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THREE LEVEL H BRIDGE GRID CONNECTED INVERTER WITH MULTIFUNCTIONAL CAPABILITY BASED ON THE CONSERVATIVE POWER THEORY

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Abstract

This article presents use of single stage transformer less cascaded H bridge multilevel inverter for smart grid application with nonlinear loads to explore multifunctional capabilities. The salient feature of the presented scheme is the use conservative power theory-based control strategy for multifunctional operation modes besides injecting available solar energy. Presented system apart from injecting active power also accomplish the task of power factor correction, reactive power support, harmonics compensation, islanding detection and Low voltage ride through. Conservative power theory scheme does not use any reference frame transformation. Multifunction capability makes proposed system one of the best choices for distributed power generation with improved consistency. Capability and Efficiency of proposed scheme is verified through simulation and experimental results.

Keywords: Cascade H-bridge, Conservative power theory, Islanding detection, Low voltage ride through, Multifunctional capability, Multilevel inverter.

1. Introduction

Renewable energy resources (RES) like solar, Winds are becoming the most popular sources of electricity production worldwide. This leads to the use of power electronics, an increase in renewable energy generation as well as microgrid control. Multilevel topology utilization in distributed generation is being preferred to the conventional full-bridge invertors because multilevel topology has several advantages especially when the applications involve high power processing.

The use of different digital control algorithms makes it possible to operate these inverters for a multifunctional mode without using extra circuitry [1]. Usually, the accessible type of PV systems uses conventional three-phase four leg inverter which supplies available real power to the network at numerous points in the power system while multilevel inverters have many more benefits over two-level inverters like reduced switching losses, decreased total harmonics distortion (THD), better power quality less electromagnetic interference EMI, modularity, etc. [2, 3].

Rajasekar and Gupta [4] presented the application of a grid connected cascaded multilevel inverter for power conditioning, which was based on instantaneous power (PQ) theory. Based on Synchronous reference frame theory to control grid-connected solar inverters is proposed by Trinh and Lee [5] so as to deliver a sinusoidal reference for grid, during nonlinear load connections. While Marafão et al. [6] presented a multifunctional inverter operation based on CPT-approach for grid-connected solar inverters. While Marafão et al. [7] presented a single-phase Asymmetrical Cascaded H-Bridge Multilevel Inverter (ACHMI), control for multifunctional operation in micro grid systems with nonlinear loads. Two techniques for voltage control. “Cascaded multilevel converter for power conditioning in smart-grid” was proposed by Marafão et al. [8] and Wang et al. [9]. In this revision control of a 7-level shunt based active filter cascade H-bridge multilevel inverter (CHMI) through separate H-bridge DC-link in voltage regulation was accessible and selective compensation is done through CPT algorithm.

The idea of utilizing PV solar farms as STATCOM during night hours for providing various grid support functions including all other support during daytime with inverter remaining capacity after completing real power generation was proposed [10, 1)]. A single stage transformer less grid connected system is presented on [12] in this work grid neutral is directly connected to Solar PV so as to eliminates the ground leakage current. Conservative power theory-based compensator for single phase grid connected application was proposed on [13] experimental results validate effectiveness of CPT algorithm.

Next generation smart PV inverter based on single phase PQ theory is presented on [14]. Prepose work addresses many integration issues of single-phase PV. smart batter storage base hybrid PV and wind hybrid energy system based on CPT is proposed in [15].

In altogether the aforementioned orientations the compensator goals power factor improvement, reactive power and harmonics compensation, and have their own topographies and authority. Though, there are numerous other functionalities to be addressed like islanding discovery Low voltage ride through/ High voltage ride through (LVRT/HVRT). These functional for the prospect smart PV inverters can donate to abridged energy and therefore allow more cost beneficial PV connections.

To complete some smart structures, a multifunctional compensator is established in this work that can be arranged in this solar inverter and accomplished to achieve dissimilar process modes while compliantly alteration from one to another mode throughout the process. The inverter is also exposed to numerous fleeting circumstances alterations such as load change, system parameter change, and its performance during weak grid conditions as well as grid voltage disturbance.

The brief review of the state of the art on multi-functional inverter topologies for grid connected PV application and control strategies reported in the previous literature have been described in Table 1. All these references have their own efficacy and legitimacy. However, there are many functionalities can be explored in grid connected applications. Novelty of this paper is that presented multilevel multifunctional compensator is capable to perform six different operations using CPT based selective compensation, i.e., Injecting active power and operating as active filter simultaneously, Operating exclusively as active filter, power factor correction, reactive power compensation, grid support during low voltage ride through, islanding detection. The choice for multilevel inverter is due to the advantage of using a reduced output filter and its capability to apply low-voltage semiconductor devices in grids.

Table 1. Previous work comparison.

Reference	Work reported in the research article	Research gap
Rajasekar and Gupta [4]	Only Shunt active filter based on PQ theory presented with simulation results is presented	Multifunctional capacities not explored; nighttime application not proposed. reliability issues not discussed
Trinh and Lee [5]	Advanced current control is presented with active filtering operation for	Selective compensation not explored. reliability issues not discussed
Marafão et al. [6]	Active filtering with voltage control and load current compensation during disturbance is presented with experimental results	More operations can explore like reactive support etc reliability issues not discussed.
Mortezaei et al. [7, 8]	CPT based multifunctional operation for asymmetric & symmetric CHB inverter is proposed	Utilization of DG is not included
Wang et al. [9].	Multifunctional UPS were proposed with functionality of UPS and good improvement in power quality	Selective compensation not explored. reliability issues not discussed
Seo et al. [16]	PV system operations as active filter is proposed	Multifunctional capacities not explored. reliability issues not discussed
Sawant and Chandorkar [17]	p-q theory based multi-functional shunt compensator was presented. neutral current elimination in a three-phase four-wire system also included	Selective compensation and nighttime application not explored. reliability issues not discussed
Varma et al. [18]	DQ theory-based PV-STATCOM for nighttime application was presented	Selective compensation not explored. reliability issues not discussed

Broadside is prearranged in the subsequent way system description presented in segment (system configuration) 2. Conservative power theory application for three-phase circuits is explained in section (control strategy) and its implementation for anti-islanding and LVRT discovery is presented in Segment 3. simulation results and its conversation presented in Portion 4. The last part is the conclusions presented in section 5.

2. System Configuration

In this work conservative power theory-based photovoltaic (PV) array maintained through a three-level cascaded inverter is recommended. Propose system is a single-stage transformer less application which not only improves system efficiency but also reduced the weight and size of the overall system. The Inverter is not only able to inject real power supplied by PV array but also compensate harmonics and reactive energy required by distribution networks. The proposed H-bridge inverter is use as Static synchronous compensator (STATCOM) in the time when no solar power is there, and the inverter is idle and the whole volume of the inverter is utilized for STATCOM operation. Apart from these functions proposed multifunction inverter is capable to identify islanding actions and LVRT. Capability of the proposed inverter is also checked for critical system disturbances which are discussed incoming section. The whole inverter capability is free to afford grid provision for transient disturbing conditions. This solar PV inverter come back to its normal operation after the grid provision essential is satisfied.

Figure 1 displays the complete diagram of the future multifunctional solar inverter. Three-level H bridge PV converter is connected to the 415V distribution network, (Z_g) is here equivalent impedance. The diode bridge rectifier with R-L load in its output is taken as non-linear load which is associated at PCC. L_f and R_f are modelled as filter inductance and resistance to mitigate harmonics generated by the inverter. Here I_{abc} and $I_{loadabc}$ are inverter and load current sensed and provided to the controller. V_{pccabc} is a three-phase PCC voltage. The output of d.c voltage controller, as of H-bridge cells, is multiplied through the PCC voltage (V_{pccabc}, this results in the supplementary reference current (i^*_{pabc}) this supplementary reference current is then added to the disruption currents (i^*_{fabc}). The current reference (i^*_{abc})is obtained now is added to the current controller for active filtering operation.

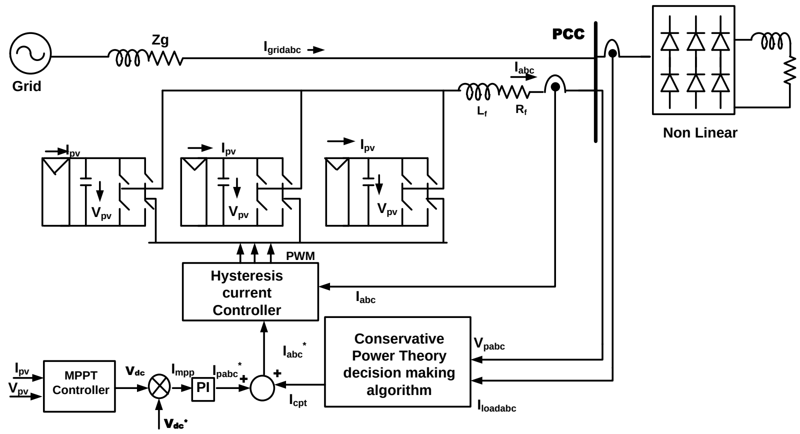


Fig. 1. Block diagram of proposed system.

The main objective of the grid-connected three-level H bridge scheme is to deliver concurrent functionalities established on the CPT for inoculating active power, recompensing harmonics of the nonlinear load, supporting reactive power demanded by load, unity power factor operation, and allowing safe transition between grid-connected mode of operation and islanding mode of system. System parameters used for simulation is given in Table 2. Figure 2 shows the flow chart of various operating modes of presented system, during nighttime, daytime, LVRT and islanding mode. which is explained below; Full PV mode, Full STATCOM mode, LVRT mode, and Islanding Mode

Both during night and day, active filtering and power factor correction will be priority. During daytime, the remaining inverter capacity after real power generation based on available solar insolation is computed at every time step. If at any time (day or night) due to any system disturbance Voltage falls below 80% of specified grid voltage inverter goes to LVRT mode it will stay connected and start supplying reactive support to system up to 1.2 s as per IEEE P1547 Standard after that it will ride through or trip. If any time grid is disconnected for maintenance or other reasons inverter will goes on islanding mode immediately. In nighttime operating mode is switched to Full-STATCOM mode. Active filtering performed with reactive power exchange up to the entire inverter capacity along with power factor correction.

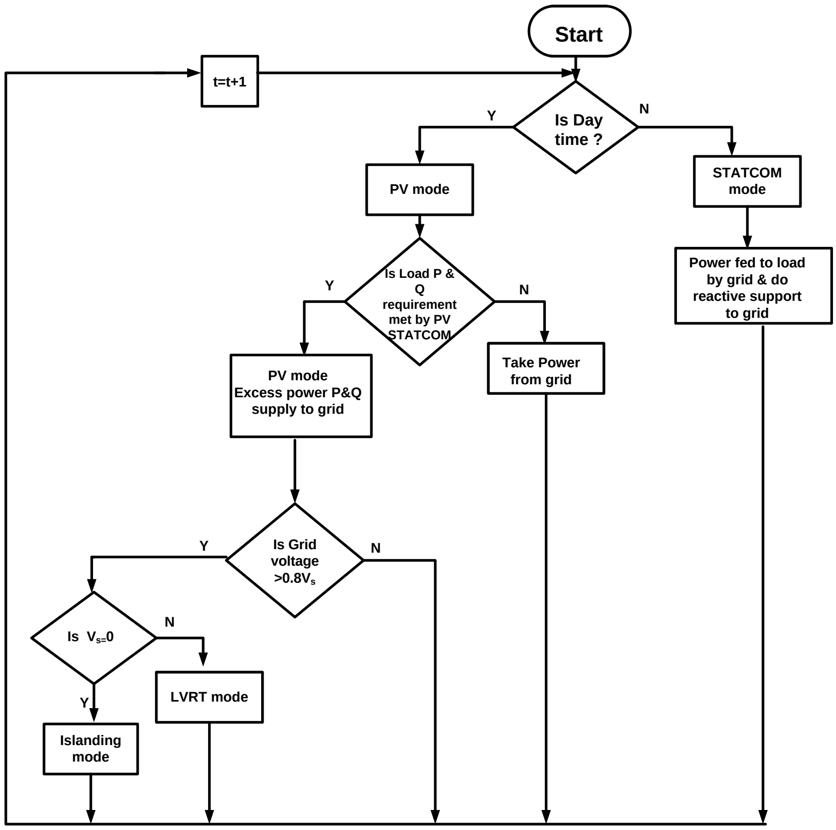


Fig. 2. Flow chart for multifunctional operation modes.

3. Control Strategy

The conventional influence philosophy was developed by Tenti et al [19]. CPT works for time domain systems, and this stands also successfully applied to single phase as well as poly-phase system for both system with neutral and without neutral. Tenti suggests the theory in which energy and current is decomposed into stationary frame. The term which are directly related to characteristics of electrical network, such as: reactive energy, average power transfer, nonlinearities and unbalanced loads. CPT-based compensation theory defined all quantities which must be real, periodic and continuous variables such as Fundamental frequency ($f=1/T$), Time period (T), angular frequency ($\omega = 2\pi$). The Voltage and Current vector are' v' and 'i 'respectively which are measured at a specific network port. The subscript 'm' is used for phase here. Definitions of different operators used in following section is given in Table 2 [9]. The voltage and current scalar product for all phases defines the instantaneous power here.

Table 2. Definition of operators used [9].

Operator	**Definition**
Time derivative=	$\breve{x}=\frac{dx}{dt}$
Time integral $\mathbf{x}_{\int}$ =	$\int_0^t x(\tau)d\tau$
Internal product=	$\langle x\|y\rangle=\frac{x}{y}\int_0^t x.y\ dt$
Norm (rms value)=	$X=\|\|x\|\|=\sqrt{\langle x,x\rangle}$
Orthogonality $\langle \boldsymbol{x}, \boldsymbol{y}\rangle =$	0

$$P(t) = \underline{v}\ .\ \underline{i}\ = \sum_{k=0}^{m} =\ v_m\, i_m \tag{1}$$

where subscript m use for number of phases in multiphase system.

Here the reactive energy(instantaneous) is defined as follows.

$$W = \hat{v} \circ i=[\widehat{v_a}\ \ \widehat{v_b}\ \ \widehat{v_c}\ ]\circ \begin{vmatrix} i_a \\ i_b \\ i_c \end{vmatrix} \text{ or } W(t) = \hat{v}_{-}.\ \ \underline{i}\ = v_m\, i_m \tag{2}$$

Here the vector $\hat{v}$ is encircling the unbiased integrals for the particular phase voltages. However, the calculation of this amount $\hat{v}$ is obtained by average value of voltage and its time integral as follows:

$$\begin{aligned} \hat{v}_m &= v_{\int m} - \hat{v}_{\int m} \\ v_{\int m} &= \int_0^T v_m(\tau)\ d\tau \\ \hat{v}_{\int m} &= \frac{1}{T}\int_0^T v_m\ (\tau)\ d\tau \end{aligned} \tag{3}$$

In this method measurement of phase voltages in three-phase three-wire networks is done with respect to some exclusive reference point and measured with respect to neutral in single phase circuits or four-wire circuits. Wherever rendering to this philosophy, active power is the power which will is actually converted into the work, same as given in all traditional theories. Whereas Reactive energy is a new description specified here which signifies the average energy deposited in the polyphase grid in general situations, it moreover comprises unbalances and waveform distortions in the given system. If Both Power *P* and energy *W* placate Tellegen's Theorem actually these terms up till now are conventional quantities for particular grid, irrespective of waveform of voltage and current. Here at any instant the term P corresponds with general active power $Pconv = V\, I \cos \phi$. Contrariwise, reactive energy is correlated to general reactive power with given the fundamental frequency (ω), therefore $W = Q\, conv/\omega = V\, I \sin \phi/\omega$.

It is unblemished there for general reactive energy is related through the frequency of the electrical network, whereas in conservative power theory the reactive energy is liberated of frequency, therefore it is precise useful on behalf of schemes by likely frequency disparities, especially micro-grids. From a real-world point of opinion, it is passable to compute for the regular quantities by use of adaptive frequency procedures or basically low-pass filters, so that equally the active power as well as the reactive energy are unsusceptible to change in frequency. Established on descriptions accessible above, the phase currents are disintegrated into the subsequent components: composed balance active currents $\underline{i}^{\mathrm{b}}_{am}$, balance reactive currents $\underline{i}^{b}_{rm}$, [11]

$$P = \bar{p} = (\underline{v} \;.\; \underline{i}\;) = \frac{1}{T} \quad \int_0^T . \underline{v} \;.\; \underline{i} \;\; dt = \;\; \sum_{m=1}^{M} \quad P_m \tag{4}$$

and reactive energy [11].

$$W = \bar{p} = (\;\underline{\hat{v}} \;.\;\; \underline{i} \;\;) = \frac{1}{T} \int_0^T \; \hat{v} \;.\; \underline{i} \;\; dt = \;\; \sum_{m=1}^{M} \;\; W_m \tag{5}$$

In Eq. (5), unbiased integral of voltage vector is ($\hat{v}$). As given the descriptions accessible here three basic decomposed components of the phase currents are given by

(i) Active phase currents i_{am} are distinct as

$$i_{am} = \frac{(v_m i_m)}{\|v_m\|2} \;\; v_m = \frac{P_m}{v_m^2} V_m \;\; = G_m V_m \tag{6}$$

where (G_m) is the equal stage conductance

(ii) Reactive phase currents i_{rm} are specified by

$$i_{rm} == \frac{(\;\widehat{v_m} i_m)}{\|v_m\|2} \;\; \hat{v}_m = \frac{Wm}{Vm}\, 2\, \widehat{v_m} \;\; = B_m \hat{v}_m \tag{7}$$

where (B_m) is the equivalent phase reactivity

(iii) After subtracting active besides reactive current from total phase currents remaining currents are void current $\underline{i}_{vm}$ and given by

$$\underline{i}_{vm} = \underline{i}_m - \;\underline{i}_{am} \;\; - \;\; \underline{i}_{rm} \tag{8}$$

Void currents are those which ensure neither transfer of reactive energy nor active power. The active and reactive phase currents be able to supplementary divisions into unbalance and balance currents. Balance active current then is current given by

$$\underline{i}^{b}_{am} = \frac{(v,i)}{\|v\|2}\, \underline{v}_m = \;\frac{P}{v^2}\;\; \underline{v}_m \;\; = G^b\; \underline{v}_m \tag{9}$$

The balanced active currents take distinct as individual's currents which symbolize the smallest part of the phase currents which stand related by a balanced circuits and in authority for resounding the total active power (P) in the circuit, for subjected to given specific voltages.

The balanced reactive currents are demarcated as:

$$\underline{i}^{b}_{rm} = \frac{\langle \hat{v}, i \rangle}{\|\underline{\hat{v}}\|^2}\ \underline{\hat{v}}_m = \frac{W}{\hat{V}^2}\ v_m \ = B^b\ \underline{\hat{v}}_m \tag{10}$$

These currents signify the least ration of the phase flows that are related with a balanced equal circuit and in authority for transmission the total reactive energy (*W*) in the given circuit. The subtraction of total active current and balance active current gives the unbalanced active currents

$$i^{u}_{am} = i_{am} - i^{b}_{am} = (G_m - G^b) v_m \tag{11}$$

In similar manner, the unbalanced reactive currents are designed as

$$i^{u}_{rm} = i_{rm} - i^{b}_{rm} = (B_m - B^b)\hat{v}_m \tag{12}$$

Therefor I^{u}_{m} which is total unbalance phase currents are definite by

$$I^{u}_{m} = I^{u}_{am} + I^{u}_{rm} \tag{13}$$

The current vector (measured) can be splitted in following four parts

$$\underline{i} = \underline{i}_a{}^{b} + \underline{i}_r{}^{b} + \underline{i}_a{}^{u} + \underline{i}_r{}^{u} \tag{14}$$

However, all the components of the current are orthogonal to each other (given by definitions previously) thus the RMS value are represented as follows.

$$I = \sqrt{{I^{b}_{a}}^2 + {I^{b}_{r}}^2 + {I^{u}_{a}}^2 + {I^{b}_{r}}^2 + {I_v}^2} \tag{15}$$

In the same way, apparent power (P_a) is defined as follows

$P_a = \|v\|.\|i\|$ or

$$P_a = \|v\|.\sqrt{{I^{b}_{a}}^2 + {I^{b}_{r}}^2 + {I^{u}_{a}}^2 + {I^{b}_{r}}^2 + {I_v}^2} \tag{16}$$

or $P_a = \sqrt{P^2 + Q^2 + N_a^2 + N_r^2 + D^2}$

where

Active power is $P = VI^{b}_{a}$

Reactive power is $Q = VI^{b}_{r}$

Unbalanced active power is $N_a = VI^{u}_{a}$

Unbalanced reactive power is $N_r = VI^{u}_{r}$

Distortion power is $D = VI_v$

Conservative power theory moreover distinct the global power factor (λ) which is affected by reactive power (*Q*) circulation, load unbalances (*N*) and nonlinearities (*D*) of the system $\lambda = \frac{P}{A}$. Accordingly this theory many variables present in Eq. (15) can be utilized in power conditioning applications and these are independent of the circuit's current /voltage waveforms, only condition needed is that quantities must be periodic. The converter presented in this paper is controlled to maintain the constant DC-link voltages of each cell of multilevel bridge which is provided by MPPT algorithm apart from this proposed control also compensate the nonlinear load current. Since proposed system is single stage, no dc-dc boost converter is utilized here so MPPT is also incorporated in control. The output of voltage V_{pv} and current I_{pv} of each here H-bridge cells, is given to the P& O MPPT controller which will produce voltage (V_{dc}) this voltage is then compare with reference V_{dc}^* and generate current reference I_{mpp} this current passes through PI controller, which results an additional current reference ($i_{pabc}{}^*$) and this reference is added to the compensating currents ($i_{fabc}{}^*$) generated by CPT decision making algorithm and result of this is current reference ($i_{abc}{}^*$) which is given to the hysteresis current controller for switching. Thus, this multifunctional inverter can also work as power factor controller in sudden variable load conditions and also compensate nonlinear load current in steady state conditions. An important conclusion here is that there is no reference frame transformation is done here or any synchronization algorithm is used to obtain the reference signals. The parameters used in simulation are given in Table 2.

Anti-Islanding Concepts and Implementations for multilevel inverter using CPT

To implement anti-islanding and LVRT capability in proposed multilevel multifunctional inverter simultaneously GE AI scheme proposed by Ye et al. [20] and Dietmannsberger et al. [21]. This scheme is based on positive feedback concept and these concepts are implemented in this work for grid connected multilevel inverter.

Figure 3 shows the voltage feedback scheme applied in three phase three level inverter using d-q control technique (voltage is converted to *d-q* using *a-b-c* to *d-q* block in MATLAB) from V_d to i_d^* here direct axis voltage V_d is passes through one band-pass filter (BPF) plus gain, and then one limiter and which results in a current dissimilarity I_{dd} and added directly to current reference.

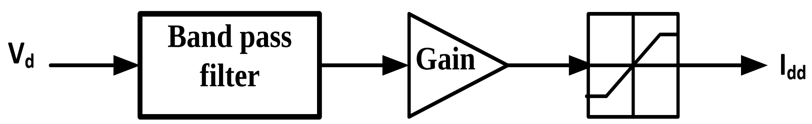


Fig. 3. AI voltage feedback block.

Before giving reference for generation of PWM signal for hysteresis controller for enabling the inverter for islanding detection as well as fault ride through capability. . For generation LVRT signal rms value of voltage is passed through relay whose contact opens when voltage increases to 80% of its nominal value and contact close when the voltage falls below 70% of nominal value as shown in Fig. 4. Following subsystem which is shown in Fig. 5 explains these capabilities. With this block inverter will distinguished between the islanding events by the LVRT incident. Here under voltage trip is disabled and increased and the limit for overvoltage trip to see the islanding operation and low voltage ride through of inverter. Corresponding references are generated by comparing the threshold limits set between islanding event and low voltage ride through. Here P_{ref} and Q_{ref} are active and reactive power references and V_{abcref} is voltage reference in a-b-c coordinate.

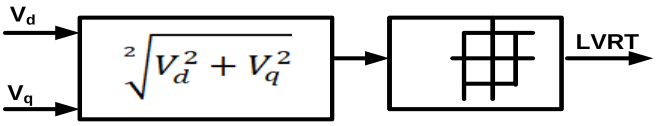


Fig. 4. The LVRT implementation block.

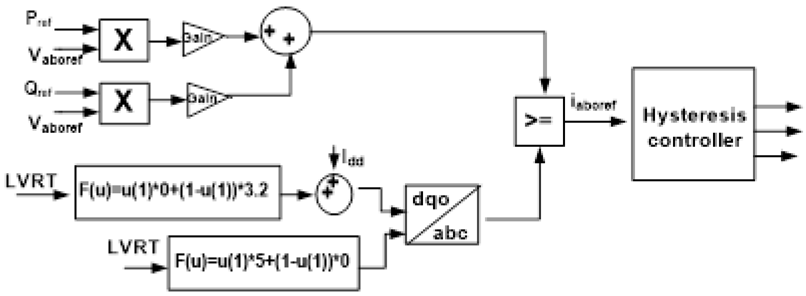


Fig. 5. Current controller for generation of current reference in CPT control.

4. Results and Discussion

4.1. MATLAB Simulation

In this segment presentation of three phase three level inverter is evaluated on behalf of multiple functionalities in MATLAB Simulink based on block diagram shown in Fig. 1 and simulation parameters are given in Table 3. The main aim is to examine the presentation of the multilevel multifunctional inverter, measured by means of CPT based compensation for active power integration, harmonics free current injection, reactive support and power factor control. Figure 6 displays the line voltage, and all three phase voltages are shown in Fig. 7. It is clear from both figure that stepped out-put voltage of inverter reduces the harmonics significantly and out waveform become closer to sinusoidal All three PV panel voltages and MPPT voltages are shown in Fig. 8.

Table 3. Simulation parameter.

Parameter	Design values
Voltage of grid	440V
Frequency of grid	50Hz
Each cell open circuit voltage	45.7Volts
Each cell short circuit current	5.7Ampere
No of cell in each module	60
Series connected modules in each string	10
Paralleled connected modules	1
Solar irradiance(G)(variable)	500~700
Module temperature(variable)	250C~350C
Source resistance	1×10^{-3} Ω
Source inductance	1×10^{-7}mH
Three-phase diode bridge rectifier with RL in output	R=2×90 Ω, L=11×10^{-3} H

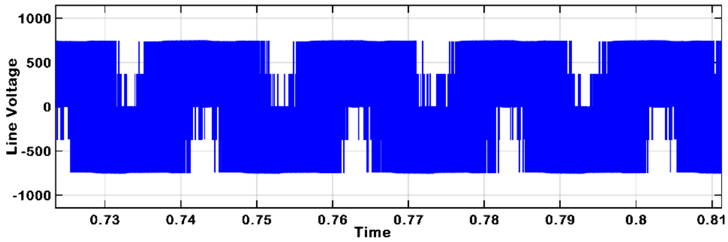


Fig. 6. Inverter line voltage.

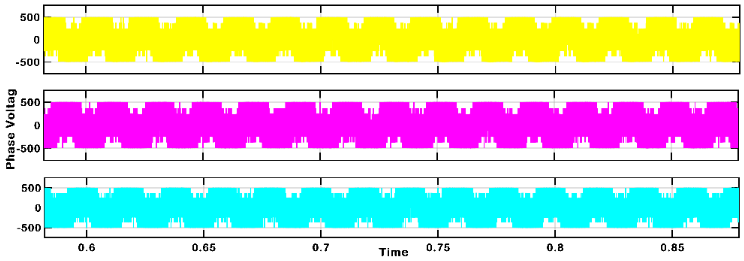


Fig. 7. Inverter phase voltages of all three phase.

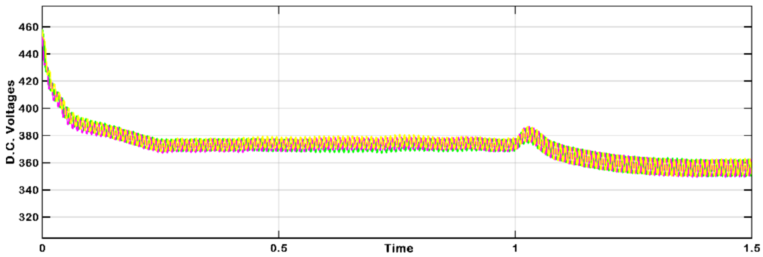


Fig. 8. PV panel and MPPT voltages of all three phases.

Dynamic behavior of presented system is shown when it is subjected to variable irradiation temperature change. At the time t = 1 s in simulation the solar irradiation is increased from 500 W/m^2 to 700 W/m^2 and temperature from 25 ºC to 30 ºC inverter is now feeding more power to grid as load is constant this results in increase in the amplitude of the current of the inverter as well as the grid. Figure 9 shows the waveforms of grid current I_s transition at t=1 s.

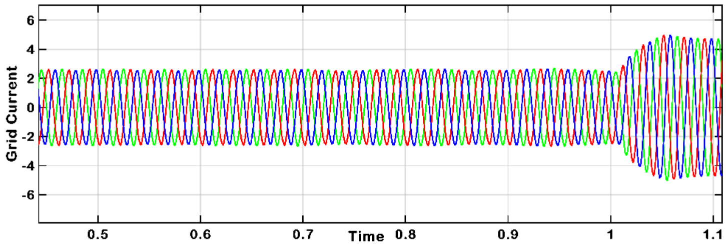


Fig. 9. Grid current for varying irradiation/temperature.

The active and reactive power flow in the given electric power system is given by Eqs. (17) and (18) respectively which is clear from Figs. 10 and 11.

$$P_i + P_l + P_g = 0 \quad (17)$$

$$Q_i + Q_l + Q_g = 0 \quad (18)$$

Proposed inverter remains capable of supplying active and also reactive power demand of load during daytime, i.e., PV mode.at time $t = 1$ s when irradiance increases inverter current increases, so power of inverter also increases accordingly. This increase in power from solar pv leads to increment in grid power. Active and reactive powers of the grid, inverters, load, is shown by Figs. 10 and 11. From Fig. 11, it is vibrant that the inverter completely compensate the reactive power demand of the load though supplying it with the essential active power. So, the engrossed active power of the grid is reduced. Here inverter capacity is made slightly higher then require load capacity so that apart from supplying required active power of load inverter also supplies reactive power with remaining capacity as explain in flow-chart. In the night when there is no solar irradiations inverter turn into idle, to increase utilization factor of system same inverter can be supposed to work in STATCOM mode.

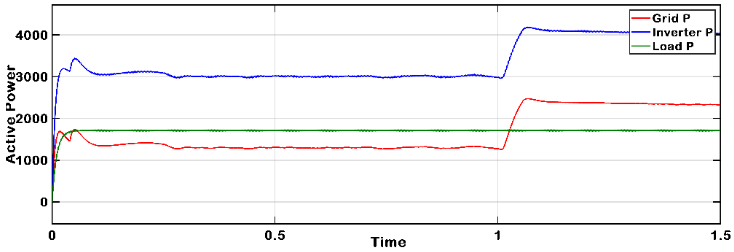


Fig. 10. Active power of grid, inverter, and load in PV mode.

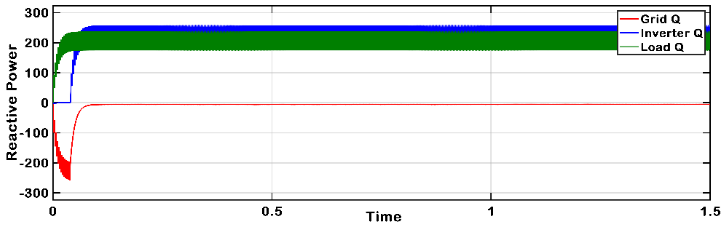


Fig. 11. Reactive power of grid, inverter, and load in PV mode.

Figures 12 and 13 present the performance of system in STATCOM mode. Active and reactive power of the grid, inverter, and load in STATCOM mode of operation of proposed system is shown in these two figures, at this time active power demand of load is fulfil by grid and inverter is supplying entire load and grid reactive power demand it is clear from Fig. 12 and 13 inverter is successfully supplying reactive power demand of load and grid at nighttime and act as fully STATCOM.

In this way when there is no sunlight and PV is not producing any power inverter can be utilized as DSTATCOM and support grid for power quality operations.The voltage (V_{sa}) and current of the grid (i_{sa}) are shown in Figs. 14(a) and (b) for the phase a. It is clear from the figures that the current and voltage are in phase opposition because grid is absorbing surplus power supplied by inverter which conforms the power factor correction operation of proposed PV inverter. While in STATCOM mode all load reactive power is compensated by inverter so grid currents and voltage are in same phase. This change in angle is due to the grid changes its mode from the active power absorption in PV mode to the active power supplying procedure in STATCOM mode.

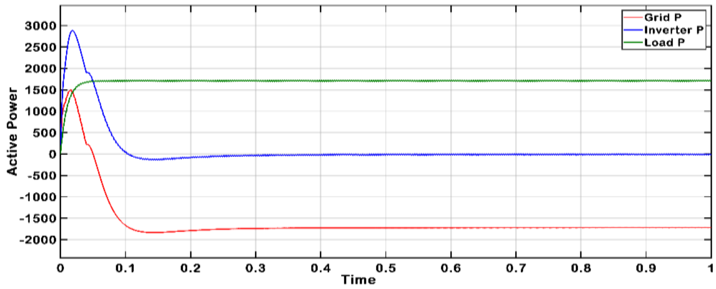


Fig. 12. Active power of grid, inverter, and load iv STATCOM mode.

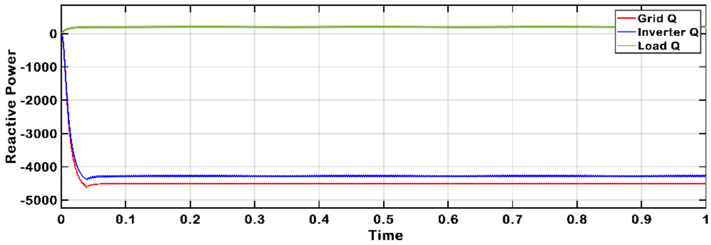
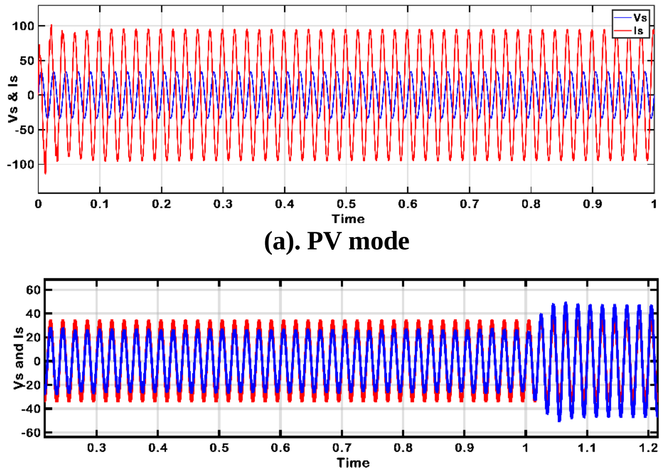


Fig. 13. Reactive power of Grid, inverter, and Load iv STATCOM mode.



(a). PV mode

(b). STATCOM mode.
Fig. 14. Power factor correction in the two modes.

Figure 15 shows the grid, current I_s inverter current I_{inv}, and load current I_l. It is clear from this figure that amplitude of inverter current is more than both load current and grid current which means inverter is capable of supplying load demand as well as feeding excess power to grid. Dynamic performance is also evident from this figure as irradiation temperature set to more values inverter respond quickly and increase its current up to its remaining capacity. While Fig. 16 shows grid current THD which is 1.99% well below 5% IEEE standard requirement. Proposed inverter is capable of compensating harmonics of non-linear load successfully using CPT based compensation and act as active filter Simulation results show effectiveness of the CPT based multilevel compensator for shunt APF function along with suppling real power and harmonic's free grid current injection.

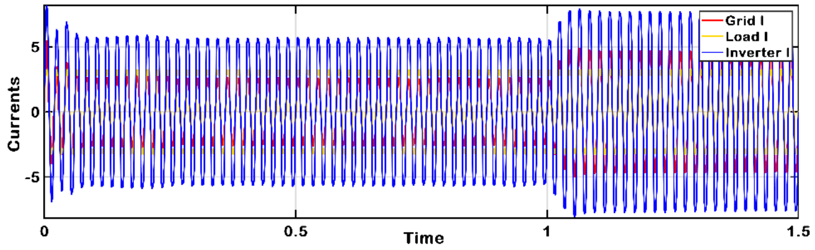


Fig. 15. Grid current, inverter current, load current.

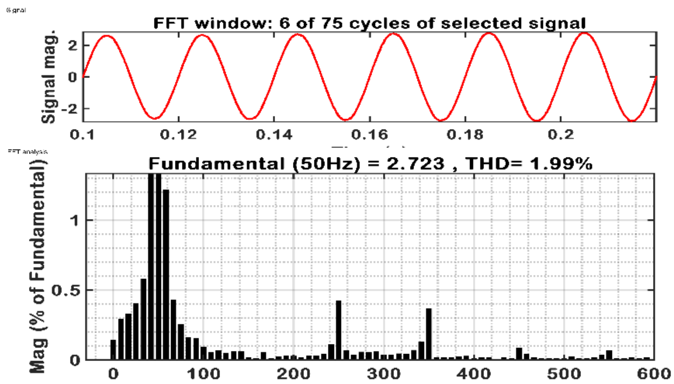


Fig. 16. FFT analysis of grid current.

The Low Voltage Ride Through performance with islanding detection of the proposed inverter is investigated in Fig. 17. Performance is investigated when system is working in PV mode. Disturbance is created by creating short circuit at t=0.1 sec for 0.03 s. After that normal operation is restore and then grid is disconnected to show anti-islanding capacity of presented inverter Fig. 17 shows grid voltage (V_{sa}) grid current (i_{sa}) and inverter current (i_{ca}) and load current (i_{la}) It is clear from figures that system monitors the grid status, acts to synchronize and ride through with fault for time limit prescribed by regulations and come back to service again. At time of low voltage ride through grid voltage is reduced to 80% of normal value inverter differentiate clearly between LVRT and islanding because inverter current is not zero actually at this point inverter is supplying require reactive power and support to grid.

which is clear from figure that inverter current with significant value at time of grid fallout invert stop feeding power and disconnected as its current became zero.

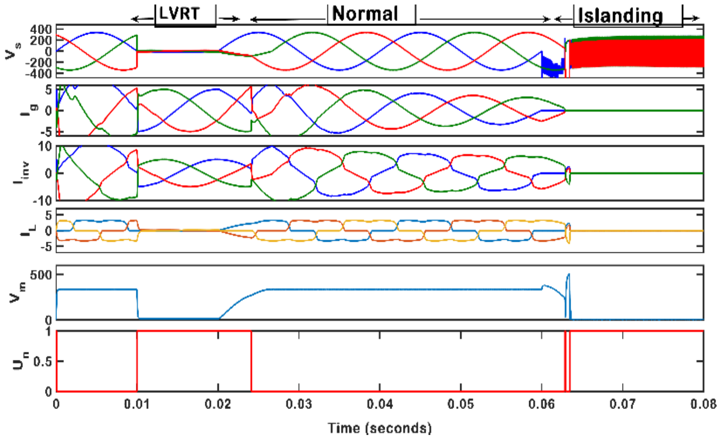


Fig.17. Grid voltage V_s, grid current I_s, inverter current I_{inv}, load current, LVRT voltage, detection signal.

This system also detects islanding within 4msec, which is well below standard time limit of 2 s. Detection signal used to check the LVRT in simulation is also shown in Fig. 17 and islanding because inverter current is not zero actually at this point inverter is supplying require reactive power and support to grid**.**

Table 4. Details ratings of experimental components.

Parameter	Design values
Voltage of grid	440 V
Frequency of grid	50 Hz
Nominal Maximum Power (Pm) in Watts	150 Wp
Each cell Open circuit voltage	44.3 Volts
Each cell short circuit current	4.51 Ampere
Capacity of three phase inverter is	5 kVA
Fixed frequency hysteresis at	20 kHz
DC-Link Capacitor (Single on each DC LINK)	4700 mF 450V
RC Filter at PCC	R 10 ohm/10 W, C=2.5 mF/440V
PI controller value	K=0.3 and Ki=0.2
Three-Phase Diode Bridge Rectifier	IRI MDS100/16

4.2. Experimental setup

To validate results presented in simulations hardware prototype of the presented system is developed in the laboratory which is shown in Fig. 18 three-phase grid supply of 230 V 50 Hz reduced to 30 V with varec. Three inductance of value 6 mH are used as coupling inductors. Six PV panels (150Wp of Warree make) are used two in series for each phase. Three D.C. link voltages are kept between 65V to 70 V. Harmonic currents were generated by a three-phase diode bridge rectifier (IRI MDS100/16) as the non-linear load single phase four switch IGBT inverter module

(NiTech make) each in all three phases is realized as H bridge inverter. NiTech make hall effect-based sensor cards are used to sense the DC-bus voltage, PV current. The grid voltage, the load current and grid currents are measured by NiTech make inductive current transformer. The Control technique is implemented through arm cortex STM32F407VGT microcontroller. Details of hardware is shown in Table 4.

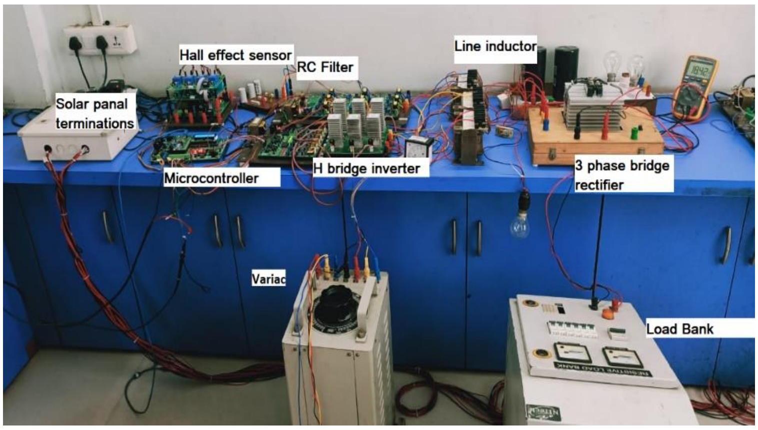


Fig. 18. Experimental setup.

Figure 19 shows grid voltage (V_{sa}) grid current (i_{sa}) and inverter current (i_{ca}) and load current (i_{la}) in steady-state with non-linear load and active filtering operation. Figure 20 shows the dynamic performance of the presented system for varying load conditions in PV mode. It is clear from the diagram that the inverter is capable of compensating harmonics of nonlinear load all the time as grid current waveform is close to sinusoidal apart from that grid current and is in phase with the grid voltage that shows the power factor correction operation of the inverter.

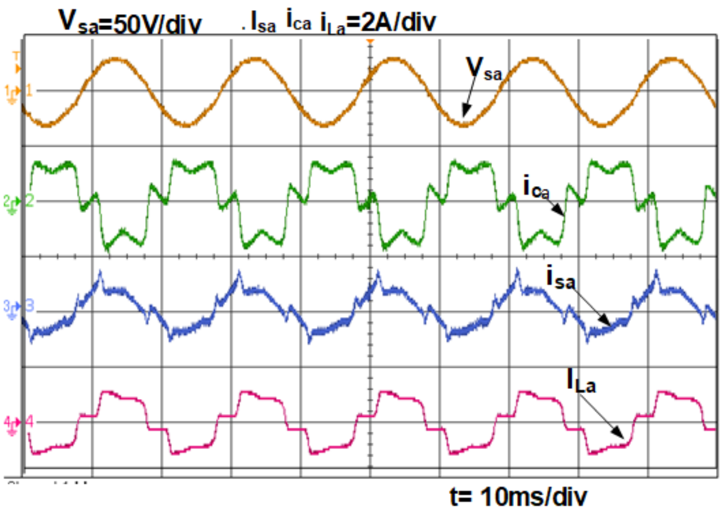


Fig. 19. Grid voltage V_{sa}, grid current I_{sa},
Inverter current I_{ca}, load current I_{La}, steady state mode.

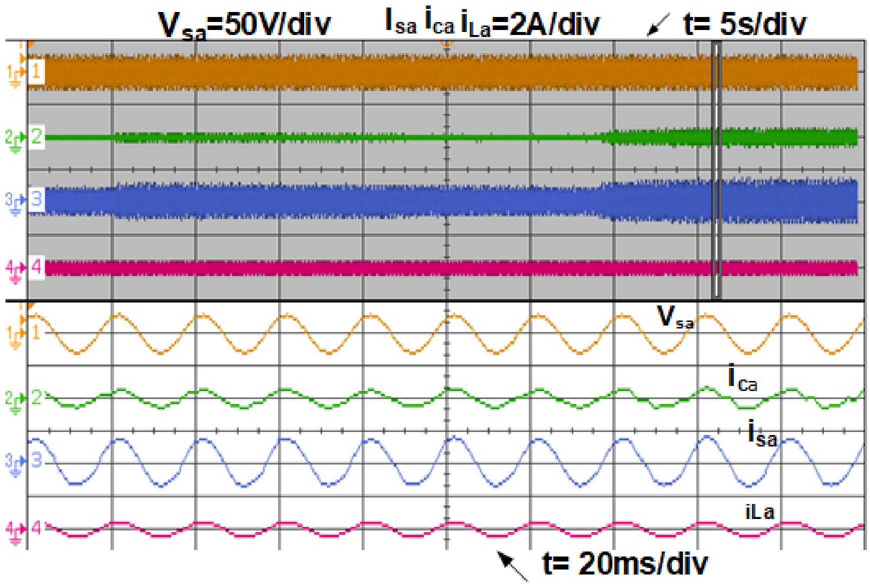


Fig. 20. Dynamic performance of inverter grid tied system under nonlinear load in phase a.

Figure 21 shows the islanding detection operation of the presented inverter it is clear from this figure as grid voltage/current reduced to <10% of its normal value inverter command voltage (V_d)dropped to zero value which causes the inverter to stop feeding to the grid. Presented simulation and experimental results validate the multifunctional operation of the proposed inverter with CPT control.

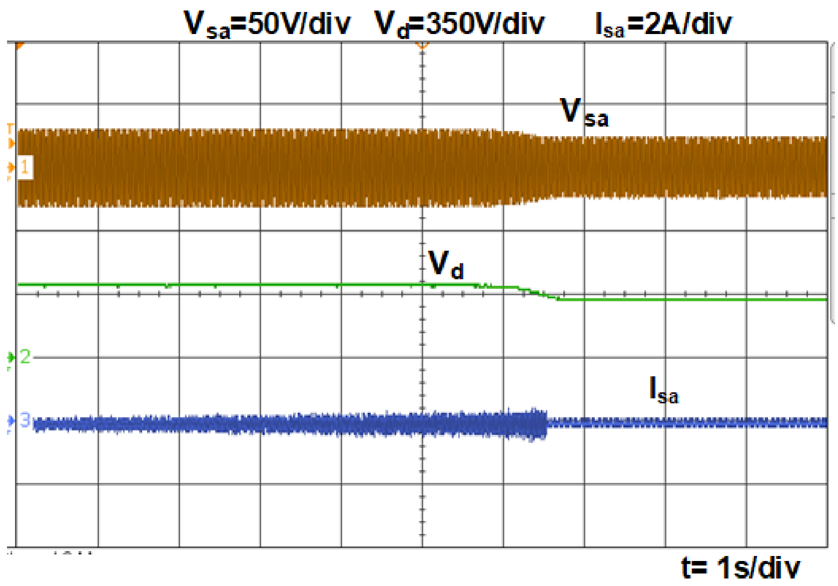


Fig. 21. Islanding detection.

5. Conclusion and Future Scope

This broadsheet has presented a multifunctional multilevel inverter for grid connected solar PV. Objective here is to compensate various unwanted signals presents in wave forms with the help of Conservative power theory.

Multilevel inverters have numerous advantages, e.g., the modular structure and more reliability in the system. These appearances make this topology a perfect choice for medium as well as high power requirements in power systems. Also, this control plan controls the output current through following positions providing by CPT, without applying any type of reference frame transformations. There is manifold operation that projected inverter can achieve apart from active power inoculation.

The Low Voltage Ride through (LVRT) presentation with ant islanding capability of the proposed smart inverter is examined through MATLAB Simulink environment. All-purpose has its own present orientation that is gotten by resources of the CPT. Simulation and experimental results established the effectiveness of the multifunctional multilevel inverter to function in all manners of process a causal to the development of the quality, dependability, efficiency and constancy of the electrical system. So, recommended system have auspicious application probable.

This paper explores three level multifunctional inverter for distribution grid application more level can be increased to use this system in medium and high voltage applications. Multifunctional compensator with battery storage capability can also include to make system more efficient and reliable.

Abbreviations

ACHMI	Asymmetrical Cascaded H-Bridge Multilevel Inverter
CHMI	Cascade H-bridge multilevel inverter (CHMI)
CPT	Conservative power theory
DG	Distributed generation
EMI	electromagnetic interference
HVRT	High voltage ride through
LVRT	Low voltage ride through
PV	Photovoltaic
STATCOM	Static synchronous compensator
THD	Total harmonics distortion

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