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Active Power Conditioner For Compensation Of Reactive Power, Active Power And Harmonics Under Different Loading Condition

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Abstract:

The voltage at the point of common coupling (PCC) in a weak network is very sensitive to load changes. A sudden change in active load will cause both a phase jump and a magnitude fluctuation in the bus voltage, whereas reactive load changes mainly affect the voltage magnitude. With the addition of energy storage to aActive Power Conditioner (APC), it is possible to compensate for the active power change as well as providing reactive power support. In this paper some effective active power compensation schemes are proposed. Simulation results are also presented showing the benefits of active power compensation to certain applications with phase sensitive load. This paper presents a novel control strategy for achieving maximum benefits from these grid-interfacing inverters when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously. This new control concept is demonstrated with extensive MATLAB/Simulink. Finally the proposed shceme is applied for both unbalanced linear and non linear loads.

Key words: *International electro-technical commission (IEC), power quality,wind generating system (WGS).*

1.Introduction

In order to improve the survivability of a navy ship in battle condition, APC or Distribution Static Compensator can be used, which reduces the impact of pulsed loads on the bus voltage and thus keeps the bus voltage at desired level. APC is a voltage-source inverter (VSI) based shunt device generally used in distribution system to improve power quality. The main advantage of APC is that, it has a very sophisticated power electronics based control which can efficiently regulate the current injection into the distribution bus. The second advantage is that, it has multifarious applications, e.g. i. cancelling the effect of poor load power factor, ii. suppressing the effect of harmonic content in load currents, iii. regulating the voltage of distribution bus against sag/swell etc., compensating the reactive power requirement of the load and so on. The performance of the APC is very much dependent on the APC controller.

1.1.Basic Principle Of APC

A APC is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a APC are based on the exact equivalence of the conventional rotating synchronous compensator.

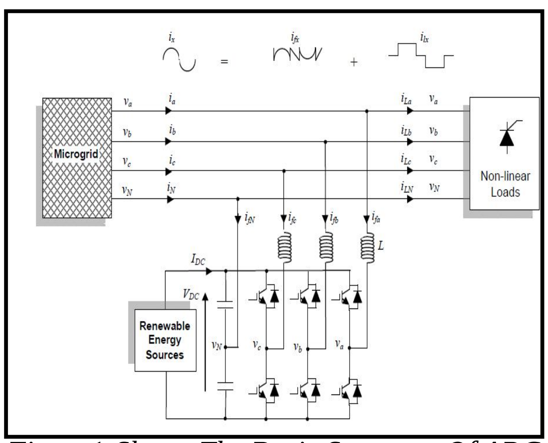

Figure1:Shows The Basic Structure Of APC.

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in fig 1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the APC is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a APC used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to study-ing the performance of a APC for power factor correction and harmonic mitigation. However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously.

2.Actice Power Compensator (Apc)

A APC consists of a two-level VSC, a dc energystorage device, controller and a coupling transformer\ connected in shunt to the distribution network. Figure 2 shows the schematic diagram of APC.

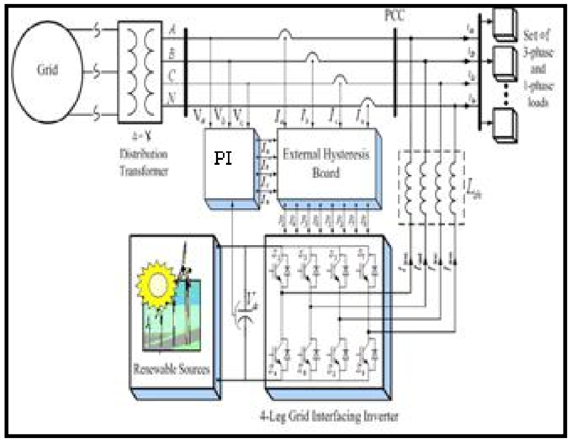

Figure2 :Schematic Diagram Of A APC With RES

2.1.Voltage Source Converter (Vsc)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9].

2.2.Controller For APC

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of APC. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The control scheme is represented in Fig. 2. The basic equations of control algorithm of APC are as follows.

2.2.1.<u>Computation Of In-Phase Components Of Reference Supply Current</u>

The instantaneous values of in-phase component of reference supply currents (*I*spdr) is computed using one PI controller over the average value of DC bus voltage of the APC (*v*dc) and reference DC voltage (*v*dcr) as

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{V_{de(n)}$$

where Vde(*n*) □□Vdcc-Vdc*n*) denotes the error in Vdcc and average value of Vdc *Kpd* and *Kid* are proportional and integral gains of the DC bus voltage PI controller. The output of this PI controller (*I*spdr) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed using the in-phase unit current vectors (*u*a, *u*b and *u*c) derived from the AC terminal voltages (*v*tan, *v*tbn and *v*tcn), respectively.

$$U_a = V_{ta}/V_{tm} \quad U_b = V_{tb}/V_{tm} \quad U_c = V_{tc}/V_{tm}$$

where *V*tm is amplitude of the supply voltage and it is computed as

$$V_{tm} = \sqrt{[(2/3)(V_{tan}^2 + V_{tbn}^2 + V_{tcn}^2)]}$$

The instantaneous values of in-phase component of reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed as

$$I_{sadr} = I_{spds}U_a \;\; I_{sbdr} = I_{spdr}U_b \;\; I_{scdr} = I_{spdr}U_c$$

2.2.2.<u>Computation Of Quadrature Components Of Reference Supply Current</u>

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (*v*tm) and its reference value (*v*tmr)

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{V_{ac(n)} - V_{ac(n-1)}\} + K_{iq}V_{ac(n)}$$

Where Vac = VtmcVmc(n) denotes the error in Vtmc and computed value *Vtmn* from Equation (3) and Kpq and Kiq are the proportional and integral gains of the second PI controller.

$$W_a = \{-U_b + U_c\}/\{\sqrt{3}\}$$
$$W_b = \{U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$
$$W_c = \{-U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$

Three-phase quadrature components of the reference supply currents (*i*saqr, *i*sbqr and *i*scqr) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (*w*a, *w*b and *w*c) as

$$i_{saqr} = I_{spqr} W_a, \; i_{sbqr} = I_{spqr} W_b, \; i_{scqr} = I_{spqr} W_c,$$

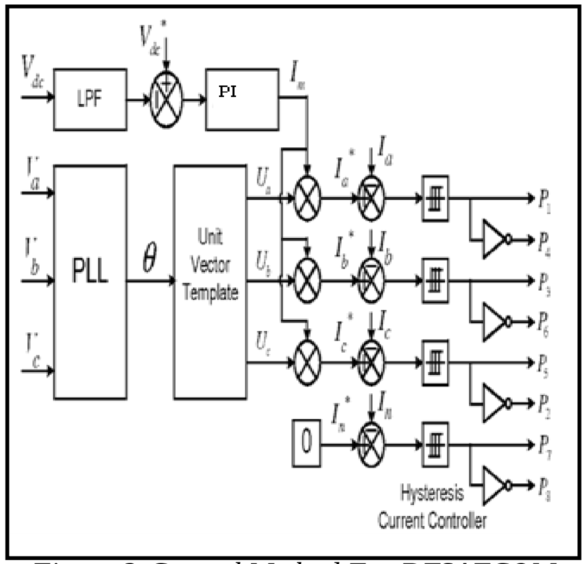

Figure 3:Control Method For DTSATCOM

2.2.3. <u>Computation Of Total Reference Supply Currents</u>

Three-phase instantaneous reference supply currents (isar, isbr and iscr) are computed by adding in-phase (isadr, isbdr and iscdr) and quadrature components of supply currents (isaqr, isbqr and iscqr) as

$$i_{sar} = i_{sadr} + i_{saqr}, \qquad i_{sbr} = i_{sbdr} + i_{sbqr}, \qquad i_{scr} = i_{scdr} + i_{scqr}$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference (isar, isbr and iscr) and sensed supply currents (isa, isb and isc) to generate gating pulses for IGBTs of APC.

3.Matab/Simulink Modeling Of APC

3.1.Modeling Of Power Circuit

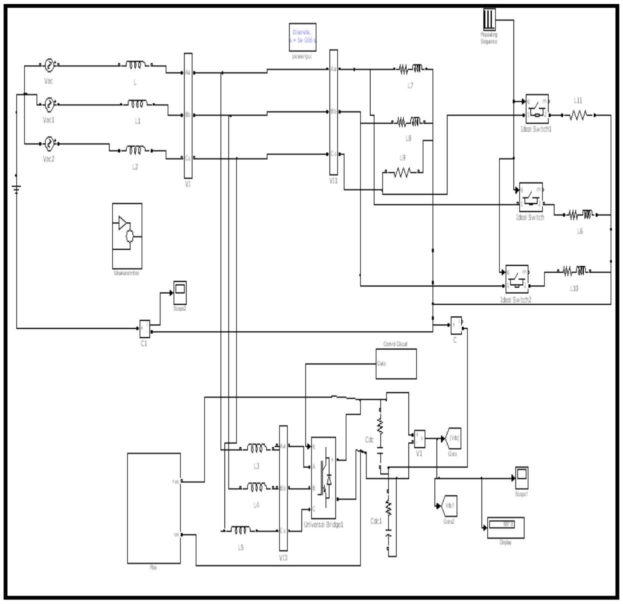

Figure 4

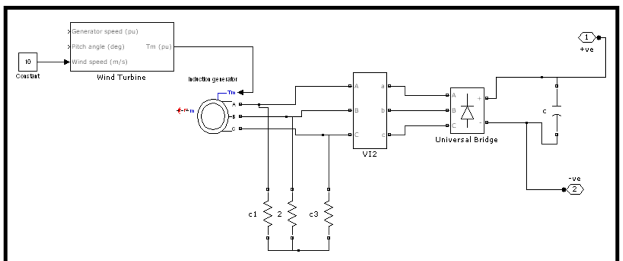

Figure5:Matlab/Simulink Model Of APC Power Circuit With Linear Load .

Fig. 5 shows the complete MATLAB model of APC along with control circuit. The power circuit as well as control system are modelled using Power System Blockset and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. APC is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of APC system is carried out for linear and non-linear loads. The linear load on the system is modelled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modelled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modelled using appropriate values of resistive and inductive components.

3.2.Modeling Of Control Circuit

Fig.6 shows the control algorithm of APC with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of APC reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

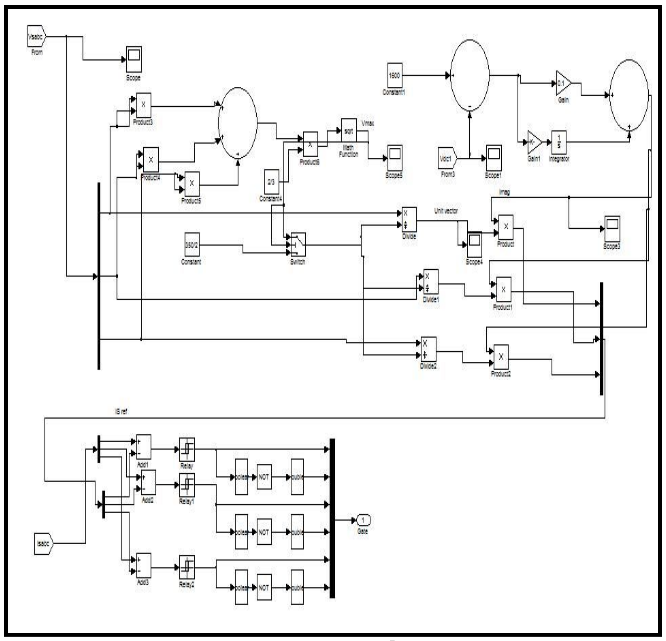

Figure 6:Control Circuit

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrierless hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of APC. The controller controls the APC currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as APC.

4.Simulation Results

Here Simulation results are presented for two cases. In case one reactive power and harmonic compensation, case two active power, reactive power and harmonic compensation is considered.

4.1.Case One

Performance of APC connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This figure shows variation of performance variables such as supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), APC currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc).

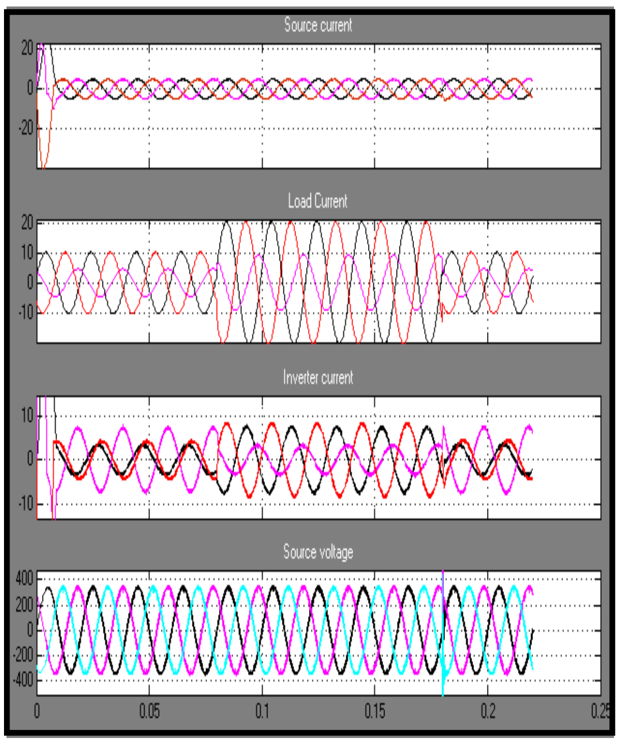

Figure 7: Simulation Results For Balanced Non LinearLoad (a) Source current. (b) Load current. (c) Inverter injected current.(d) wind generator (induction generator) current

Fig. 6 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds.

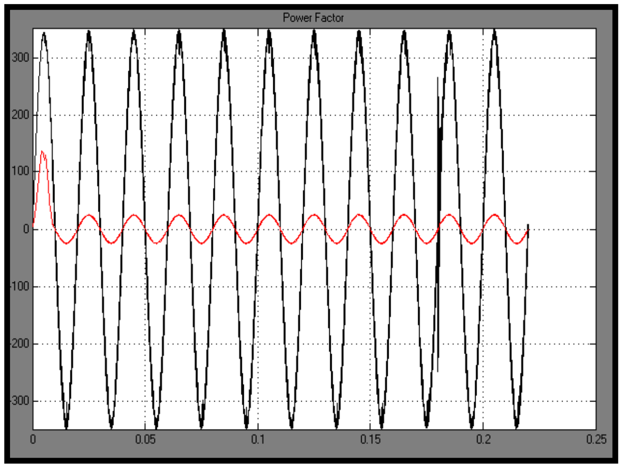

Figure 8: Simulation Results Power Factor For Linear Load

Fig. 7 shows the power factor it is clear from the figure after compensation power factor is unity.

4.2 Case Two

A Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig. 7 shows the transient responses of distribution system with APC without battery for supply voltages (*v*sabc), supply currents (*i*sabc), load currents (*i*la, *i*lb and *i*lc), APC currents (*i*ca, *i*cb and *i*cc) along with DC link voltage (*V*dc) and its reference value (*V*dcr) at rectifier nonlinear load.

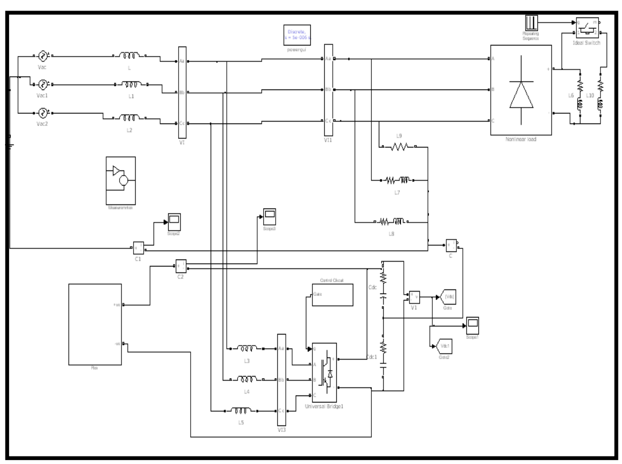

Figure 9: Matlab Circuit Of Power System With Unbalanced Nonlinear Load

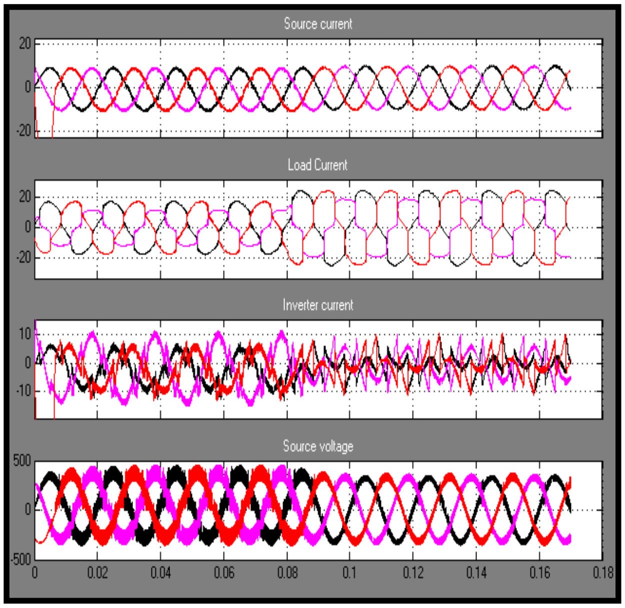

Figure 10: Simulation Results Non- Linear Unbalanced Load (A) Source Voltage (B) Source Current (C) Load Current (D) Induction Generator Current

Fig.9 shows the Source current, load current and compensator current and induction generator current. From the figure it is clear that even though load is unbalanced source currents are balanced and sinusoidal.

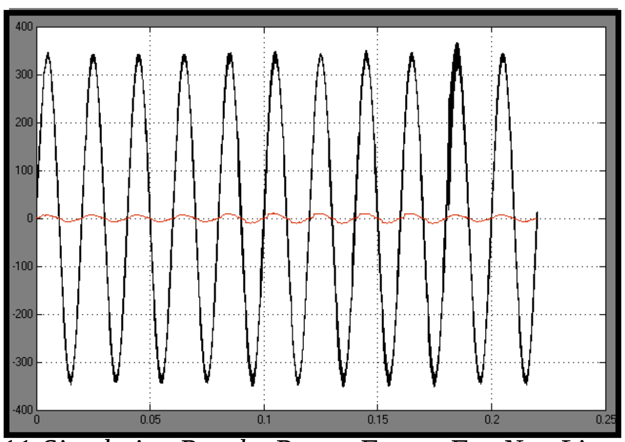

Figure11:Simulation Results Power Factor For Non Linear Load

5.Conclusion

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wireDGsystem. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The proposed APC with RES system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. APC compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of APC system has been found to be satisfactory for improving the power quality at the consumer premises. Rectifier-based non-linear loads generated harmonics are eliminated by APC. When single-phase rectifier loads are connected, APC currents balance these unbalanced load currents. Finally Matlab/Simulink based model is developed and simulation results are presented.

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