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Multilevel- UPQC for Power Quality Improvement in Distribution System Integrated with PV System

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***Abstract*— Nowadays power consumption is increasing day by day due to world industrialization. To conserve fossil fuels for future generations distribution energy generations (DG) are the best alternative. Wind and PV plays a key role on renewable power generation. The power quality is the main constraint while feeding power to distribution loads. In this paper DG are used to feed power to Unified Power Quality Conditioner (UPQC) through a multi-level converter. The multilevel converter is used as shunt and series converters of UPQC, by using this converter the harmonic component presented in the output of the converter is redused compared to the conventional 2level converter output. Also reduces %THD presented on the fundamental value. Due to this the filter component requirement is less compared to conventional case. The inclusion of multilevel converters in UPQC can reduce the filtering requirement, power loss and reactive power consumed by the converter.**

***Keywords*— Distributed Generation (DG), Multilevel converter, Power Quality (PQ), Unified power quality conditioner (UPQC), Total Harmonic Distortion (THD).**

I. Introduction

Now a days power consumption is increasing due to world industrialization. This distribution load performance depends on the voltage profile of the supply. The growth in industrialization causes increased non-linear loads and unbalanced loads. And the growth in power electronic device utilization in drives and automation of industries leads to rise of power quality problems.[1], [2].

By rapid growth in power electronic devices utilization cause harmonic injection into source side and due to unbalanced load power imbalances and negative sequence component of the currents flowing through neutral point of the system. On the other hand due to frequent load switching voltage fluctuations are occur [3].

The major power quality issues due to extended power utilization, which leads to increased harmonic distortions, increment in reactive power consumption, drop in power factor, increased losses and voltage fluctuations like sag and swells [4].

To overcome these power quality issues some of the compensators are used, these are series and shunt compensators. The shunt compensators are used to compensate reactive power consumption, to reduce harmonic content injection to source and to reduce unbalance factor due to the sequence component of current flowing in neutral point. The series compensators can improve the voltage profile of supply voltage given to loads by compensating sag/swells [5], [6].

However, instead of using individual series and shunt compensators, utilization of Unified power quality conditioner (UPQC) is most economical and reliable. Due to these advantages utilization of UPQC is widely used in distribution networks to improve power quality of the system [7].

The UPQC includes series and shunt converters in the form of back to back connection. The shunt and series converters are designed with multilevel topologies. This leads to reduction of filtering requirement to filter out harmonic content injected by converters and reduction in reactive power consumption. Here diode clamped 5 level converters are used; the output of the converter is smoothen than a conventional 2level converter. This implies reduced filtering system and economical [8].

The series and shunt converters are share same DC link voltage to compensate power quality issues. The DC link shared by converters is fed with external power supply. Such as battery storage system, small conventional power generating station and another is with distributed generation (DG) [9].

Here DGs are used as a source for DC link. The main aim is to meet the increased power utilization and to preserve fossil fuels for future generations. Here the DGs are used to fed power to loads by making shunt compensator as a shunt active power filter. Among all DGs, PV and Wind plays a vital role in power generation due to its cleanness and availability of input source. Fig.1 shows the basic configuration of UPQC based power distribution network [10].

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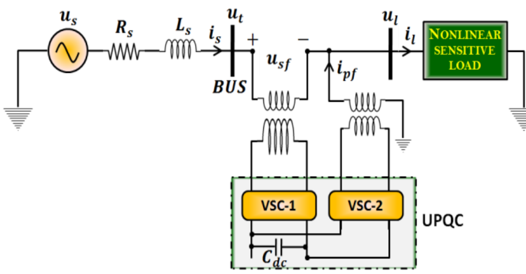

Fig. 1 Basic configuration of the UPQC

II. Proposed UPQC-DG System

A. Circuit Configuration

The single line representation of the proposed test system is as shown in fig. 2. The UPQC is connected in between source bus and distribution bus. The shunt compensator is connected in shunt with load to compensate harmonic content injected by load and to compensate reactive power consumed by the load. The series compensator is connected at source side to maintain a good voltage profile or for stable operation of supply voltage given to loads by mitigating sag/swell conditions in source voltage. U_{sf} is the voltage injected by series controller and I_{pf} is the current injected by shunt controller to improve power quality of the system.

B. UPQC-DG Structure

The internal structure of a UPQC-DG is shown in Fig. 2. It consists of two voltage source converters which are connected back to back through a common DC-link capacitor. In the proposed configuration, voltage source converter1 is connected in series with BUS and a voltage source converter2 is connected in parallel with load at the end of the feeder [11]- [13].

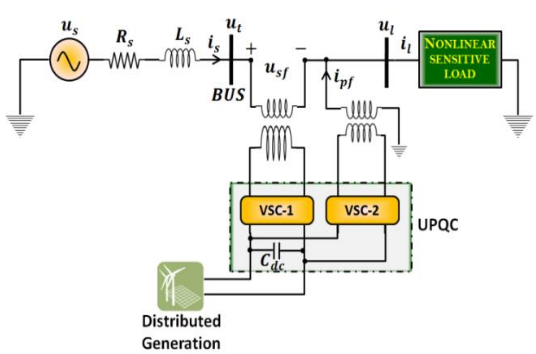

Fig. 2 Simulated test system with multilevel converter

Here the renewable power generation is connected at the DC link to feed power to the UPQC. The power fed by DG is used to compensate power quality issues and increases reliability. The UPQC uses VSC based multilevel converters in series and shunt with load. The system efficiency can increased by using VSC due to its less mal operation, high stability and it can be used to facilitates to control active and reactive power individually.

C. Multilevel Converter design

Due to industry growth wide range of loads are involved in the utility. By using conventional converters for power conversions will effects the load variations due to its constant profile. The multilevel converters are giving variable operations based on load variations and it can produce smooth output than conventional converter, this will increase system performance. The diode clamped type of multilevel converters are used in this system as shown in fig.3.

In diode clamped multilevel inverters the diodes are used to provide multiple voltage levels. In this the capacitors are placed in series connection to share the voltage equally to provide equal voltage to each level. The diode is used to reduce the stress on controllable devices by transferring some amount of power through it.

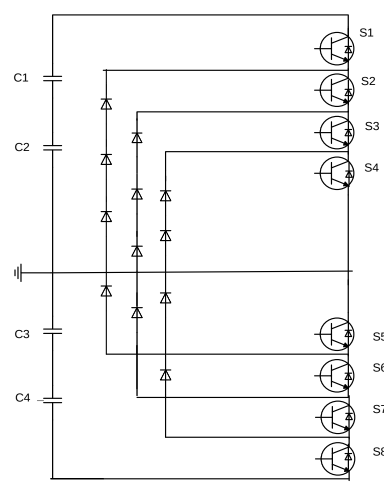

Fig. 3 5level diode clamped multilevel converter

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III. CONTROLLER DESIGNING

Basically UPQC controlling is divided into series and shunt control. And by involving DGs in UPQC source it can operate in two modes, one is grid connected and other island mode of operation.

In the grid connected mode of operation the load can draw power from the DGs and grid. Due to grid involvement they have increased capability to supply the power. In islanding mode of operation only DG can provide power supply to loads with limited capability.

A. Shunt controller

The shunt controller is used to control the output of shunt VSC to compensate harmonic content injected by load and reactive power consumed by the load. The harmonic content will reduce by injecting same harmonics in the opposite direction to load injection.

It can measure the harmonic content injected by the load from the load current and power angle, then compared with a source component of angle measure from voltage and reference current. The measured deviation can inject to lines by maintaining shunt converter in synchronism with source. This can be shown in fig.4.

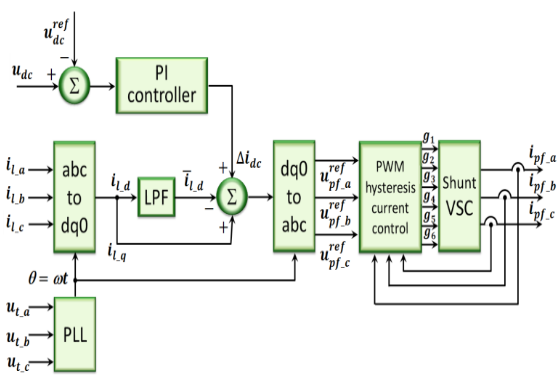

Fig. 4 Control block diagram of the shunt VSC

1. Shunt VSC in Interconnected Mode:

The measured load current (i_{l_t}) is transformed into the synchronous dqo reference frame by using,

$$I_{l\_dqo} = T_{abc}^{dqo} i_{l\_abc} \tag{1}$$

Where the transformation matrix T_{abc}^{dqo} is

$$T_{abc}^{dqo} = \frac{2}{3}\begin{bmatrix} \cos(wt) & \cos(wt-120^0) & \cos(wt+120^0) \\ -\sin(wt) & -\sin(wt-120^0) & -\sin(wt+120^0) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2}$$

By this transform, the fundamental positive-sequence component, which is transformed into DC quantities in the *d* and *q* axes, can be easily extracted by low-pass filters (LPFs). Also, all harmonic components are transformed into ac quantity with a fundamental frequency shift

$$i_{l\_d} = \bar{i}_{l\_d} + \tilde{i}_{l\_d} \tag{3}$$

$$i_{l\_q} = \bar{i}_{l\_q} + \tilde{i}_{l\_q} \tag{4}$$

Where i_{l_d} and i_{l_q} are d-q components of load current, $\bar{i}_{l_d}$and $\bar{i}_{l\_q}$ are dc components, and $\tilde{i}_{l_d}$and $\tilde{i}_{l\_q}$ are the ac components of i_{l_d} and i_{l_q} [14]- [16].

If i_s is the feeder current and i_{pf} is the shunt voltage source converter current and knowing $i_s = i_l - i_{pf}$, then d–q components of the shunt voltage source converter reference current are defined as follows:

$$i_{pf\_d}^{ref} = i_{l\_d} \tag{5}$$

$$i_{pf\_q}^{ref} = i_{l\_q} \tag{6}$$

Consequently, the d–q components of the feeder current are

$$i_{s\_d} = i_{l\_d} \tag{7}$$

$$i_{s\_q} = 0 \tag{8}$$

This means that there are no harmonic and reactive components in the feeder current. Switching losses cause the DC-link capacitor voltage to decrease. Other disturbances, such as the sudden variation of load, can also affect the DC link. In order to regulate the DC-link capacitor voltage, a proportional–integral (PI) controller is used as shown in Fig. 4. The input of the PI controller is the error between the actual capacitor voltage and its reference value The output of the PI controller is added to the component of the shunt-ML voltage source converter reference current to form a new reference current as follows:

$$i_{pf\_d}^{ref} = i_{l\_d} + \Delta i_{dc}$$

$$i_{pf\_q}^{ref} = i_{l\_q} \tag{9}$$

As shown in Fig.4, the reference current in (9) is then transformed back into the *abc* reference frame. By using PWM hysteresis current control, the output compensating currents in each phase are obtained.

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The UPQC-PV System operation with interconnected mode is shown in Fig. 5.

$$i^{ref}_{pf\_abc} = T^{abc}_{dqo} i^{ref}_{pf_{dqo}} \left(T^{ref}_{dqo} = T^{dqo_1}_{abc}\right) \qquad (10)$$

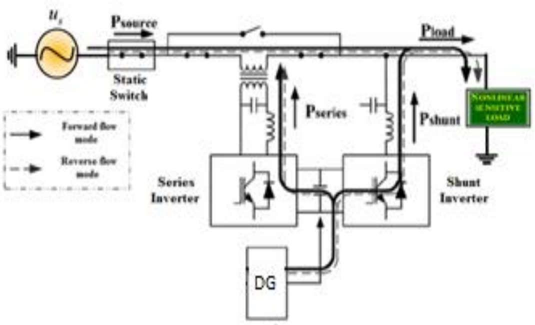

Fig. 5 UPQC-DG System operation with interconnected mode

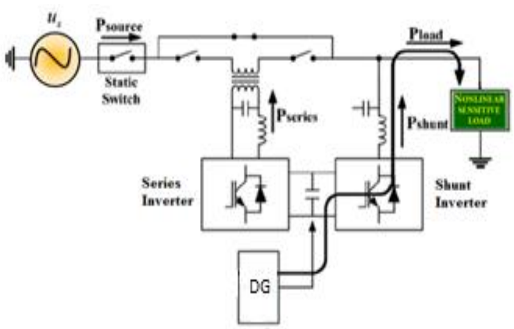

Fig. 6 UPQC-DG System operation with islanding mode

2. Shunt VSC in islanding mode:

In this case the controller will adjust the power output of shunt controller to equal with load power ratings based on DG capability. The shunt inverter during voltage interruption and islanding mode are explained in [17]-[19]. The UPQC-DG System operation with Islanding mode is shown in Fig. 6.

B. Series VSC

The series controller is used to control the voltage injected by series VSC in series with supply to maintain a constant voltage profile. The series controllers can measure voltage fluctuations by measuring source voltage. It will compensate the fluctuations by comparing the measured voltage with reference value and the deviation can inject by series VSC into supply mains.

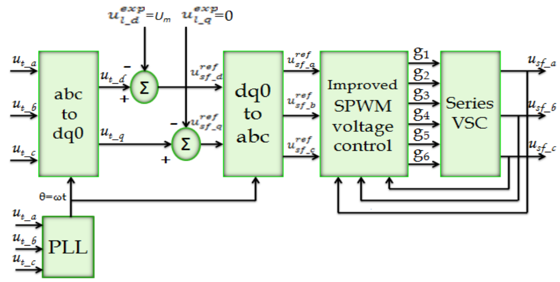

Fig. 7 Control block diagram of the series VSC

The control block diagram of series voltage source converter is shown in Fig. 7. The bus voltage ($u_{t\_}$) is detected and then transformed into the synchronous dq0 reference frame using

$$u_{t\_dqo} = T^{abc}_{dqo} u_{t\_abc} = u_{t1p} + u_{t1n} + u_{t10} + u_{th} \quad (11)$$

Where

$$u_{t1p} = \left[u_{t1p\_d} \quad u_{t1p\_q} \quad 0\right]^T$$
$$u_{t1n} = \left[u_{t1n\_d} \quad u_{t1n\_q} \quad 0\right]^T$$
$$u_{t10} = \left[0 \quad 0 \quad u_{00}\right]^T$$
$$u_{th} = \left[u_{th\_d} \quad u_{th\_q} \quad u_{th\_0}\right]^T \qquad (12)$$

u_{1}, u_{1} and u are fundamental frequency positive, negative, and zero sequence components, respectively, and u_{th} is the harmonic component of the bus voltage. According to control objectives of the UPQC, the load voltage should be kept sinusoidal with constant amplitude even if the bus voltage is disturbed. Therefore, the expected load voltage in the synchronous dqo reference frame ($u^{ex}_{l\_d}$) only has one value.

$$u^{exp}_{l\_dqo} = T^{dqo}_{abc} u^{exp}_{l\_abc} = \begin{bmatrix} U_m \\ 0 \\ 0 \end{bmatrix} \qquad (13)$$

Where the load voltage in the *abc* reference frame ($u^{ex}_{l\_c}$) is

$$u^{exp}_{l\_abc} = \begin{bmatrix} U_m \cos(\omega t) \\ U_m \cos(\omega t - 120) \\ U_m \cos(\omega t + 120) \end{bmatrix} \qquad (14)$$

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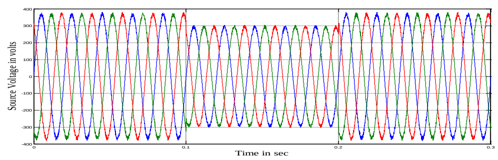
The compensating reference voltage in the synchronous dqo reference frame ($u_{l\_c}^{re}$) is defined as

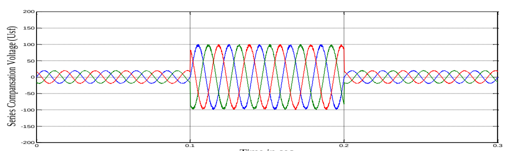
$$u_{l\_dqo}^{ref} = u_{t\_dqo} - u_{l\_dqo}^{exp} \qquad (15)$$

IV. SYSTEM RESULTS ANALYSIS

The UPQC-DG system performance is tested in three cases; they are during sag occurred in supply voltage, during fault occurred on the source side and dynamic load conditions. The UPQC can reduces the %THD injected by load from 18.64% to 3.72%.



(a)



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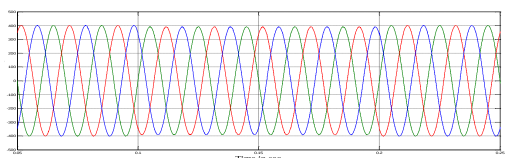


(c)

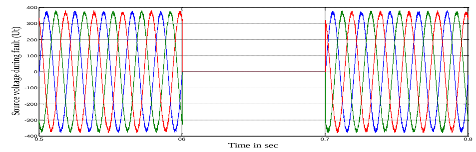
Fig. 8 system compensation during sag (a) sag in supply voltage (b) UPQC injected voltage (c) Compensated load voltage

A. *During Sag in Supply Voltage*

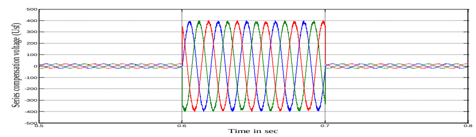
The sag will occurred in supply voltage from 0.1sec to 0.2sec. The voltage is reduced from 380V L-L to 300V is as shown in fig.8.a. The drooped voltage can injected by UPQC is as shown in fig.8.b. Fig.8.c shows voltage given to load after compensation.

B. *Upstream Fault on Feeder*

When three phase to ground fault is occurred at supply/grid side of the system. It will reduces the supply voltage drastically is as shown in fig.9.a. The fault is applied from 0.6sec to 0.7sec and in this case UPQC injects voltage to supply voltage by maintaining in phase with supply is shown in fig.9.b and it can perform the injection when the load power rating is capable to fed DG. FIG.9.c shows the voltage given to load after voltage injection.



(a)



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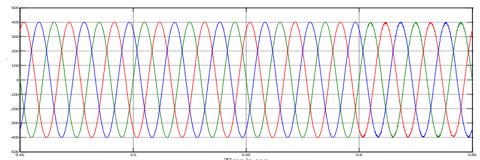
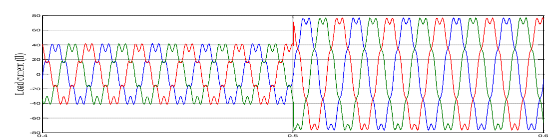


(c)

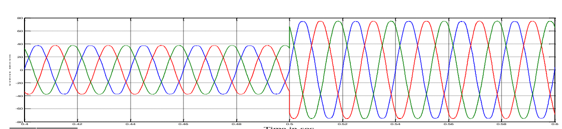
Fig. 9 System performance during three phase to ground fault (a) supply voltage (b) UPQC injected voltage (c) Compensated load voltage

C. *Load Change*

The variable load is applied in the system. The load is changes at 0.5sec is as shown in fig.10. The load current drawn during load change is shown in fig.10.a. Supply current after compensation in fig.10.b. The %THD is reduced from 37.99% to 1.98%. The system parameters are shown in Table. I.



(a)



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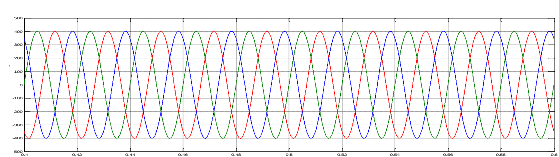

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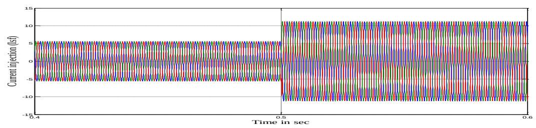
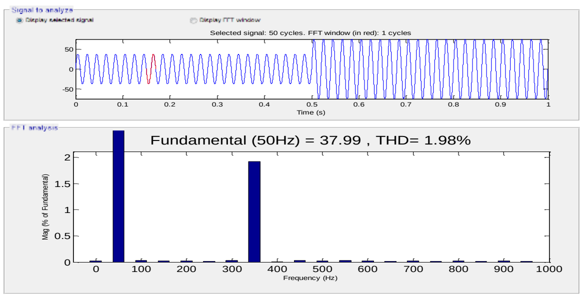


(d)



(e)

Fig. 10 System response during load change (a) Load current (b) Source current (c) Supply voltage and (d) Current injection (Isf) (e) FFT analysis for source current.

TABLE I
UPQC-PV SYSTEM PARAMETERS

System Quantities	Values
System fundamental frequency(f)	50Hz
Voltage source(U_{s1})	380V(L-L rms) phase angle of 0^0
Feeder Impedance (Rs+j2ΠfLs)	1+j0.314Ω
Load (L) Non-Linear/Sensitive Load	A three-phase diode rectifier that supplies a load of R=10 Ω,L=30μH
Series VSC-1 single phase Transformers Reactance change	5KVA,linear type,10% Leakage reactance
Shunt VSC-2 single phase Transformers	10KVA,linear type,10 to 5.5% Leakage reactance
Filter Capacitor(C_f) change	100 to 25μF
Filter Resistor (R_f)	0.081 Ω
Commutation Reactor(L_f) change	50 to 14mH
DC Capacitor(C_{dc})	2000 μF
DG Rating	40kW
V_{dcref}	600V

V. CONCLUSION

The power quality of the distribution network can be improved by including the UPQC in distribution network is analyzed. The total harmonic distortion was reduced from 37.99% to 1.98%.

The sag/swell compensation is performed in the system. By introducing multilevel converters in VSC topology reduces filter requirement, leakage reactance and voltage stress across the switches as shown in table. I. Also improves the system reliability.

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