A Novel Intelligent Neural Network Techniques of UPQC with Integrated Solar PV System for Power Quality Enhancement

Ramesh Rudraram, Sasi Chinnathambi, and Manikandan Mani

Abstract—**A Novel Intelligent control of a Unified Power Quality Conditioner (UPQC) coupled with Photovoltaic (PV) system is proposed in this work. The utilization of a Re-lift Luo converter in conjunction with a Cascaded Artificial Neural Network (ANN) Maximum Power Point Tracking (MPPT) method facilitates the optimization of power extraction from PV sources. UPQC is made up of a series and shunt Active Power Filter (APF), where the former compensates source side voltage quality issues and the latter compensates the load side current quality issues. The PV along with a series and shunt APFs of the UPQC are linked to a common dc-bus and for regulating a dc-bus voltage a fuzzy tuned Adaptive PI controller is employed. Moreover, a harmonics free reference current is generated with the aid of CNN assisted dq theory in case of the shunt APF. The results obtained from MATLAB simulation.**

Keywords—**PV system; Re-lift Luo DC-DC converter; Cascaded ANN MPPT; Adaptive PI controller; CNN assisted dq theory**

I. INTRODUCTION

THE ubiquity of sensitive power electronic loads like switched mode power supplies, computers, variable speed drives, and others have expanded with the evolution of semiconductor technology. In spite of being highly efficient, these loadshave the unfavourable property of drawing nonlinear currents, owing to which considerable distortions in voltage arise at the point of common coupling in case of distributed power systems [1-5]. The PPF [6]minimize the PQ issues induced by thenon-linear electronic components at the cost of increased resonance and system bulkiness. Thus, the APF [7] came in to existence, which improves the overall power system PQ without causing the problem of resonance or bulkiness. Unfortunately, the cost of the APF being relatively higher than PPF is considered to be its major limitation.

The shunt active filtering-based Distribution Static Compensator (DSTATCOM) [8] is a FACTS device capable of enhancing the system stability by handling conditions like non-linearity and unexpected load removals. However, the problem of reactive power injection along with the occurrence of power losses limits its application [9]. The series active filtering based Dynamic Voltage Resonator (DVR) [10] is also a FACTS

device, which is effective in protecting the loads from breakdown by curbing the PQ issues. However, its ineptness in eliminating higher level voltage sags is considered to be its major shortcoming. When compared to both DVR and DSTATCOM, the UPQC [11-14], which a multifunctional power conditioner based on the principle of hybrid active filtering is regarded as the most promising choice.

The UPQC secures the critical loads interfaced to the distribution system by resolving problems like harmonic isolation, negative and neutral sequence currents, and reactive power flow at harmonic and fundamental frequencies, voltage disturbances along with harmonic distortions.

The massive penetration of renewable sources in the power system is inevitable in view of the limited supply of fossil fuels, soaring oil prices along with increased carbon footprint. Among the available renewable sources, the one with highest yearly growth curve is PV systems owing to its unlimited supply capacity and ease of installation [15, 16]. However, the large-scale integration of PV to the power system also leads to numerous PQ issues. Thereby, the design of PV-UPQC [17-22] came in to existence, since it serves the purpose of both PQ maintenance and green energy production. Even though this research field has seen rapid growth, efforts to integrate UPQC with PV are still in relatively form active stages, and several concerns are still needed to be addressed. Moreover, the existing methodologies only focus towards the compensation capability and design of UPQC, while overlooking the issue of voltage instability caused by intermittency of PV system. The selection of an appropriate DC-DC converter and an MPPT controller addresses this limitation of a PV-UPQC architecture. A practical value of voltage gain of conventional converter topologies are very low when compared to its theoretical values [23-28]. So, a high gain Re-lift Luo converter is selected for interfacing the PV to UPQC [29-32] in this work. Additionally, a cascaded methodology is implemented for improving the accuracy of ANN MPPT.

A PV-UPQC is modelled and an appropriate control approach is proposed for enhancing its compensation capability along

Ramesh Rudraram and Sasi Chinatambi are with Electrical Engineering Department, Annamalai University, Annamalainagar,, India, (email: rameshrudraeee@gmail.com, saasimeee@gmail.com).

Manikandan Mani, is with Electrical and Electronics Engineering Department, Jyothishmathi Institute of Technology and Science, Karimnagr, Telangana, India (e-mail: cm.manikandan@gmail.com).

with improving the voltage stability at dc-bus. The configuration of PV system includes Cascaded ANN MPPT along with DC-DC Re-lift Luo converter. As the dc-bus voltage controller, a fuzzy tuned Adaptive PI controller is chosen due to its improved capacity to handle non-linear operating conditions. Additionally, the principle of CNN assisted dq-theory is employed to controlthe series and shunt APFs of UPQC. Through experimental verification in addition to MATLAB simulation, the effectualness of the introduced PV-UPQC model is ascertained.

II.   PROPOSED SYSTEM DESCRIPTION

A novel control methodology for PV-UPQC is proposed in this work, which focusses towards maintaining a voltage stability of the dc-bus along with improving a compensation capability of the UPQC. Moreover, by interfacing a PV with UPQC, the benefits of both power quality enhancement and decarbonized energy generation are accomplished. The UPQC, which is referred as universal active filter is a multifunctional power conditioner, developed based on the principle of hybrid active filtering. It inhibits the infiltration of the harmonic load current in to the power system, reduces voltage fluctuations and compensates numerous power supply related voltage disturbances.

The UPQC comprises of two compensators, which are both connected to the PCC via a transformer as illustrated in Fig. 1. Moreover, series coupled compensator acts as a Voltage Source Inverter (VSI), while the shunt connected compensator act as a Current Source Inverter (CSI). The connection between both converters is established through a shared dc-bus, and the function of a dc-link capacitor is to serve as a power energy buffer. In case of a PV-UPQC, anactive power from the PV is extracted by shunt compensator and both the compensators along with PV system is interfaced to a common dc-link capacitorC_dc.The Re-lift Luo converter is employed to seamlessly integrate the PV system with the dc-bus and

additionally a Cascaded ANN based MPPT approach is employed for maximizing an energy extraction from PV. The MPPT voltage is modelled to be equivalent to $〚V〛\_dc$. Thereby, for maintaining the voltage stability at the dc-bus, an Adaptive PI controller is employed. With the implementation of CNN assisted dq theory, a harmonics free reference current is generated from the shunt compensator.

III.   PROPOSED SYSTEM MODELLING

A.   COMPENSATOR MODELLING

For obtaining the mathematical model of shunt and series converters of UPQC, the values of aninductors and capacitors of the LCL-filter and LC filter are considered to be equal. Accordingly, it is assumed that, $C_{ra} = C_{rb} = C_{rc}, L_{ra} = L_{rb} = L_{rc}, C_{fa} = C_{fb} = C_{fc}, L_{fa1} = L_{fb1} = L_{fc1}$ and$L_{fa2} = L_{fb2} = L_{fc2}$. Additionally, it is also presumed that there is no 3Φimbalance because the existence of serious phase angle imbalance is practically not possible and amplitude imbalance has negligible effect on the dq-transform. The following mathematical expression is derived on the basis of the series converter approach implemented in Figure 2,

$$\begin{cases} \vec{v}_{Lr\_abc} = \vec{v}_{Cr\_abc} - \vec{v}_{si\_abc} \\ \vec{i}_{Cr\_abc} = -\frac{1}{n}\vec{i}_{s_{abc}} - \vec{i}_{Lr\_abc} \end{cases} \qquad (1)$$

Where, the terms v_{Cr_abc} and v_{Lr_abc} refers to the voltage across capacitorC_r and inductorL_r, the terms i_{Cr_abc} and i_{Lr_abc} refers to the current passing through capacitorC_r and inductorL_r, the transformer ratio is specified as n and the current flowing through the grid is specified as i_{s_abc}. The series compensator equivalent mathematical model after dq-transform,

$$\dot{x}_{si\_dq}(t) = A_{si}x_{si\_dq}(t) + B_{si}u_{si\_dq}(t) \qquad (2)$$

Where,

$$\dot{x}_{si\_dq}(t) = [\frac{di_{Lrd}}{dt} \frac{di_{Lrq}}{dt} \frac{dv_{Crd}}{dt} \frac{dv_{Crq}}{dt}]^T \qquad (3)$$

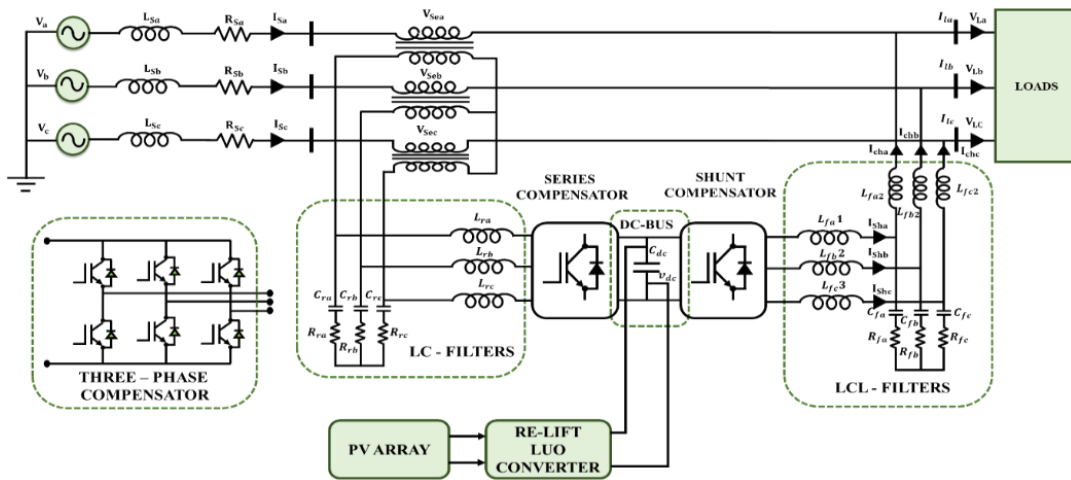$$x_{si\_dq}(t) = [i_{Lrd} i_{Lrq} v_{Crd} v_{Crq}]^T \qquad (4)$$

Fig. 1. Proposed PV integrated UPQC configuration

$$u_{si\_dq}(t) = [i_{sd}\, i_{sq}\, v_{sid}\, v_{siq}]^T \qquad (5)$$

$$A_{si} = \begin{bmatrix} 0 & \omega & \frac{1}{L_r} & 0 \\ -\omega & 0 & 0 & \omega \\ -\frac{1}{C_r} & 0 & 0 & \omega \\ 0 & -\frac{1}{C_r} & -\omega & 0 \end{bmatrix} \qquad (6)$$

$$B_{si} = \begin{bmatrix} 0 & 0 & -\frac{1}{L_r} & 0 \\ 0 & 0 & 0 & -\frac{1}{L_r} \\ -\frac{1}{nC_r} & 0 & 0 & 0 \\ 0 & -\frac{1}{nC_r} & 0 & 0 \end{bmatrix} \qquad (7)$$

The following mathematical expression is derived on the basis of the shunt converter approach implemented in Figure 1,

$$\begin{cases} \vec{v}_{Lf1\_abc} = \vec{v}_{Cf\_abc} - \vec{v}_{pi\_abc} \\ \vec{v}_{Lf2\_abc} = \vec{v}_{L\_abc} - \vec{v}_{Cf\_abc} \\ \vec{i}_{Cf2\_abc} = \vec{v}_{ch\_abc} - \vec{i}_{sh\_abc} \end{cases} \qquad (8)$$

Where, the voltages across L_{f1}, L_{f2} and C_f are represented as v_{Lf1_abc}, v_{Lf2_abc} and v_{Cf_abc} respectively, while the current flowing through them is represented as i_{sh_abc}, i_{ch_abc} and i_{Cf_abc} respectively. Moreover, an inverter output voltage and load voltage are referred as v_{pi_abc} and v_{L_abc} respectively. The state space equation for the shunt compensator is expressed as,

$$\dot{x}_{pi\_dq}(t) = A_{pi}x_{pi\_dq}(t) + B_{pi}u_{pi_{dq}}(t) \qquad (9)$$

Where,

$$\dot{x}_{pi\_dq}(t) = [\frac{di_{shd}}{dt}\, \frac{di_{shq}}{dt}\, \frac{di_{chd}}{dt}\, \frac{di_{chq}}{dt}\, \frac{dv_{Cfd}}{dt}\, \frac{dv_{Cfq}}{dt}]^T (10)$$

$$x_{pi\_dq}(t) = [i_{shd}\, i_{shq}\, i_{chd}\, i_{chq}\, v_{Cfd}\, v_{Cfq}]^T \qquad (11)$$

$$u_{pi\_dq}(t) = [v_{pid}\, v_{piq}\, v_{Ld}\, L_{Lq}\, 0\, 0]^T \qquad (12)$$

$$A_{si} = \begin{bmatrix} 0 & \omega & 0 & 0 & \frac{1}{L_{f1}} & 0 \\ -\omega & 0 & 0 & 0 & 0 & \frac{1}{L_{f1}} \\ 0 & 0 & 0 & \omega & -\frac{1}{L_{f2}} & 0 \\ 0 & 0 & -\omega & 0 & 0 & -\frac{1}{L_{f2}} \\ -\frac{1}{C_f} & 0 & \frac{1}{C_f} & 0 & 0 & \omega \\ 0 & -\frac{1}{C_f} & 0 & \frac{1}{C_f} & -\omega & 0 \end{bmatrix} \qquad (13)$$

$$B_{si} = \begin{bmatrix} -\frac{1}{L_{f1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{L_{f1}} & 0 & 0 & 0 & 0 \\ \frac{1}{L_{f2}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{L_{f2}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad (14)$$

B. DESIGN PARAMETER OF UPQC

The shunt compensator is designed in such a way that it is capable of handling the optimal PV power output along with compensating current harmonics and load current reactive power. Moreover, V_{dc} is similar to MPP voltage, since PV is directly coupled to the dc-link of UPQC. The dc-link voltage is expressed as,

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \qquad (15)$$

Where, the terms m and V_{LL} refers to modulation depth and grid line voltage respectively. MPPT voltage in addition to the dc-link voltage is set at 600V (607pprox). The expression for C_{dc} is given as,

$$C_{dc} = \frac{3kaV_{ph}i_{sh}t}{1/2(V_{dc}^2 - V_{dcmin}^2)} \qquad (16)$$

Here, the per-phase current and voltage is represented as i_{sh} and V_{ph} respectively. The required minimum dc-link voltage value is specified as V_{dcmin}, while the minimum time taken for compensating the disturbance is specified t, and the overcrowding factor is specified as a. Moreover, the quantification of energy fluctuation in a dynamic scenario is denoted as k. The expression for the interfacing inductor is given as,

$$L_f = \frac{\sqrt{3}mV_{dc}}{12af_{sh}I_{cr,pp}} \qquad (17)$$

Here, the inductor ripple current and switching frequency are represented as $I_{cr,pp}$ and f_{sh} respectively. The series transformer's turns ratio is,

$$K_{SE} = \frac{V_{VSC}}{V_{SE}} \qquad (18)$$

The series injection transformer rating is,

$$S_{SE} = 3V_{SE}i_{SE_{sag}} \qquad (19)$$

The inductance of the series compensator interfacing inductor is,

$$L_r = \frac{\sqrt{3}mV_{dc}K_{SE}}{12af_{se}I_r} \qquad (20)$$

For governing the operation of the UPQC compensators, the methodology of CNN assisted dq theory is used.

C. CNN ASSISTED DQ THEORY FOR CONTROL OF COMPENSATORS

The prominently used reference current generation technique in UPQC is dq theory, however this technique is not effective in producing a completely harmonics free reference

current. Thereby, the technique of CNN assisted dq theory is introduced in this work for obtaining a reference current signal, which is purely in the form of sine wave.

D.   CNN CLASSIFIER

The deep learning technique of CNN is effective in systems characterized with non-linearity or diversity. When it comes to identifying the distinct features, this diagnostic approach demonstrates exceptional performance over conventional methods, owing to its superior learning capabilities. The features such as standard deviation, loss-energy entropy, mean, entropy and energy are considered for separating the harmonics from the reference signal. The three-layered CNN, selected for harmonic extraction is a one-dimensional feed-forward network as illustrated in Figure 2 and it encompasses the maximum pooling, convolutional and fully connected layer.
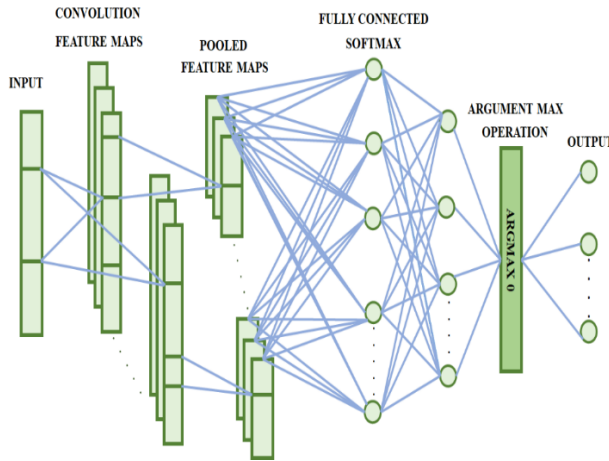
Fig. 2. Architecture of CNN classifier

The convolution layer of the CNN learns about the prominent and essential features of the input, while the pooling layer reduces the dimensionality of CNN. Both these layers together perform the process of feature extraction. Moreover, the pooling layer combines the similar features in to a group along with executing the role of a down-sampling operator. The maximum pooling operation identifies the optimum value in the feature map. The output from the pooling layer goes to the fully connected layer, which comprises of numerous hidden layers. Furthermore, weights are used to form the connection between the CNN layers. Forward and backward propagation are used in the training process, with the former providing the input data andthe latter focuses on improving the parameters of training. A features that are used for extracting the harmonics from the reference signal is given as,

$$Energy, E_{ki} = \sum_{j=1}^{N} \left(|X_{ij}|^2 \right) \tag{21}$$

$$Log - energy\ entropy, LE_{ki} = -\sum_{j=1}^{N} log\left(X^2{}_{ij}\right) \tag{22}$$

$$Mean, M_{ki} = -\frac{1}{N}\sum_{j=1}^{N} X_{ij} \tag{24}$$

$$Entropy, ET_{ki} = -\sum_{j=1}^{N} X^2{}_{ij}\ log\left(X^2{}_{ij}\right) \tag{25}$$

$$Standard\ deviation,\ \sigma_{ki} = \frac{1}{N}\sum_{j=1}^{N}\left(X_{ij} - \mu_i\right)^{\frac{1}{2}} \tag{26}$$

E.   CONTROL OF THE COMPENSATORS

The series compensator effectively stabilizes the load voltage by injecting voltage of a precise amplitude and frequency when issues like voltage sag/swell occur. The series compensator in UPQC emulates the behaviour of a voltage source by introducing voltage of either opposite or identical phase through injection. Along with resolving load voltage imbalance, it also eliminates the supply voltage flickers and enables the shunt compensator to absorb the non-linear load induced current harmonics. Figure 3 presents the series compensator control loop using dq theory.
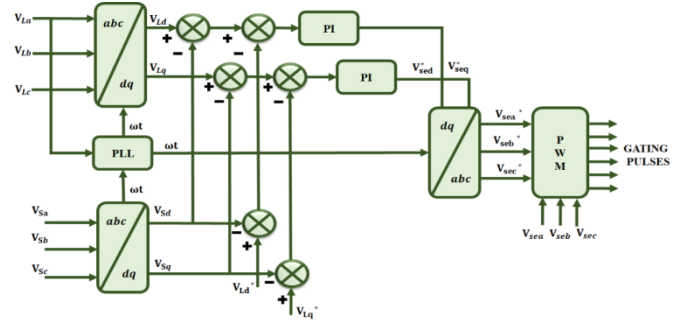

Fig. 3. Series compensator control loop using dq theory

In an UPQC, the shunt compensator functions as a current source that enhances the power factor by minimizing the current harmonics. It also supports the dc-link voltage regulation and reduction of ratings of dc-link capacitor. The CNN assisted dq theory as seen in Figure 4 is used for controlling the shunt compensator of the UPQC.
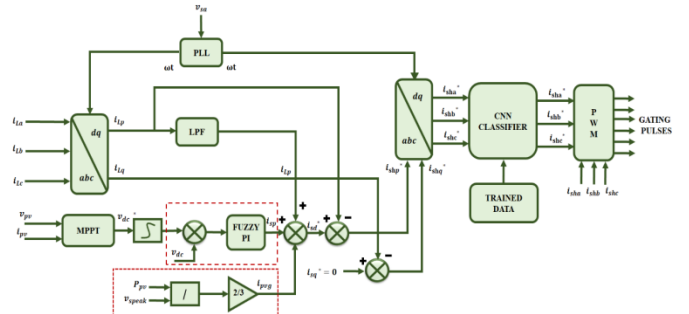

Fig. 4. CNN assisted dq theory for shunt compensator

In dq axis, reference load voltage is given as,

$$\begin{bmatrix} v_{Ld}^* \\ v_{Lq}^* \end{bmatrix} = \begin{bmatrix} \sqrt{2}V_s^* \\ 0 \end{bmatrix} \tag{27}$$

The term V_s^*, refers to grid voltage in the absence of voltage fluctuations. A produced reference grid current is given as,

$$i_{sd}^* = \bar{\iota}_{Lp} + i_{sp} - i_{pvg} \tag{28}$$

The output current of power feed forward and dc-bus controller is represented using the terms i_{pvg} and i_{sp} respectively. The DC component of the active current in the load is,

$$\bar{\iota}_{Lp} = \sqrt{2}i_{L1}\ cos(\theta_u - \theta_i) \tag{29}$$

By accelerating the power balance, power feed forward unit enhances dynamic performance amid shifting irradiation conditions. The current i_{pvg} is given as,

$$i_{pvg} = \frac{2V_{PV}I_{PV}}{3V_{sp}} \tag{30}$$

Where, the grid peak voltage is represented using the term V_{sp}.

The proportional gain is required to be higher for compensating large steady state error, while the integral gain is maintained to be moderately high for eliminating smaller steady state error. Table I gives the control matrix of adaptive PI controller. The negative sign refers to the condition of reaching steady state when both e_{dc} and de_{dc}/dt are not high and the proportional gain is required to be reduced. Stability deviation is noticed in case of same sign condition, then the integral gain is kept moderate and the proportional gain is increased. Fuzzy logic is a control technique that utilizes linguistic variables and rules to model human reasoning.

It allows for the representation of imprecise or vague information and decision-making based on fuzzy sets and fuzzy rules. In the context of the fuzzy tuned adaptive PI controller, fuzzy logic is employed to adjust the gains of the PI controller based on the voltage error and its rate of change, considering the non-linear and intermittent nature of the PV system.

Table I
Adaptive Pi Control Matrix
(k_p/k_i, 0: Zero, 1: Small, 2: Medium, 3:
Big, $-$: Negative change, $+$: Positive change)

de_{dc}/dt \ e_{dc}	-3	-2	-1	0	+1	+2	+3
-3	−3/+3	−3/+3	−2/+2	−2/+2	−1/+1	0/0	0/0
-2	−3/+3	−3/+3	−2/+2	−1/+1	−1/+1	0/0	−1/+1
-1	−2/+3	−2/+2	−2/+1	−1/+1	0/0	+1/−1	+1/−1
0	−2/+2	−2/+2	−1/+1	0/0	+1/−1	+2/−2	+2/−2
+1	−1/+2	−1/+1	0/0	+1/−1	+1/−1	+2/−2	+2/−3
+2	−1/0	0/0	+1/−1	+2/−1	+2/−2	+2/−3	+3/−3
+3	0/0	0/0	+2/−1	+2/−2	+2/−2	+2/−3	+3/−3

Where, the term P_L refers to the load consumed power and the terms T_s and v_{sp} refers to the power frequency period and peak voltage respectively.

F. CASCADED ANN MPPT

The ANN is a popular computational model inspired from biological neural network, which is commonly used in many technical applications to address variety of issues, including optimization, prediction, pattern recognition, and function approximation. Since MPPT is a function approximation problem, the ANN is prominently used for MPPT operation in PV system for automatically detecting the MPP. However, the accuracy of the ANN in detecting the MPP is very low, therefore, the cascading technique is employed for improving the accuracy rate of the ANN.
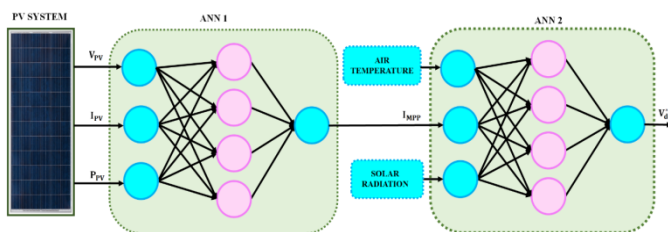

Fig. 5. Cascaded ANN MPPT structurey

Moreover, the proposed Cascaded ANN considers input parameters such as V_{PV}, I_{PV} and P_{PV}, which refers to voltage, current and power derived from PV system in addition to the air temperature and solar radiation. The increase in the number of inputs also aids with improving the accuracy of the MPPT technique. The proposed Cascaded ANN MPPT entails two ANN feed forward networks, which are connected sequentially as seen in Figure 5. The inputs given to ANN 1 includes V_{PV}, I_{PV} and P_{PV}, and the output obtained is I_{MPP}. In case of ANN 2, the ambient temperature and solar irradiance is provided as input along with I_{MPP} and V_{dc}^* is derived as output. The L layers of the ANN without considering the input layer is represented as,

$$a^0 = p \tag{31}$$

$$a^j = f^j(W^j a^{j-1} + b^j) \tag{32}$$

Where, the layer index is given as $j = 1, \dots L$, the activation function is f, the output layer is a, the biases are represented as b, the weights are represented as W and the input vector is specified as p. The difference between the desired value and the network output is minimized by adjusting the weights during the training process. The problem of overfitting is avoided with the aid of the regularization algorithm. The generalization capability of the ANN is improved by including different I-V curves in the training data.

IV. RESULTS AND DISCUSSION

The heightened presence of RES, non-linear loads and power electronic devices has complicated the power system architecture, resulting in an onset of numerous PQ issues. These PQ issues are detrimental to the life time of the components interfaced to the network and evokes huge economic losses. Thus for ensuring the effective working of the power system, the PQ issues has to be resolved quickly. Hence, a PV-UPQC design is introduced along with novel control methodologies for significant minimization of PQ concerns of both source side and load side. The parameters of the proposed design is given in Table II and based on the simulation results attained from MATLAB, its compensation capability is evaluated.

Table II
Specifications Table

Parameters	Specifications
PV panel	
Power	10kW
Number of panels	500W, 20 panels
V_{OC}, I_{SC}	22.6V, 41.6A
V_{SC}	12V
Interleaved Cuk converter	
Inductors L_1, L_2, L_3, L_4	4.2mH
Capacitors C_1, C_2	22.6 µF
Capacitors C_{01}, C_{02}	2200µF
Switching frequency	10kHz
Switch	IGBT
Non-Linear load	
Resistance	100Ω
Inductance	10mH
AC Source	
Voltage	$330 - 470V$
Current	0-30A

Case 1: Step Magnitude (+0.2)

The simulation results are carried out for two different cases. The case 1 evaluates the performance of the proposed UPQC design along with its control methodology in cases of the PQ issue of voltage swell (+0.2). A 0.2 p.u voltage swell is induced and its impact on the load and source side parameters are analysed on the basis of waveforms given in Figure 6. Accordingly, the source voltage that is initially 400V is increased to 470V from 0.1s to 0.2s. However, a slight dip in magnitude is observed on the current waveform during this time interval.

For easy understanding of the changes inflicted by the voltage swell condition over both the source voltage and current waveforms, a single phase (Phase A) of both these waveforms are considered. The negative impact of the induced voltage quality issue is not seen in the load side current and voltage waveforms due to effectiveness of the proposed control methodology. Thus, the effects of voltage swell is minimized and unity power factor is maintained. During the voltage swell condition, the real power also increases and then it stabilizes around a magnitude of 20 kW. The reactive power is very low and is almost zero.
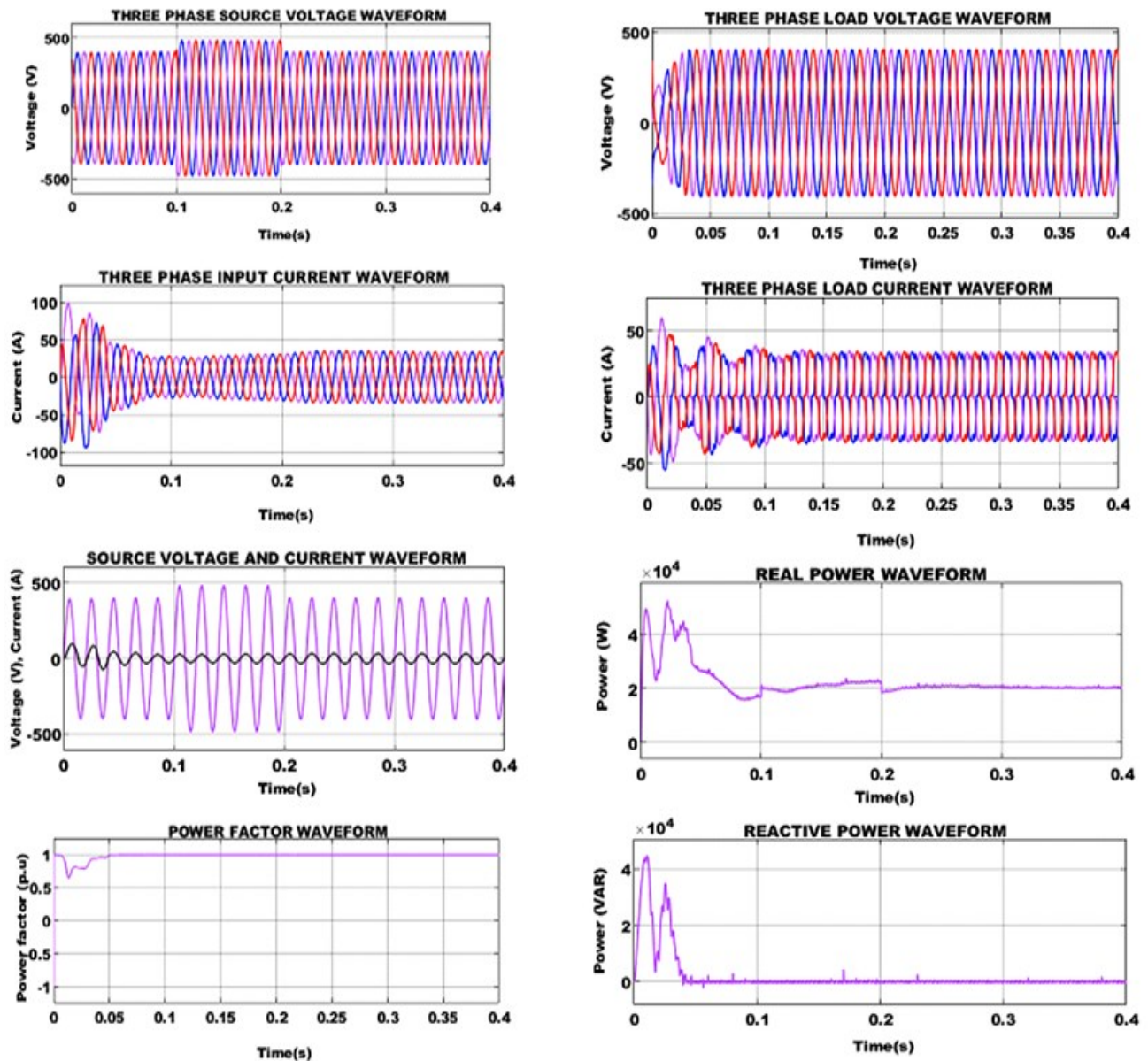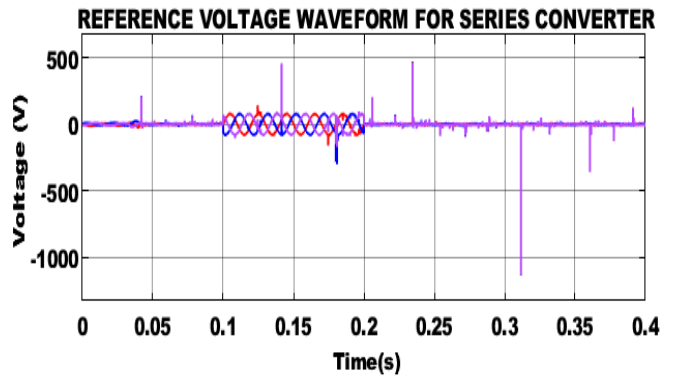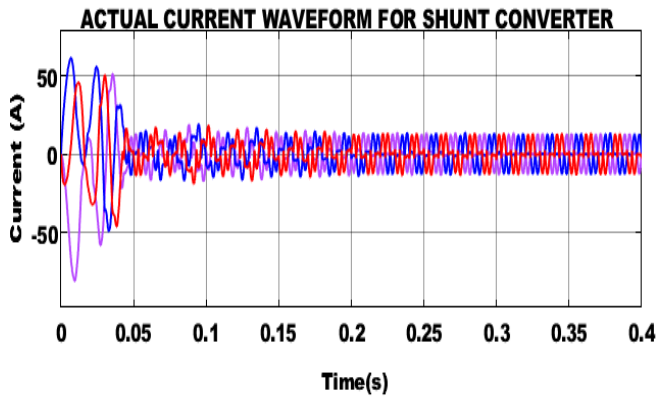

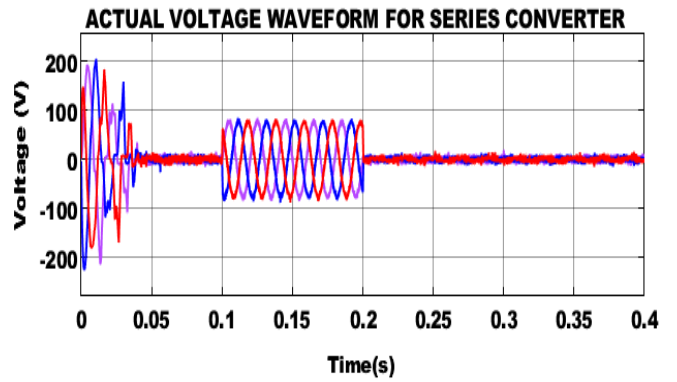Fig. 6. The source side and load side waveforms for 0.2 step magnitude
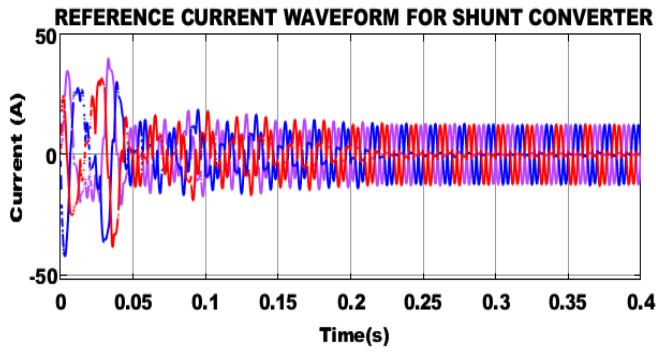
a

b

c

d

Fig.7.(a),(b),(c) & (d) The series and shunt compensator waveforms to compensate voltage swell
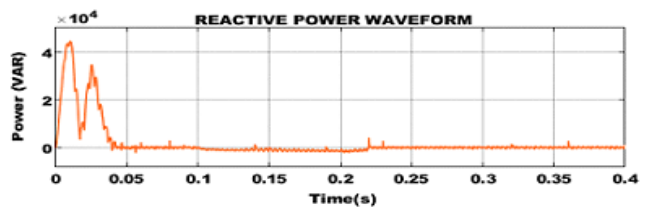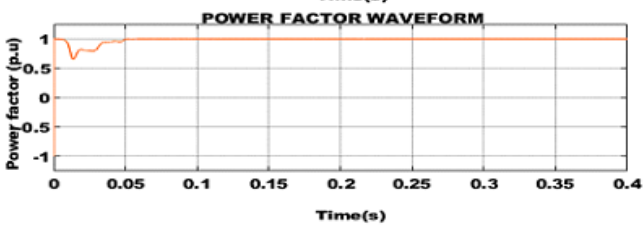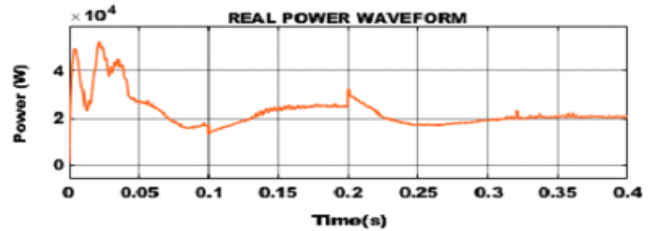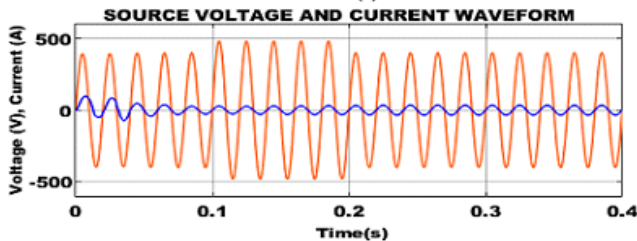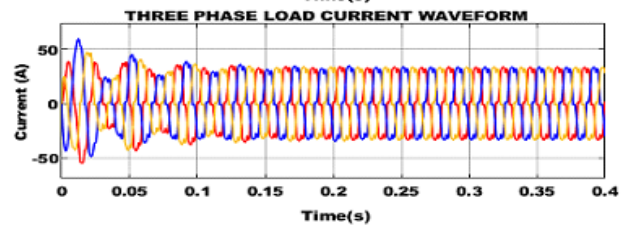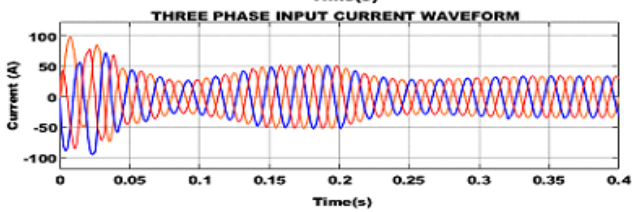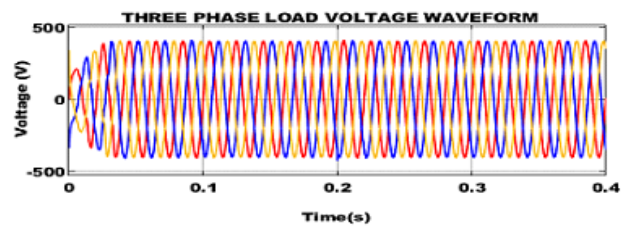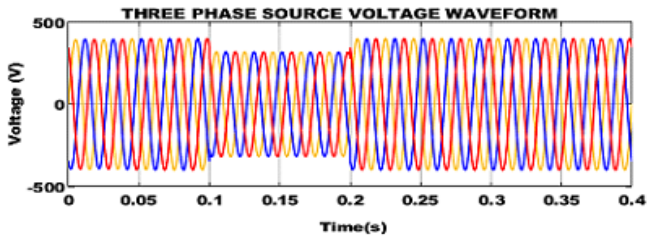

Fig. 8. The source side and load side waveforms for -0.2 step magnitude

The CNN assisted dq theory is employed in this work for a generation of the reference current and voltage signals that are displayed in Figure 7. Both series and shunt compensator of an UPQC generates the required compensation waveforms in accordance to the generated reference signals, to mitigate the effects of voltage swell. The series compensator injects a voltage of magnitude 70V in opposite phase during the time period of 0.1s to 0.2s to compensate the PQ issue.

Case 2: Step magnitude (-0.2)

The feasibility and effectiveness of the suggested PV UPQC design are examined in case 2, specifically during a voltage sag scenario.A sag magnitude of -0.2 p.u is introduced during a time interval extending from 0.1s to 0.2s.The supply voltage without the influence of any power quality issue is of magnitude 400V. However, with the introduction of -0.2 p.u voltage sag, the voltage level decreases from 400V to 370V from 0.1s as seen in Figure 8.
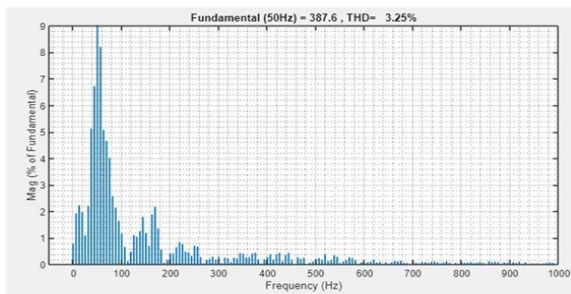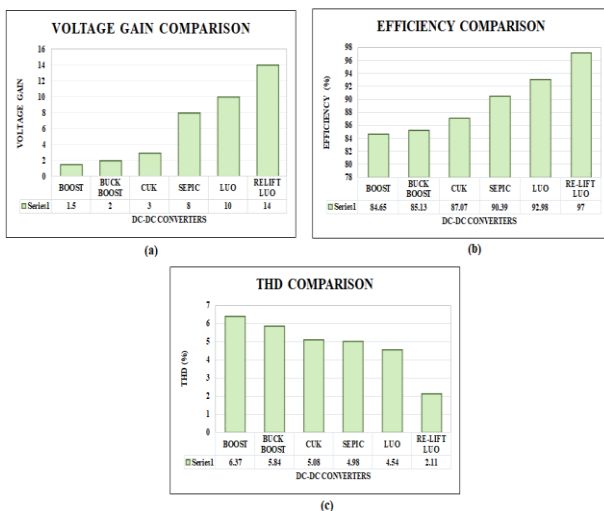

Fig. 9. THD waveform

Fig. 10. DC-DC converters performance comparison (a) Voltage gain (b) Efficiency and (c) THD

In contrast to case 1, the injected voltage in this scenario possesses the same phase to counterbalance the voltage sag. By examining Figure 9, it can be observed that the THD waveform reveals a THD value of 3.2%.
The effectiveness of Re-lift Luo is assessed by comparing it with conventional converters. From the graphs given in Figure

10, it is concluded that the Re-lift Luo outclasses the other converters with high voltage gain, improved efficiency and low THD.

V.   CONCLUSION

An architecture of the modern-day power system is becoming increasingly complex in response with massive integration of RESs, non-linear loads and power electronic devices. The increase in complexity has thus led to the emergence of severe PQ issues. Thereby, for minimizing the detrimental impact of these PQ issues, which ultimately leads to overall system failure, a PV-UPQC design with novel control approach is presented. The proposed design aims to facilitate the large-scale integration of PV system, which is considered to be the energy generation source of the future, to the distribution network. Moreover, from the MATLAB simulation and hardware outcomes, it is confirmed that the presented PV-UPQC model is effectual in compensating voltage fluctuations of deeper magnitude in addition to maintaining voltage stability in the dc-link. The Cascaded ANN MPPT aids the Re-lift Luo converter to optimize power extraction from PV arrays. Re-lift Luo converter has a high voltage gain and it also operates with an excellent efficiency of 97%, owing to the effectiveness of the Cascaded ANN MPPT. The unity power factor and reduced THD (3.2%) further accredits to an exceptional performance of the proposed PV-UPQC design in maintaining a power quality.

Moreover, by adjusting the duty cycle of the Interleaved Cuk converter, the power extraction from the PV array is maximized by the application of CSA assisted P&O MPPT. The designed hybrid MPPT technique operates exceptionally well under both PSC and uniform insolation conditions. According to the outcomes derived from MATLAB simulation, it is proved that the proposed PV-UPQC configuration is effective in improving the PQ of the load current and source voltage. The Interleaved Cuk converter functions with an impressive efficiency of 96% alongwith a minimum THD of 3.25%.

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