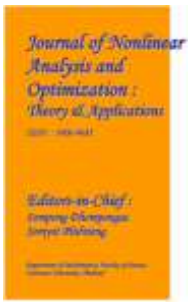
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INTEGRATION OF SOLAR PV INTO GRID USING A NEW UPQC WITH DIFFERENTIAL INVERTER CONTROL

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ABSTRACT:
The voltage stability of integrated photovoltaic (PV) distribution systems is crucial for ensuring the smooth operation of all linked equipment in the distribution network. Maintaining the voltage profile is a difficult challenge when integrating PV systems. The major objective of this research is to provide a consistent voltage profile for a delicate load of 22 kVA. The project focuses on a distribution system that integrates a single-phase photovoltaic system. The unique aspect is that dynamic voltage is achieved by using differential inverters.
Restoration and distribution The static synchronous compensator is a component of the universal power quality conditioner (UPQC). The primary benefit of employing the differential inverter is its ability to provide active power decoupling. The project aims to integrate a 10 kW solar PV system with the distribution system utilizing the latest UPQC technology. The research paper examines and determines the optimal control method for the Unified Power Quality Conditioner (UPQC) with battery energy storage system. A 20 kVA Unified Power Quality Conditioner (UPQC) is specifically designed for the integration of photovoltaic (PV) systems and to enhance the voltage stability of the distribution system. The distribution system is considered to have a constant frequency, voltage, and reactance/resistance ratio. A prototype of a differential Unified Power Quality Conditioner (UPQC) has been constructed. The experimental and simulated findings confirm the primary purpose.

I.INTRODUCTION

1.1 Back ground and related works

The utility should supply power at the rated voltage and frequency meeting the power quality (PQ) standards. The present-day PQ issues include high reactive power consumption due to low power factor loads, the low harmonic current burden due to non-linear loads such as converters, battery chargers, mercury vapour lamps, computers, welding sets, arc furnace, etc. Moreover, the loads in distribution supply maynot be in a balance due to single-phase loads. photovoltaic (PV) system is a renewable energy source and is pollution free. Integration of PV will reduce the general energy requirement and losses in the distribution system. Although there are studies that explore the possibility of PVs providing reactive power [1, 2], the most common equipment on the market is deficient in its ability to supply reactive power to the system. Measures to mitigate these PQ issues is the need of the hour in the power sector. Unified PQ conditioner (UPQC) is a compensating device widely used for PQ improvement of the system. It has two Voltage Source Inverter(VSIs), namely distribution static synchronous compensator (D-STATCOM) and dynamic voltage restorer (DVR). Dynamic compensation of reactive power is essential in the system and D-

STATCOM is an excellent choice for the above compensation, as it will work with extra active filtering functionality. The DVR is mainly used to eliminate voltage-sag and swell, the two VSIs connected in differential mode (DM) and the differential inverter is explained in one of the sections separately. This paper presents the integration of solar PV to the grid using UPQC.

The PQ indicates voltage quality and frequency stability. The frequency of the Indian grid is stable but the voltage profile requires improvement in certain areas. If the voltage changes by 1%, the power will vary by 2% for impedance type loads. Similarly, if the demand/generation changes by 5%, the frequency changes by 1 Hz for the integrated national (India) Grid. The output power of lights and induction motor will be affected with frequency deficiency.

IEEE standard 1159(1995) governs the PQ of low tension (LT) voltage and currents of the power supply. The allowable dip limits are from 10 to 90%, which last for 0.01 to 0.06 s. The classifications in dip are temporary, instantaneous and momentary. When earth fault occurs in one of the lines, there will be a rise in voltage (swell) in other phases [3]. It is possible to realise active power compensation with the energy storage device at the input of the inverter [4, 5].

The conventional methods of reactive power compensation are using fixed capacitors or reactors, controlled capacitors or reactors, static volt-ampere reactive (VAR) compensators, tap-changing transformers, excitation control of generators etc. These methods suffer from the dynamic adjustment of reactive power. The shunt reactors are in use for reducing line over-voltage and shunt connected capacitors are connected to improve voltage when the system load is high. Shunt capacitors and reactors are not useful in maintaining voltage under dynamic load variations and will not support or provide real power requirement. Usually, D-STATCOM injects reactive power to the grid with proper scheduling of load compensation. Also, active power can be injected into the line if the DC link of D-STATCOM makes use of battery energy storage system (BESS).

To maintain the voltage at any node or bus in a power system, balancing of the reactive power generation and demand at that node or bus is essential. If any mismatch occurs, there will be a change in voltage. Unlike frequency, the voltage is a local parameter to be analysed. Each node or bus plays a role in balancing reactive power. Moreover, the voltage in a bus is inversely proportional to the fault level of that bus. The voltage profile of a power system depends on the V–Q sensitivity. It should be positive in all buses and nodes to maintain voltage stability. If it is found negative in any one node or bus, then the system enters in voltage instability mode [6]. The issue of voltage sag and swells would be taken care of by DVR with good design and control strategy.

Analysis of the literature review that follows in a separate section shows that the design parameters of LCL filter, BESS, DVR, D-STATCOM and UPQC are missing in most of the proposals. Conventionally, grid-tied inverters for PV integration is in place. In this research work, the author aims to mitigate the gap by developing a new UPQC using differential inverters for both DVR and D-STATCOM for PV integration with the design of all the necessary parameters.

1.2 Major contributions

i. The novelty is that a single-phase UPQC, rated at 20 kVA, using differential inverters, is proposed with BESS for the PV Integration. The active power decoupling functionality of differential inverter ensures ripple-free voltage and current in the dc input (battery) of D-STATCOM. It also injects the active power of the PV source, the entire reactive power of load and reactive losses of the system. The DVR, connected in DM, takes care of sag and swell in the system.

ii. The design is economical considering low DC link voltage, low capacity for BESS,

the low voltage level for PV System and low rating of inverter switches. The author's design ensures good tracking by the D-STATCOM.

iii. A prototype model of the UPQC using a differential inverter is developed in the research laboratory with D-space controller, simulation studies are carried out for linear, non-linear and transient loads in grid and PV sides and the results are validated.

2 PV-INTEGRATED DISTRIBUTION SYSTEM AND UPQC

The UPQC is one of the custom power devices which consists of D-STATCOM and DVR. D-STATCOM is in shunt connection with the distribution line. The primary function lies in injecting or absorbing the reactive power set by the controller. It is possible to achieve unity power factor in source current if the D-STATCOM pumps entire reactive power and losses. Using the best control algorithms, we obtain proper tracking (injected current is the same as that of the reference current) and total harmonic distortion (THD) reduction of source current. So the current reference generation is significant in the control strategy. D-STATCOM injects or absorbs active power with the BESS in the DC link.

DVR is connected in series with the line and used for sag and swell mitigation. The load voltage remains constant irrespective of disturbances in current or voltage. UPQC, a combination of DSTATCOM and DVR, is used for PQ improvement of the system.

Patel et al. [7] presented a novel control, namely synchronous reference frame theory-based power angle (PAC) for UPQCDG to integrate solar PV system to the grid effectively. Reactive powersharing of load between series and active power filters with a better kVA utilisation and good PQ is a major advantage. The system was tested using simulation, though experimental validation is not provided. Chaudhari et al. [8] reviewed the impacts and challenges caused by PV integration in the distribution network. The research puts forward a number of solutions to various problems of voltage rise existing due to PV penetration. The authors have suggested usage of pumped hydro energy storage systems and other storage systems as a solution to voltage rise mitigation for future work.

Luo et al. [9] presented the optimal location and size of DG with solar farm functioning as STATCOM. A sensitivity analysis test procedure has been employed to study the impact of STATCOM in voltage recovery. The proposed optimisation model could have been more practical and the economic profits of the scheme shall be quantified. Sakar et al. [10] studied the hosting capacity and harmonic distortion limits of the PV-based DG units using PQ and energy efficiency parameters. Authors used the harmonic penetration ratio to analyse the impact of harmonics on the hosting capacity. Nieto et al. [11] investigated the effect of a wind generation on a power grid. Authors emphasise the importance of energy storage systems in regulating the power injected from distributed generation.

Fujitha and Akagi [12] proposed the integration of DVR and DSTATCOM for UPQC. A 20 kVA UPQC was designed to verify its effectiveness and viability of performance. Aredes et al. [13] presented a universal power line conditioner. This paper is, however, an extension of the conventional instantaneous real and reactive power theory. Tolbert et al. [14] proposed a multilevel diode clamped controller-based universal power conditioner, wherein the authors use multilevel PWM to increase switch utilisation. Ghosh et al. [15] presented the simultaneous voltage and current control of UPQC. In the voltage control mode, the voltage of a distribution bus is balanced. Meanwhile, load compensation is also obtained, leading to balanced sinusoidal currents from the distribution system bus in the current control mode. Haghighat et al. [16] proposed an instantaneous theorybased control of UPQC for transient and steady-state conditions. The scheme also identifies a method to reduce oscillations in power during transient conditions. Han et al. [17] presented

a new configuration of UPQC for LT applications. By increasing the number of H-bridge modules, the operation voltage can be expanded.

Kolhatkar and Das [18] experimented on a single-phase UPQC with minimum VA loading. This was achieved when the DVRinjected voltage at the right angle to the grid. Hingorani et al. [5] presented types and categories of various controllers with different control strategies. Central Electricity Regulatory Commission and others [19] published the Indian Electricity Grid Code with effect from 1 April 2006. Hingorani et al. [5] explained various controls for STATCOM. Padiyar [4] explained the synchronous reference frame(SRF) and directed current extraction techniques for D-STATCOM installed in three-phase, four-wire system. Bhim Singh and Ram Niwas proposed ADALINE control for PMSG-based DG set to reduce THD. Pawar et al. [20] proposed the D-STATCOM for load compensation in the line for voltage stability and power factor improvement using instantaneous reactive power (IRP) control strategy. The performance of the device was analysed for unbalanced and non-linear loads. With the help of this strategy, a balanced source current for unbalanced loading is achieved. Saradva et al. [21] proposed D-STATCOM for frequency regulation and voltage regulation of the distribution system. The system is not tested for transient loading. However, both real and reactive power compensation was achieved. The comprehensive study of D-STATCOM configurations has been presented by Singh et al. [22]. Bina et al. [23] presented the design and installation of 250 kVAR D-STATCOM in one of the distribution substations in Tehran. Singh et al. [24] presented different control strategies viz. IRP Theory, SRF theory, SRF theory and ADALINE control for DSTATCOM. The operating characteristics of the D-STATCOM and the demonstration of practical results were carried out successfully by the authors.

3 DIFFERENTIAL INVERTER

The DM buck inverter consists of two dc–dc buck converters, as shown in Fig. 1, with two operating modes, namely the DM and the common mode (CM). DM transfers active power while the CM compensates the second-order ripple power arising from the differential mode. Fig. 2 shows the CM circuit diagram, which is self-explanatory. The design of components of the inverter is discussed separately in the following section [25]. The control strategy is also discussed in a separate section.

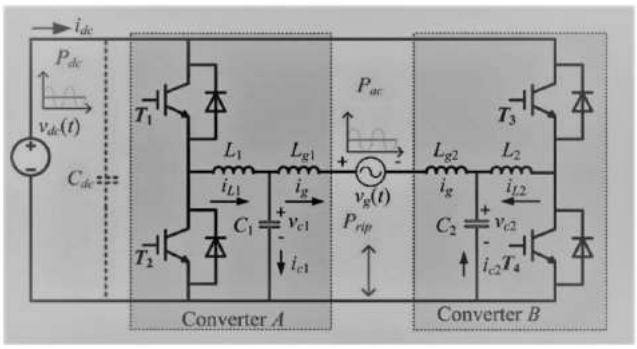


Fig. 1 Circuit diagram of the differential inverter

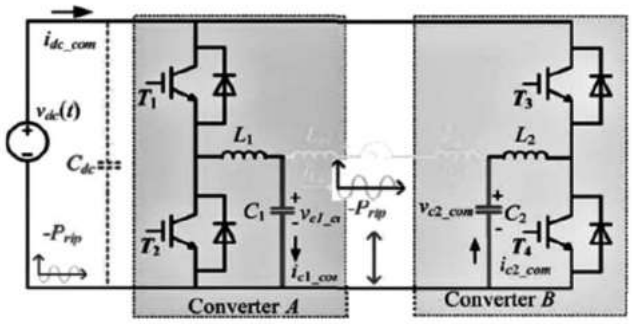


Fig. 2 CM circuit diagram of the differential inverter

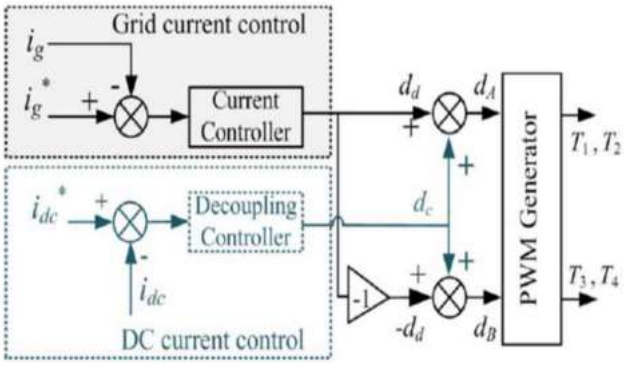


Fig. 3 Overall control structure of the differential inverter

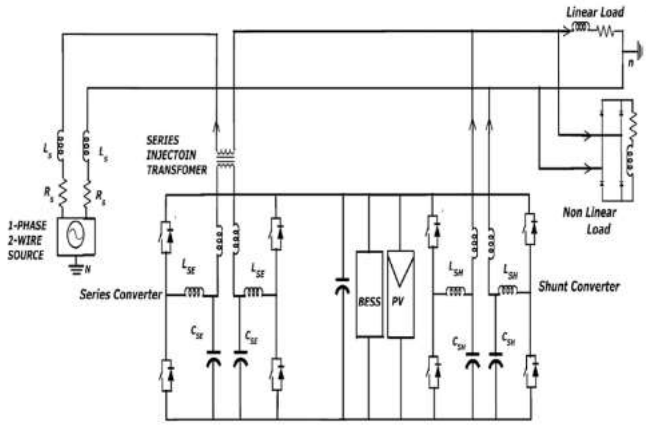


Fig. 4 Circuit diagram of 1-phase UPQC using differenial inverters

Fig. 3 shows the control circuit of the differential inverter. This circuit has an additional DC compensation that achieves power decoupling. The battery current will be free from double frequency ripples and the life of the battery will be more if decoupling is employed. Moreover, the value of the ripple capacitor can be reduced.

Table 1 System parameters

Item description	Values for simulation
source voltage	230 V, 50 Hz
feeder impedance	0.2 + j0.2 Ω
linear load	Z = 2.09 + j1.09 Ω
other loads	rectifier
	(RL): 40 + j31.4 Ω
20 kVA	$V_{dc} = 360$ V, $C_{dc} = 7$ mF
UPQC	$L_1 = 2$ mH, $L_2 = 0.4$ mH
	$R_d = 5\,\Omega$
	$C = 36\,\mu F$

4 Circuit topology of UPQC

Fig. 4 shows the circuit diagram of single-phase UPQC using differential inverters. The source is modelled as 230 V, singlephase system, (R-phase of a three-phase, four-wire system and neutral) is considered as the distribution grid. The DC Link voltage is 360 V DC. A BESS of 360 V, is proposed in the DC link [22].

The shunt D-STATCOM controller is mainly intended to inject reactive power to the grid at the PCC. Unity power factor can be achieved if no reactive current is taken from the source. The reference current should be derived by forcing the source to deliver real power and losses only. The DVR is used to mitigate the voltage sag and swells in the network. The system parameters are shown in Table 1.

4.1 Design of compensator components

Robustness of the controller means good tracking and better stability during the transient response. This, in turn, depends on the input DC voltage (Vdc), DC link capacitor (Cdc) and filter.

(i) DC bus capacitor: The capacitor Cdc, depends on the instantaneous energy available to the D-STATCOM during transients. According to energy conservation theory

$$\frac{1}{2}C_{dc}(V_{dc}^2 - V_{dc1}^2) = V(aI)t \qquad (1)$$

where Vdc is the reference dc voltage and Vdc1 is the minimum voltage of dc bus, 'a' is the over loading factor, V is the voltage, I is the current and t is the time. Considering the dc bus voltage Vdc1= 350 V, Vdc = 360 V, I = 87 A, t = 1 ms and overload factor of 1.2, Cdc is ∼7 mF

(ii) Design of LCL filter: In designing LCL filter, we have to consider the cost of inductor, resonance frequency fres, damping resistor Rd and switching frequency attenuation fsw. The following formula is useful in calculating the inductor value

$$L_1 = \frac{V_{dcref}}{4hf_{max}} \qquad (2)$$

Consider only L1 of LCL filter is used. The proposed rating of compensator is 20 kVA, a current ripple of 10% comes to 8.7 A. Taking Vdc as 360 V and f max as 10 kHz, L1 is 2 mH. Once L1is chosen, L2 and C need to be computed to eliminate higher-order harmonics. Referring to Fig. 5 and neglecting all resistances including Rd, the transfer function of LCL filter combination is arrived as follows:

$$G_F(s) = \frac{I_1(s)}{V_1(s)} = \frac{s^2 + (1/L_2C)}{sL_1(s^2 + (L_1 + (L_2/L_1L_2C)))} \qquad (3)$$

where I1 is the inverter current and V1 is the inverter voltage

$$\frac{I_{f2}(s)}{V_{inv}(s)} = \frac{1/L_1L_2C}{s(s^2 + (L_1 + (L_2/L_1L_2C)))} \quad (4)$$

$$\frac{I_{f2}(s)}{I_{f1}(s)} = \frac{1/L_2C}{s^2 + (1/L_2C)} \quad (5)$$

$$P = z\sqrt{1+k} \quad (6)$$

where

$$f_{res} = \frac{1}{2\Pi}\sqrt{\frac{1+k}{kL_1C}} \quad (7)$$

and

$$k = L_2/L_1 \quad (8)$$

Resonance frequency fres is taken as 2400 Hz, which is 20% higher than the highest order of 40 (2000 Hz). Value of k should be less for minimum loss and good efficiency. C is designed as 36 μF. Taking k as 0.172, L2 = 0.34 mH [26].

5 Control strategy of UPQC

The schematic representation for the control strategy of UPQC is given in Fig. 5 using the circuit topology as per Fig. 4

5.1 Control of D-STATCOM

First of all, it is required to calculate the active power and reactive power of the load using a positive sequence power measurement tool available in the Simulink library. Adding the losses of the inverter to the active power and subtracting the PV power is required. The power so obtained is the power to be delivered by the source. Then, we have to calculate the reference current for this source power using the function block as i_s .

$$i_s = 320\frac{P_s}{\frac{2}{v_1}}\sin(wt) \quad (9)$$

where Ps is fundamental active power of source and v1 is the positive sequence voltage at the PCC. Then the error between the total load current il and is is iref ∗. We have then compared this current with the injected current ii of the inverter. This is given to a PR controller and the output is UREF. This is given to a PWM for pulse generation of pulse for leg A of the D-STATCOM. UREF is inverted and is provided as the second PWM generation pulse for leg B of the D-STATCOM. The generated voltage is filtered using the LCL filter, as shown in the circuit diagram. The D-STATCOM injects the active power of the PV source and the entire load reactive power demand (the DM connection takes care). The CM connection is used to circulate the ripple power through switches and capacitors. The filter capacitance generates the second-order frequency component of active power and is connected between the alternating current (AC) terminal and the negative side of the battery.

5.2 Control of DVR

The phase-locked loop (PLL) receives the source voltage as the input and the output is wt. Using a function block the vref ∗ is obtained as

$$v^*_{ref} = 320\sin(wt) \quad (10)$$

and its error with the load voltage, vl is given to a PR controller. The output is UREF and given to a PWM for pulse generation of leg A of the dc–dc converter of the DVR. UREF is inverted and given to the second PWM for the generation of pulse for leg B of the DVR. The generated voltage is filtered using the LCL filter, as shown in the circuit diagram. This voltage is given to the injection

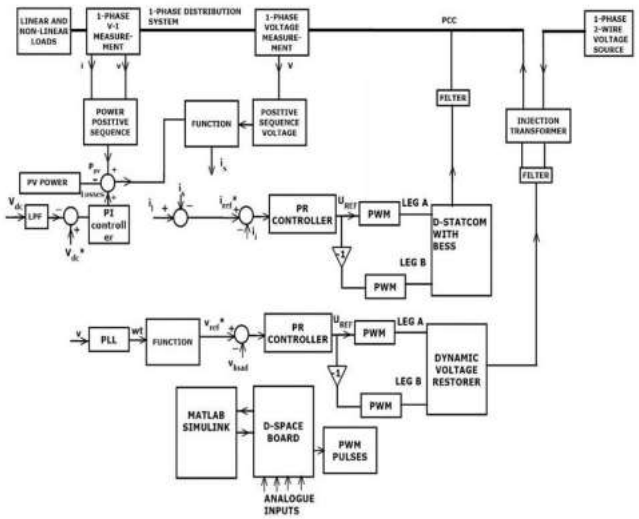


Fig. 5 Simple block diagram for the control strategy for UPQC

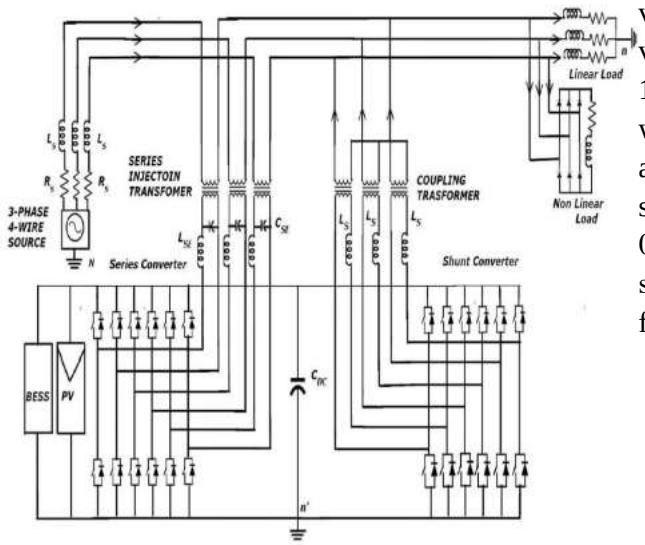


Fig. 6 Simple circuit diagram of UPQC for three-phase distribution system with PV integration

transformer primary. The secondary of the injection transformer is in series to the line, as illustrated in Fig. 5. During sag and swell, the DVR injects appropriate voltages to the system and maintains the load voltage. Here the DM is used to transfer the power, whereas the CM is used to bypass the ripple power.

7 Results and discussions

7.1 Simulation results of proposed UPQC

A 20 kVA UPQC has been designed in a PV-integrated distribution system using a reduced DC link voltage of 360 V and simulated in MATLAB R2016a using ode23tb solver. The system parameters as per Table 1 are used for simulation. The main objectives are

i. To maintain a constant voltage of 320 sin(ωt) (root mean square (RMS) value, 226 V) for a sensitive load of 22 kVA (linear and non-linear) irrespective of transient loading, sag and swell in the system.

ii. To maintain uniform and pure sine wave of 60 sin(ωt) for the source current during the entire period of simulation.

iii. Another objective is to maintain unity power factor for the source current.

iv. THD reduction and PQ improvement is another factor are other factors of concern.

Fig. 11a shows the source voltage with UPQC in service. The values of voltages are similar to that of Fig. 10a. Fig. 11b shows the load voltage waveform of the UPQC and the peak value is 320 V as seen from the figure. Fig. 11c shows the waveform of source current with same transient loading and same loading as per Fig. 10c. It is clearly seen that the source current is uniform from time 0.1 to 0.4 s and the peak value is 60 A. (is = 60 sin(ωt). This current is the equivalent current for 10 KW active power and losses in the

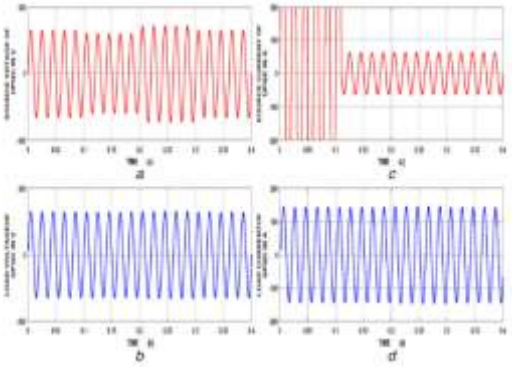


Fig. 11 Wave forms showing (a) Source voltage, (b) Load voltage, (c) Source current during transient loading, sag, swell and normal conditions, (d) Load current with UPQC

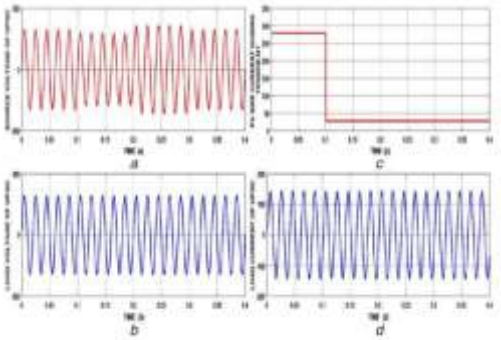


Fig. 12 Wave forms showing (a) Source voltage, (b) Load voltage, (c) PV side current during transient, (d) Load current with UPQC

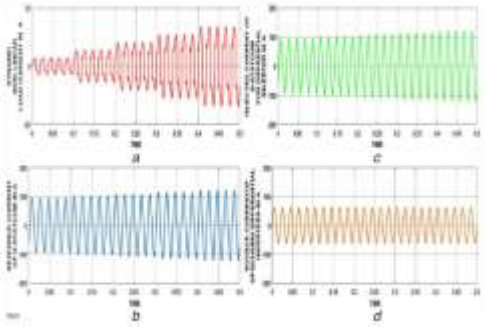


Fig. 13 Wave forms showing (a) Dynamic non-linear loading, (b) Reference current of D-STATCOM, (c) Actualinjected current of D-STATCOM using differential inverter, (d)

Source current of UPQC using differential inverters

system. The source current maintains the unity power factor during sag and swell with UPQC in service. Fig. 11d shows the waveform for load current for a load voltage of 320 sin(ωt) which is 140 A (peak). Simulation results validated all the objectives mentioned above.

Fig. 12a shows the source voltage with UPQC in service with a transient loading in the PV side. The values of voltages are similar to that of Fig. 11a. Fig. 12b shows the load voltage waveform of the UPQC and the peak value is 320 V as seen from the figure. Fig. 12c shows the waveform of PV side current with a transient loading of 280 A DC from time 0 to 0.1 s. This is achieved using switch control and delay timer. The transient load is taken as 10 times that of the normal PV integration of 10 kW (28 A). From time 0.1 to 0.4 s the PV side load is 28 A. Fig. 11d shows the waveform for load current for a load voltage of 320 sin(ωt) which is 140 A (peak). During the transient fault on the PV side also, the UPQC was able to maintain the load voltage and load current. Simulation results validated all the objectives mentioned above.

Table 2 FFT analysis of injected current

Time period	Reference current peak, A	H-bridge inverter H1, H2, H3, H5, H7 peak, A	Differntial inverter H1, H2, H3, H5, H7 peak, A
0–0.1	93	143, 0.15, 1.31, 0.92, 0.66	92, 0.13, 1.3, 0.95, 0.69
0.1–0.2	99	149, 0.13, 2.88, 1.93, 1.37	98, 0.13, 2.91, 1.88, 1.37
0.2–0.3	105	156, 0.12, 4.44, 2.91, 2.09	105, 0.12,4.45, 2.86, 2.08
0.3–0.4	112	163, 0.13, 6.01, 3.90,2.81	111, 0.12,5.95, 3.83, 2.78
0.4–0.5	120	169, 0.13, 7.65, 4.73, 3.48	117, 0.09, 7.63, 4.73, 3.46

Table 3 FFT analysis of source current

Time period	Reference current peak, A	H-bridge inverter H1, H2, H3, H5, H7 peak, A	Differntial inverter H1, H2, H3, H5, H7 peak, A
0–0.1	60	66.8, 0.15, 2.86, 1.56, 1.00	62.2, 0.08, 0.09, 0.10, 0.09
0.1–0.2	60	69.5, 0.11, 5.46, 3.55, 2.21	62.2, 0.01, 0.06, 0.06, 0.00
0.2–0.3	60	72.83, 0.06, 8.11, 2.91, 3.50	62.2, 0.01, 0.13, 0.14, 0.14
0.3–0.4	60	76.47, 0.10, 11.08, 3.90, 4.15	62.2, 0.10, 0.24, 0.24, 0.23
0.4–0.5	60	81.25, 0.06, 14.92, 4.73, 4.92	62.2, 0.10, 0.11, 0.09, 0.11

Table 4 System parameters

Item description	Values for simulation
source voltage	230 V, 50 Hz
linear load	$Z = 200 + j\,62.8\Omega$
other loads	rectifier (R L): 200+ j62.8Ω
800 VA	$V_{dc} = 320\,V, C_{dc} = 2\,mF$
UPQC	$L_1 = 2\,mH, L_2 = 0.4\,mH$ $R_d = 5\Omega$ $C = 36\,\mu F$
injection transformer	1 kVA



Fig. 19 Photograph of the hardware setup control of prototype model of UPQC at Resesrch Laboratory, GEC, Thrissur

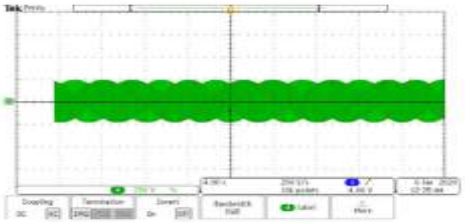


Fig. 20 Waveform showing reference load voltage

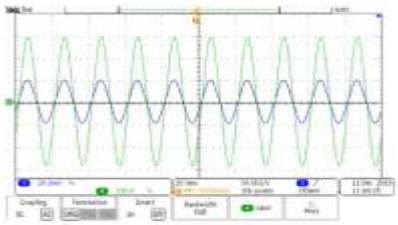


Fig. 21 Waveform of source voltage and current after compensation

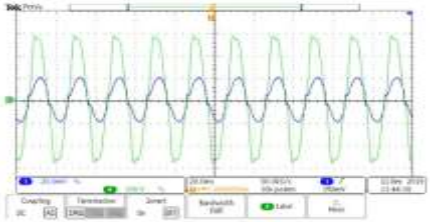


Fig. 22 Waveform of D-statcom voltage and current before compensation

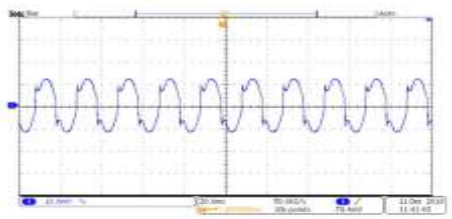


Fig. 23 Waveform of current of non-linear load in ampere

DVR. A swell of 20 V is initiated after a delay time using a delay timer and then there is removal of pre-determined resistance load in the load circuit. The DVR absorbs 20 V from the system, and the voltage is maintained at 200 V.

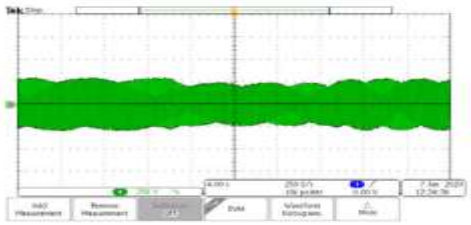


Fig. 24 Waveform of load votage, first portion normal 200 V, second portion sag (180 V) and third portion DVR injection (200 V)

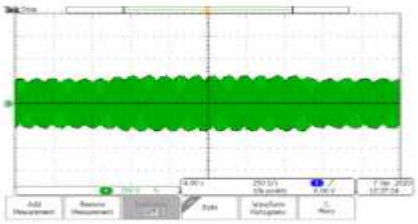


Fig. 25 Waveform of load voltage first portion normal 200 V, second portion swell (220 V) and third portion DVR absorption (200V)

8 CONCLUSION

The research used MATLAB R2016a to simulate a 20 kVA, single-phase Unified Power Quality Conditioner (UPQC) with a PV-integrated distribution system architecture. The simulation employs the ode23tb solver with a lower DC link voltage of 360 V. The system had a total load of 22 kVA and the voltage was maintained at 226 V. In order to minimize Total Harmonic Distortion (THD), it was determined that compensating for a reactive load of 10 kVAR and eliminating undesirable harmonics from the power supply were adequate measures. The source only consumes active power, and the simulation results confirmed that the input power factor is equal to one. In our laboratory, we created a prototype model of the Unified Power Quality Conditioner (UPQC) with a capacity of 800 VA. This was achieved by integrating a 10 kW photovoltaic (PV) power source into the electrical grid and using a D-SPACE controller. The model consistently attained a load voltage of 200 V, regardless of any sag or swell, while also being cost-effective. This innovative design would be suitable for PV-integrated distribution systems and PV producing firms that need the integration of PV generation into the utility grid in order to maintain power quality (PQ) requirements. In order to ensure that the load on the line does not exceed the thermal limit of the conductor, it is necessary to restrict the capacity of the UPQC to a lower level. We want to create and construct a 100 kVA-rated three-phase, four-wire Unified Power Quality Conditioner (UPQC) that is specifically tailored for use in a healthcare institution or hospital.

REFERENCES

[1] Donadel, C.B., Fardin, J.F., Encarnação, L.F.: ‘Optimal placement of distributed generation units in a distribution system with uncertain topologies using monte carlo simulation’, Int. J. Emerging Electr. Power Syst., 2015, 16, (5), pp. 431–441

[2] Donadel, C.B., Fardin, J.F., Encarnacao, L.F.: ‘The influence of distributed generation units penetration in the technical planning process of electrical distribution networks’, IEEE Latin America Trans., 2017, 15, (11), pp. 2144– 2151

[3] I.P.W. Group, , et al.: ‘Recommended practice for monitoring electric power quality’. Tech. Rep., Technical report, Draft 5, 1994

[4] Padiyar, K.: ‘Facts controllers in power transmission and distribution’, 2007

[5] Hingorani, N.G., Gyugyi, L., El-Hawary, M.: ‘Understanding FACTS: concepts and technology of flexible AC transmission systems’, vol. 1 (Wiley Online Library, New York, NY, USA, 2000)

[6] Kundur, P., Balu, N.J., Lauby, M.G.: 'Power system stability and control', vol. 7 (McGraw-hill, New York, 1994)
[7] Patel, A., Mathur, H.D., Bhanot, S.: 'A new srf-based power angle control method for upqc-dg to integrate solar pv into grid', Int. Trans. Electr. Energy Syst., 2019, 29, (1), p. e2667
[8] Chaudhary, P., Rizwan, M.: 'Voltage regulation mitigation techniques in distribution system with high pv penetration: a review', Renew. Sustain. Energy Rev., 2018, 82, pp. 3279–3287
[9] Luo, L., Gu, W., Zhang, X.-P., et al.: 'Optimal siting and sizing of distributed generation in distribution systems with pv solar farm utilized as statcom (pvstatcom)', Appl. Energy, 2018, 210, pp. 1092–1100
[10] Sakar, S., Balci, M.E., Aleem, S.H.A., et al.: 'Integration of large-scale pv plants in non-sinusoidal environments: considerations on hosting capacity and harmonic distortion limits', Renew. Sustain. Energy Rev., 2018, 82, pp. 176– 186