series compensator voltages is passed on to PI controllers. These signals are translated to abc domain and passed through the voltage controller for pulse width modulation (PWM) to produce suitable gating signals for the series compensator.The difference between the voltage of the load reference and the voltage of the PCC gives the series compensator reference voltage.

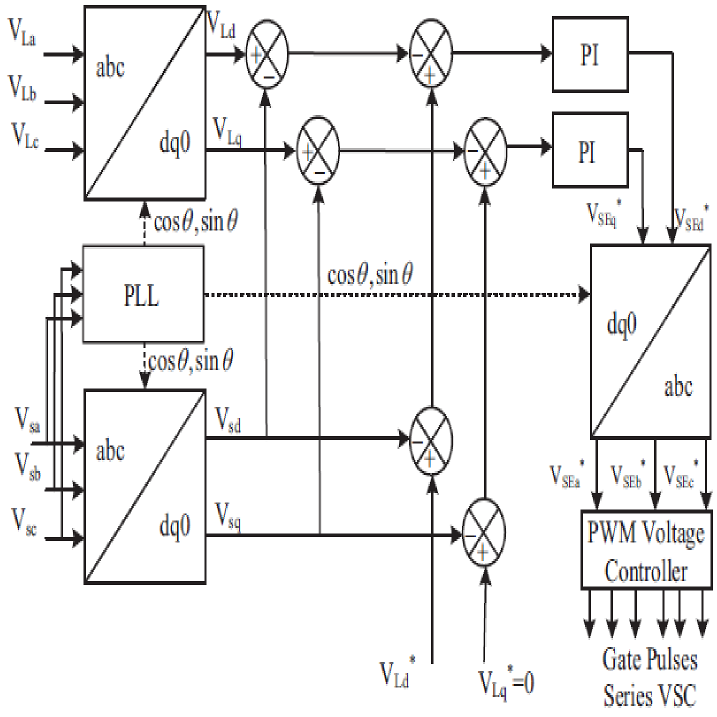


**Fig.** Control Structure of Series Compensator

## V. ANN Control Design

The ANN-based controller is designed for the current control of the shunt active power filter and alsotrained offline using the data from the conventional proportional-integral controller. An exhaustive simulation study is carried out to investigate the performance of the ANN controller and compare its performance with the conventional PI controller results. The primary requirement for the desired compensation of UPQC are the rapid detection in the disturbance of the signal along with high accuracy, high dynamic response of the controller and quick processing of the reference signal. The conventional controller fails to perform satisfactorily under parameter variations nonlinearity load disturbance, etc. A recent study indicates that NN- based controller's gives quick dynamic response and also maintains the stability over a wide operating range of the converter system. ANN is made up of interconnecting various artificial neurons. ANN is essentially a cluster of suitably interconnected nonlinear elements of very simple form that possess the ability to learn and adapt. It resembles the brain in two aspects: 1) Through the learning process the knowledge is acquired by the network. 2) To store knowledge the Interneuron connection strengths are used. These networks are differentiated by their topology, the way in which they communicate with their environment, the manner in which they are trained, and their ability to process information. ANNs are used to solve the AI problems without necessarily creating a model of a real dynamic system.

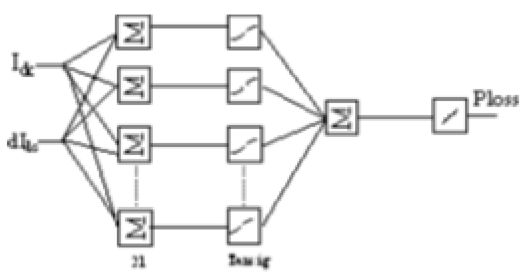


**Fig.**Exploded diagram of the artificial neural network

A multi-layer feed forward type ANN based controller is designed for the improvement in the performance of the UPQC. The network is so designed that it has three layers, such that the input layer with has 2 neuron, the hidden layer has 21 neuron, and the output layer has 1 neuron, respectively. The large data of the dc-link current forand intervals from the conventional method are collected and are stored in the MATLAB workspace.These data are used for training the NN. Theactivation functions chosen are tan sigmoidal forinput and hidden layers and pure linear in the outputlayer, respectively. The multilayer feed forward typeNN works as the compensation signal generator.

## VI. Conclusion

The design and dynamic performance of three-phase PV-UPQC have been analyzed under conditions of variable irradiation and grid voltage sags/swells. Harmonic rich source currents are compensated even under load change conditions. It is observed that PV-UPQC mitigates the harmonics caused by nonlinear load and maintains the THD of grid current under limits. The system is found to be stable under variation of irradiation, voltage sags/swell and load unbalance. Therefore Solar PV integrated with UPQC has shown satisfactory performance for power quality improvement. The performance of d-q control particularly in load unbalanced condition has been improved through the use of moving average filter. It can be seen that PV-UPQC is a good solution for modern distribution system by integrating distributed generation with power quality improvement.

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