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Total Harmonics Distortion and Unbalance Regulation of Power Grid and Load Voltages by Photovoltaic Tied UPQC with Artificial Neural Networks

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Abstract: An Artificial Neural network-based Unified Power Quality controller (UPQC) is proposed in this paper. An unbalanced grid voltage and Load voltage are compensated by the UPQC in the single-phase power system. The Renewable energy source solar energy is connected to the grid. The perturb and observe algorithm *(*P&O*)* is used to track the Maximum power from the Solar panels. This system UPQC is used to compensate the supply voltage and load voltage at the same time in a power distribution network. The grid and load voltage unbalances are regulated, and the Total Harmonics Distortion (THD) of the grid and load voltages is controlled by the UPQC via an Artificial Neural Networks (ANN) controller. In MATLAB/Simulink, the results are simulated and analyzed.

Keywords: Photovoltaic, MPPT, *P&O,* Unified Power Quality Controller(UPQC), ANN, AI, THD.

1. Introduction

Concerns about global warming and the state of the environment have sped up the adoption of renewable energy sources in recent years. Distributed generation from renewable sources has increased quickly in recent years. This has helped satisfy load demands while decreasing reliance on traditional energy sources like petroleum. Distributed generation (DG) technologies, such as solar and wind rotor systems, benefit greatly from microgrid installations. Almost all load and load-side equipment is very sensitive to power quality issues. Each kind of load category will get electricity from the microgrid at a distinct power quality [8], selectable by a switch. Extra power quality (PQSs) such as the apf and the dynamic constant power source may be implemented and provide energy to sensitive loads [9–11].

Existing PQS of all types may be readily implemented at any network site to improve energy efficiency; however, this does need dedicated space for PQS and incurs an additional cost. Alternately, the power quality may be enhanced by the incorporation of a microgrid electric inverter [12]. Supplying that converted energy to the grid grid underneath the grid power control is the primary function of the inverter, which is utilized in the micro grid to convert the DC producing power into such an AC system. Alterations to the inverter's control or topology may, however, be made to accommodate for harmonics or voltage. Modern power electronics have made custom devices such as DSTATCOM, DVR, and UPQC available to help mitigate energy quality issues.

The sags/swells in the grid voltage are offset with DVR connected to the grid series [8]. DSTACOM, the parallel shunt compensation system connected to the PCC, offsets power quality issues including reactive currents, harmonics, and load imbalances [9]. UPQC provides for a VAR load requirement so that supply voltage and current are always in phase; no further power factor adjustment equipment is therefore needed. It decreases supply current harmonics to enhance nonlinear loading utility current efficiency. UPQC retains the rated load end voltage even when the voltage is supply sag.

This article deals with UPQC's implementation in the distribution system with PV Arrays. There are two voltage sources inverters for UPQC. The main objective of the inverter series is to separate the subtraction and delivery mechanism harmonically. Furthermore, the inverter series can compensate for voltage flicker/impact and regulate voltage and harmonic offset on the utility-consumer PCC.

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2. Related Work

This paper examines the techniques for the phase synchronization integrated so far in UPQC control system. Phase synchronization consists of two common techniques used in past: Zero crossing detection (ZCD); Phase Locked Loop(PLL). and recent techniques such as the fundamental component extraction, artificial neural network (ANN) and unit vector. In this article the synchronization one-phase power system technique is classified for the intended application of UPQC. Over the years, three-phase works on UPQC have become more common in comparison with single-phase system, particularly as power device applications and nonlinear loads are broader in the three-phase context. This paper, examines the synchronization technique itself in order to prevent redundancy, and then highlights the suitability of each single-phase device implementation technique.

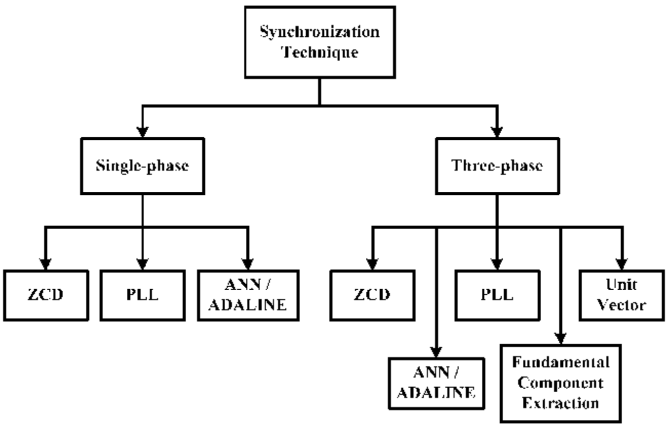
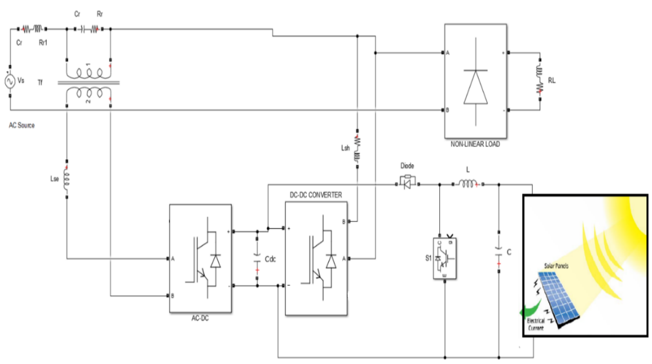


Figure.1 Block diagram of Synchronization Techniques to SAPF. Zero Crossing Detection (ZCD); artificial Neural Network (ANN), Phase-Locked Loop(PLL).

2.1. Phase-Locked Loop (PLL) Technique

The phaselockedloop (PLL) technique was recognized and widely used, due to its simple control structure and efficiency in handling different grid situations, the technique discussed in this article.



In a closed loop controller operation, PD first compares the two input signals to create a phase error signal for the same phase of operation. A Low – PassFilter(LPF), which deletes noise and other high-frequency elements from PD, then filters the generated error. VCO then processes the filtered signal to produce a modified output phase, i.e. feedback to the PD. The looping process is continued to minimize the errors caused continually and the output phase is locked and the desired reference signal-phase is matched when it reaches zero value.

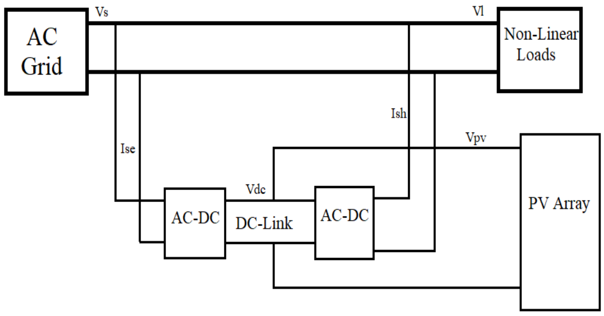


Figure.2 Circuit diagram of a proposed PV tied UPQC.

PLL is an old technology, and in many fields, control systems, communication, and instrumentation, it has been used successfully in recent years. Its structure comprises three basic functional blocks known as PD, LF, and voltagecontrolledoscillator (VCO).

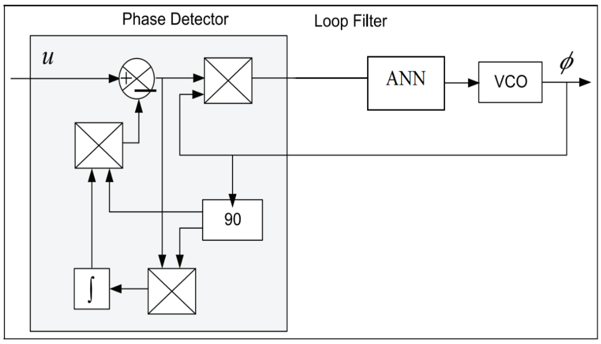


Figure.3 Basic phase-locked loop (PLL) technique Control structure.

The basic PLL was then further enhanced for the UPQC as a synchronous SRF-based PLL (or simply SRF-PLL). In single phase systems, SRF-PLL technology has been successfully implemented. The evident difference in the implementation method of the PD block is, as seen from the SRF-PLL and simple PLL techniques. As its appellation suggests, SRF-PLL uses the SRF principle to create a PD-Block in which three-phase voltage is transformed into a stationary, two-phase $\alpha\beta$ frame (by Clarke transformation) and then a d-q, rotary, park-transformation reference frame as shown in Equ (1) & (2), respectively. Notice that the 'k' constant refers to the rate of sampling. The resulting q variable is then manipulated by means of a proportional integral (PI) and the angular frequency - the output of the utility- is provided. The user angle of α–dq is

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accomplished by the inclusion of the corner frequency and the looping mechanism proceeds to flow the corner of phase back to the transition block of β–dq until the angle of the phase is set.

$$v_\beta = V\cos(\omega t + 90^\circ) = V\sin(\omega t)$$

$$v_{dq} = \begin{bmatrix}\cos(\omega t) & \sin(\omega t)\\ \sin(\omega t) & \cos(\omega t)\end{bmatrix} v_{\alpha\beta}$$

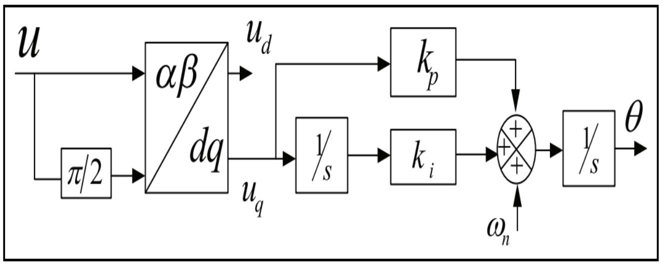

Figure.4 Block diagram of synchronous Reference Frame (SRF)-PLL technique for Single-Phase Systems.

For an ideal case park transformation provides $v_{q=0}$, however any grid frequency change results in $v_{q\neq 0}$.

$$v_{q\approx\cos(\omega t)(\sin(\omega t)-\sin(\omega t)-\cos(\omega t)\varphi)} = \cos^2(\omega t)\varphi = \frac{-\varphi}{2}(1+\cos(2\omega t))$$

Implementation in three-phase method, the SRF-PLL technique was initially developed. However, it can also be used in a single-phase device by changing slightly the initial signal processing approach. The translation of the single-phase signal to stationary αβ-frame is necessary by means of the different approach in single-phase application because it does not apply to Clarke transformation on a single-phase device. An interesting approach is found when a single-phase signal is handled directly by α-frame signal, β-frame signal by inserting a phase-delay of π/2 into actual single-phase signal. For SRF-PLL single-phase, the subsequent phase lock processes are essentially identical to the SRF-PLL 3-phase.

The key benefit of SRF-PLL is that the utility frequency and phase angle can be reliably and easily monitored in case the supply voltage is free from any distortions and imbalances. Sadly, the voltage of the source is unbalanced and/or skewed because of harmonics, for 3-phase device. The voltage does not function properly. The use of a further low-pass filter (LPF) in an interlock after the αβ–dq transformation block is an excellent way to mitigate this inherent issue. However, the ordering and cutting frequency of the LPF must be carefully matched heuristically to make a reasonable balance between its performance of distortion refuse and its speed. The decent update is that conventional SRF-PLL, in order to ensure the efficiency when operating under an unbalanced and/or distorted utilities grid.

As shown in Figure3, the original stage of the processing is identical to the traditional PLL method shown in Figure2 in which three-phasis voltage is transformed into stationary two-phasis β-frame, then into a dq rotating reference-frame in the abc natural reference. However, the positives vSdq+1 and vSdq−1 are isolated in the dq revolving reference frame. Every decoupling cell is subsequence by extracting elements of fundamental frequency (potential-sequence v ̅Sdq+1 and negative-sequence v ̅Sdq−1). In the phase-locking loop the extracted positive-sequence element is then added to the desired phase-angle c. Although it was revealed that this improved technique eliminated fully the detection fault of conventional SRF-PLL, operated precisely even in under unbalanced and skewed useful situations, it is a very complex detection method due to the need for an additional SRF loop.

Different modifications to conventional PLL techniques were found during phase tracking techniques, which can provide comparable performance with a robust PLL. The method is called the method of D-estimation. It's not a standard PLL approach, but rather a basic filtering approach called D-filter. In reality, it can provide a phase and frequency estimate similar to the PLL. Notice that in UPQC applications this approach is not yet used. But it was experimentally tested that even under the influence of harmonic deformation and polluted noise, it was stable and robust. This is an significant aspect of UPQC phase-tracking/synchronization technique. The adaptability analysis of the D-estimation system can therefore be a possible research in UPQC applications for future activities.

3. Control References of Series & Parallel Inverters by ANN

Management of UPQC time domains Techniques are most commonly used in three-phase p-q theory and three-phase d-q theory or the synchronous reference system. In this mode the voltage and current signals are passed to the stationary (p-q' theory) or synchronous (d-q theory) frames in the ABC frame, so that the basic and harmonic quantities are released [13].

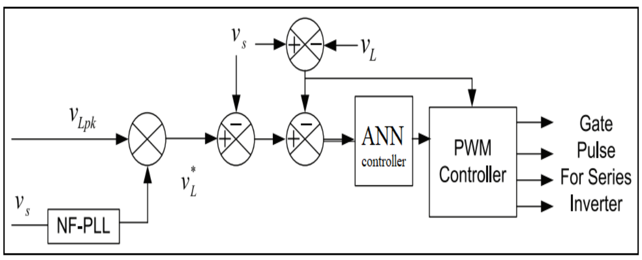

Figure 5. Control structure of ANN

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Active and reactive spontaneous forces are calculated in p-q theory, while in d-q the current is handled regardless of the energy source. The interesting feature of these theories is that the real and reactive powers of basic elements (p-q theory) and of basic elements (d-q theory) are DC quantities. dc quantities.

With a low-pass filter or high-pass filter, these quantities can be filtered easily. The filtering of the signal dc extraction in the α-β reference frame is insensitive to any phase change error that occurs in the LPF. These cut-off frequencies of LPF or HPF can, however, affect the dynamic look of the controller[5]. In terms of distortion and/our unbalance in the supply voltages the initial p-Q phase theory has disadvantages. The unique p-q theory has been modified and commonly referred to as p-q-r[5] to solve these limitations. In addition, both p-q and d-q theories in three phases were altered to allow these methods to be extended for single-phase

APFs like UPQC systems in a single-phase fashion. Input and output voltages of UPQC to regulate speed and distinguish the operation of the device by using a PI control are controlled by a d-q-o axis (SRF) dependent controller (d-q-o axes). When continuous check references (V&I) in the SRF based controller are authorized[1] the PI control contributes to a reduction in steady-state errors. In this sense, a-b-c to d-q is called the transformation of Park. The 3 phase PLL is used in combination with 3 phase PLL scheme with disturbances of the utility voltage, such as harmonics or imbalances. Since the controller mainly addresses d-q amounts, the device is very powerful.

Using the traditional SRF method, harmonics found in supply voltages or current can be extracted. The distorted currents are initially transmitted to two-phase stationary coordinates for current harmonic compensation by means of an α-β transformation. The stationary frame quantities are then moved from the phase-locking loop into synchronous rotating frames using cosine and sinus function (PLL). Often called d-q approach is the traditional SRF algorithm. d-q-0 transformation equations, filters, and modified PLL algorithms are employed for the proposed SRF control system. This is a quick and convenient solution, with reduced current calculation.

It can also work on DSP platforms effectively. Thus, under unbalanced and skewed load conditions, UPQC is intensively improved by the proposed modified PLL algorithm. Artificial neural network models focused on the neural brain structure are relative electronic models.

The brain learns essentially from experience[3]. It goes without saying that small energy-efficient packages will actually solve them outside the reach of existing computers. This brain modelling promises to also create computer solutions in a less technical way. The ANN consists of artificial neurons that interconnect. It is essentially a class of well-connected, very simple nonlinear elements which have the ability to learn[15]. ANN takes data samples to find solutions that saves time and resources instead of full data sets. Mathematical models for developing current data analytics technology are considered fairly simple ANNs.

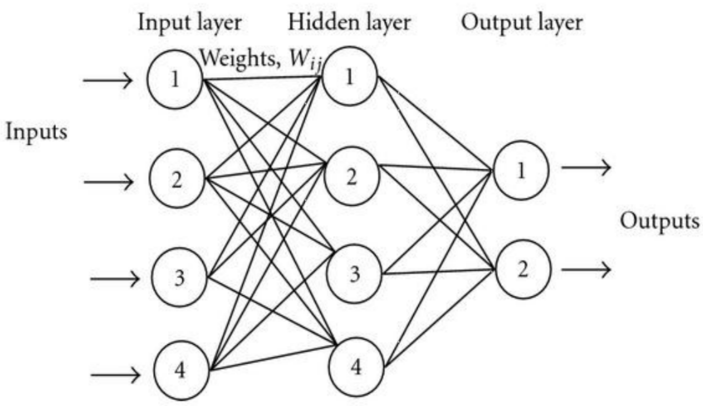

Figure.6 ANN structure

In the experiment, source voltage $vs(k)$ is first measured and compared with an estimated voltage $vfund_{est(k)}$. Note that k refers to the digital implementation sampling rate. E(k) is processed with an algorithm to change weight W or amplitude(coefficient) W_{11} and W_{21} of $\sin(k\omega\Delta t)$ and $\mathrm{Cos}\,(k\omega\Delta t)$) vectors as shown in equation (7).

The source voltage $vs(k)$ is calculated and compared with an approximate $vfund\_est(k)$ voltage (k). Notice that the constant k refers to the digital sampling rate. Here, e(k) error results in an algorithm that updates the sine sin (k ft) or cosine cos(k ft) vector by weight, as shown in the Equ (7) for weight W updates or amplitude W_{11} and W_{21}.

$$W(k+1) = W(k) + \left(\frac{\alpha e(k)Y(k)}{Y(k)^T Y(k)}\right)$$

Where, $W = \begin{bmatrix} W_{11} \\ W_{21} \end{bmatrix}$ is weight-factor,

$$Y = \begin{bmatrix} \sin(k\omega\Delta t) \\ \mathrm{Cos}(k\omega\Delta t) \end{bmatrix}$$

is fundamental sine and cosine components, $e(k) = vs(k) - vfund\_est(k)$ is the error among estimated and measured voltage signal, and α is learning rate.

At same time, W_{11} & W_{21} will be utilized to compute sudden magnitude $vfund\_est(k)$ of $vs(k)$ according to following approach.

$$vfund_{mag(k)} = \sqrt{W_{11}^2 + W_{21}^2}$$

The iteration continues until $vfund_{est(k)} = vs(k)$ actual

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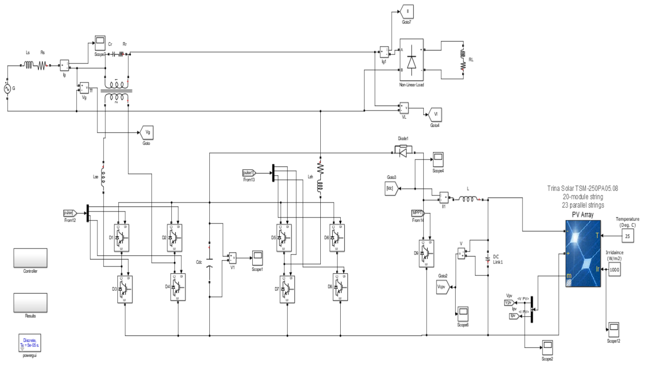
magnitude of the $vs(k)$ is twisted at this moment and finally divided between $vs(k)$ calculated to generate the desired synchronization signal $\sin(k\omega\Delta t+\theta)$ please note that a unit representation of instant source voltage is the desired synchronization signal generated in this way.

4. Results

A PV tied UPQC is operated by MPPT technique to extract the maximum power by using the P&O technique with the ANN controller here we get the maximum power of 220 volts and the currents of 20 amps without any interruptions within a short period of time t=0.1 seconds the voltages and currents are settled down.



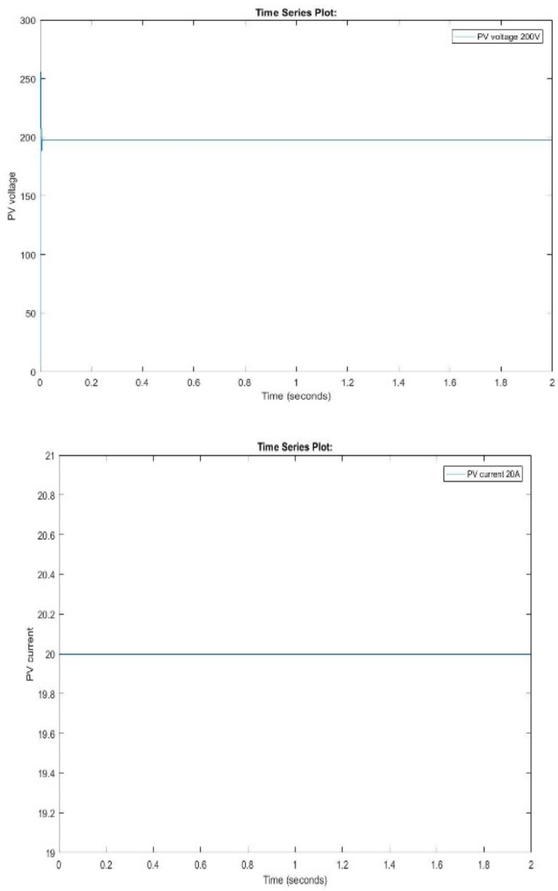


Figure.8 a)Voltage of the PV system. b) Current of the PV system.

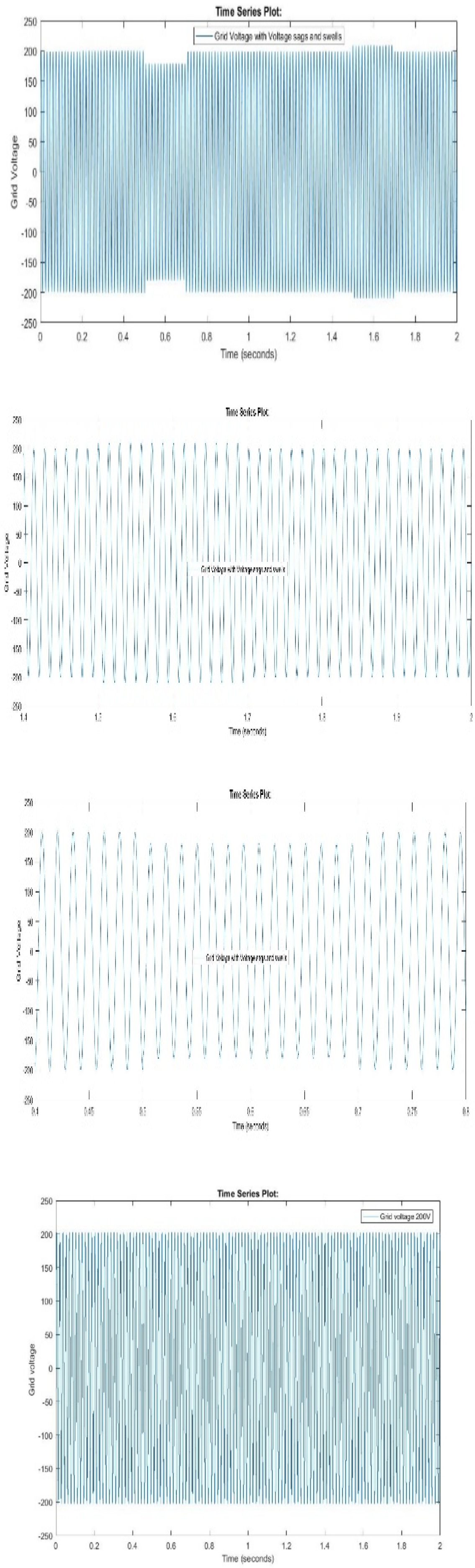


Figure9. a) grid voltages sags and swells b) Grid voltage without sag/swell with ANN controller

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In the figure 9. The voltages of the grid with PI and ANN are shown, at the time t=0.5 to 0.7 voltage sag is occurred and at time t=1.5 to 1.7 voltage swell is occurred in the figure9.(a), where as in figure9. (b) Voltage sag/swells are controlled by using the ANN controller, grid voltages are maintained stable.

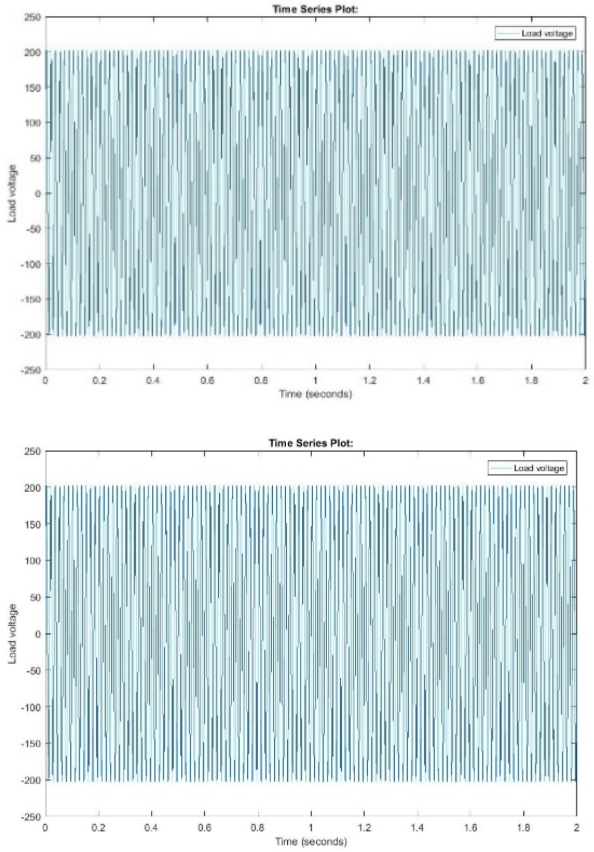


Figure.10. (a) load voltage of the PI controller and (b) load voltage of the ANN controller

Figure10. shows the Load currents in figure10(a) the load voltages have the THD of 3.36% but in the figure10(b) THDs are reduced to 0.47%.

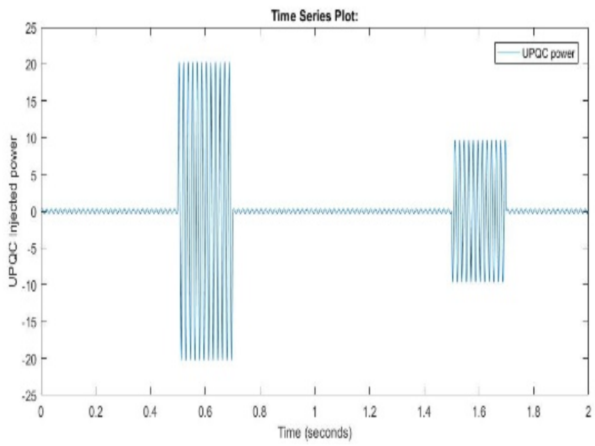


Figure.11 UPQC injecting impedances.

The PV tied UPQC injects the impedances to the VSI at the Voltage sags at time period t=0.5 to 0.7 and consumes the extra voltages at time period t=1.5 to t=1.7.

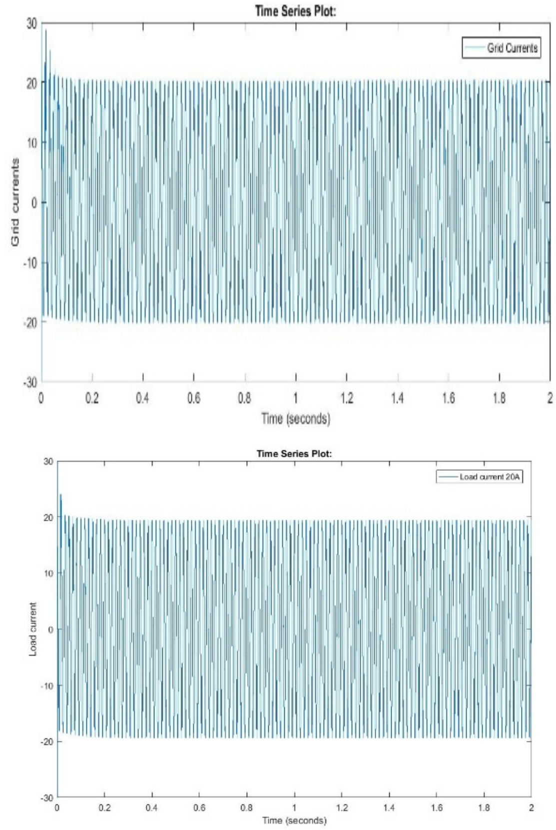
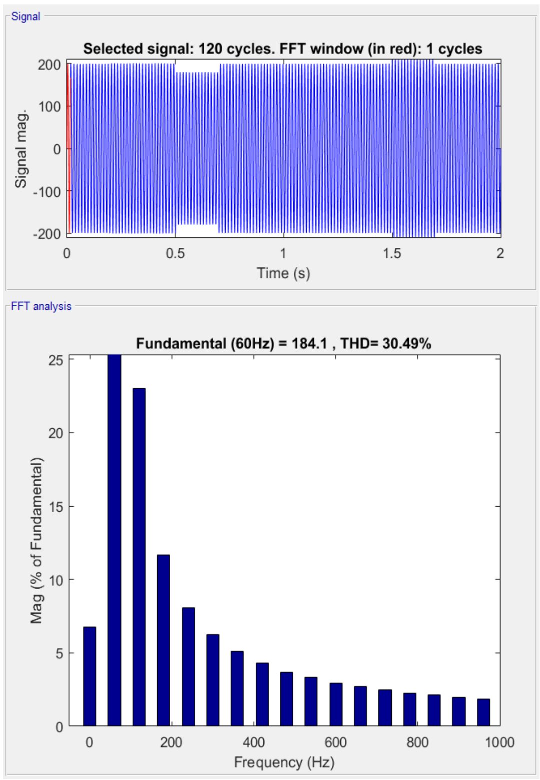


Figure12. a) load currents with PI controller b) Load currents with ANN controller

In the figure12.a) load currents are disturbed at the time t=0 to t=0.2 with the PI controller where as in the Figure12. b) there is a small disturbance occurred in the initial stage after that they are stable by the ANN controller.



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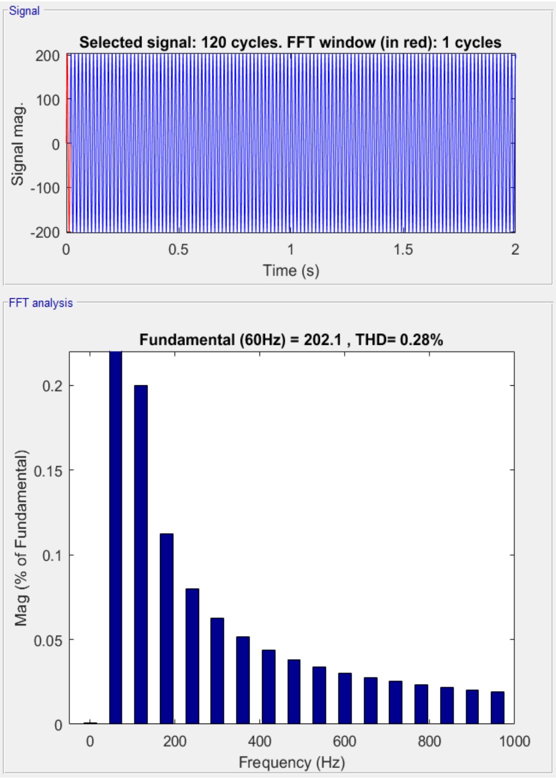
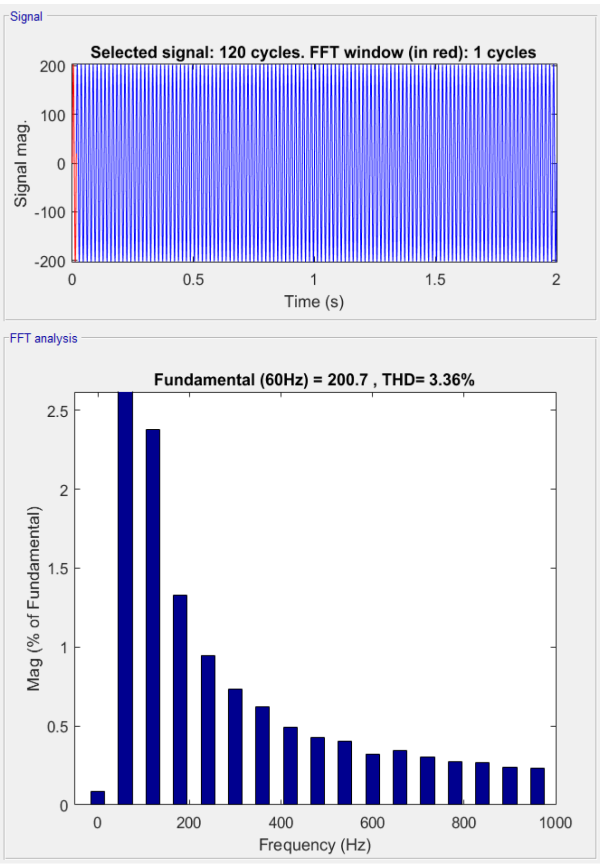


Figure.13. a) THD of the grid voltage with PI b) THD of the grid voltage with ANN

Figure12. a)b) shows that the THD of the grid voltages are measured by using the FFT analysis with the PI controller the THD is 30.49% with the 60Hz, whereas the THD of the Proposed ANN controller is 0.28% with the 60Hz.



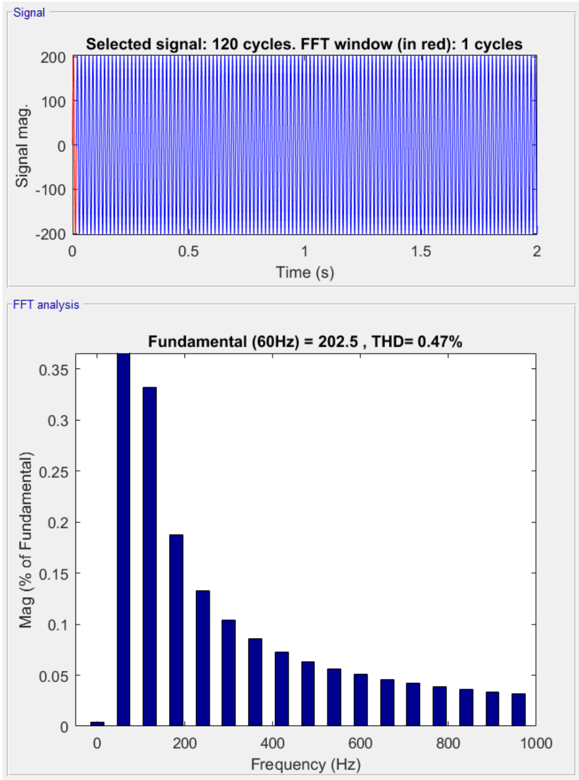


Figure.14. a) THD of the Load voltage with PI b) THD of the Load voltage with ANN

Figure 14. a)b) exposes the THD of the Load voltages are measured by using the FFT analysis with the PI controller the THD is 3.36% with the 60Hz, whereas the THD of the Proposed ANN controller is 0.47% with the 60Hz.

5. Conclusion

The efficiency of variable offsetting of distortions of the current and voltage, as well as their combinations, for the PV UPQC with MATLAB/Simulink have been validated. The variable compensation is economical, in particular when there is a low ratings for VSIs used for power conditioning. The responsibility for the utility and the user can be assigned only by removing the cargoes produced by harmonics. UPQC is able to prevent distortion from the delivery system by means of Synchronous Reference Frame (SRF), series control strategies, and shunt conversion devices, including volume fluctuations, transients, distortions and harmonics at DC-link voltage.

This paper describes a PV interface to the grid via UPQC to mitigate various disturbances in current and voltage. The problems of grid syncing and mitigation of power system disruptions in the presence of the traditional PLL-based regulation are seen in a highly skewed grid as difficult to mitigate in the mitigation phase. UPQC is thus simultaneously improving both voltage and current power issues. The recommended dual-unified power quality will meet the non-linear charging currents as well as ensure the sinusoidal charging voltage in all three phases. In the load

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and voltage disturbance at the source, the control was also very effective. In contrast to other planned systems the key advantage of the proposed control was the use of sinusoidal references for series and for shunt active filter control without the need of complicated calculations or co-ordinate transformations. To preserve the power efficiency, it minimises the total harmonic content of the load voltages. THDs are less than tactics without UPQC and with UPQC using the PI controller in the ANN controller.

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