

Multiple Control of Unidirectional Ac-Dc Step-Up Converters for Improving Power Quality

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ABSTRACT

The ineluctability of solid state ac-dc step-up converters to raise power quality in terms of power factor correction (PFC), diminished total harmonic distortion at input ac mains and absolutely regulated dc output have motivated the control methods based on power electronics based compensators and other static controllers, such as FACTS technologies. Utmost power factor correction circuits present in the industrial market exploit unidirectional ac-dc step-up converter topologies, this is an around no-cost solution for compensating harmonic current and reactive power in residential application. By using unidirectional ac-dc step-up converter harmonic current and reactive power compensation is at beforehand investigated. But the amount of reactive power injected from an individual converter to the grid should be bounded due to input current distortion. This paper propose additionally to quantify the input current distortion by the unidirectional ac-dc step-up converter used for supplying not only active power to the load but also reactive power.

KEYWORDS - Active power filter(APF), harmonic current compensation(HCC), power factor correction(PFC), reactive power compensation(RPC), unidirectional ac-dc step-up converter.

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I. INTRODUCTION

In an ac power systems related with moving of the voltage or current from the desired ideal sinusoid of constant amplitude and frequency for an analysis of power quality. Unfiltered harmonics cause interference in other facilities, making undesirable and abnormal behavior of electrical equipments and transformer overheating. Fractious reactive power enlarge transmission conduction losses and go down the performance of voltage regulation. Therefore, it is desired to reduce these effects through sufficient medium, i.e. harmonics current compensation (HCC) and reactive power compensation (RPC).

Multiple technologies, having advanced power capacities rooted on power electronics theory have aimed to renovate grid power quality and compensate reactive power at the transmission and distribution system level. Flexible alternating current transmission systems (FACTS) have been studied by commercial and classical researchers since 1990s. A.C. transmission system unifies power electronics based compensators and other static controllers largely enlarge controllability and enhance power transfer caliber. During FACTS technologies, the static VAR compensators (SVC), static synchronous compensator (STATCOM), and unified power quality conditioner (UPQC) all obtain the capacity to compensate reactive power . Active power filter configurable with several power topologies can be exploit for improving power quality through harmonic current compensation and reactive power compensation. Albeit static VAR compensators, static synchronous compensators, unified power quality compensators and active power filters exhibit outstanding performance, but they may not be the best solution for improvement of power quality of an overall power system due to high capital and operating costs, as well as additional power losses due to long distance transmission of reactive power.

To discover extra lucrative key, the demand of improving power quality have continuously stimulate power electronics engineer to include HCC and RPC capabilities as consequential services in bidirectional power converters. As power converter for non-conventional energy sources become more renewed in ac power systems, the potential for HCC and RPC will increase, as these control design can be employed in existing topologies without hardware changes. Nevertheless the increased utility and cost savings, the number of non-conventional power converters adequate of fulfilling these function is still confined.

Alternatively, vehicle-to-grid (V2G) technology has lately escape for incorporation of electric vehicle (EVs) into the electric grid an energy storage units, which can supply power quality mitigation as consequential service. This will consequence in enhanced reliability and performance of power system. However, V2G connections desire a bidirectional power converter, which grown up system costs and complexity compared to that of a unidirectional power converter. For this reason, a unidirectional topology is a preferable configuration for level 1 battery chargers in EV and plug-in electric vehicle (PHEV) applications, meant for residential interconnection, whereas V2G exploit bidirectional converters is more applicable for level 2 battery chargers.

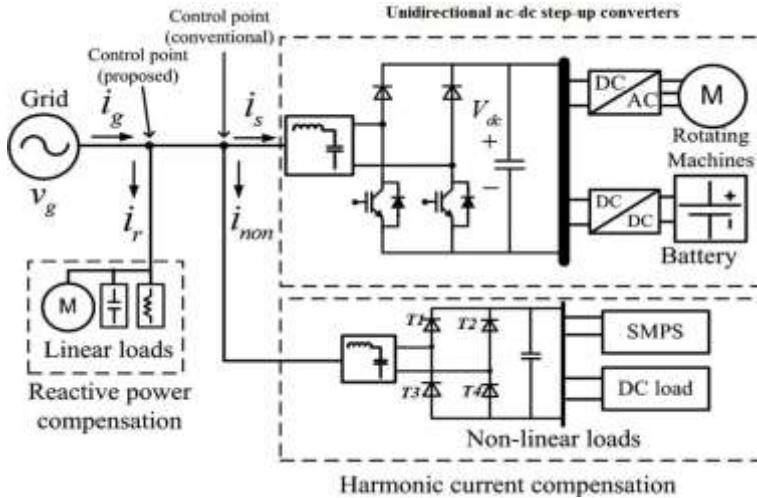


Fig.1.1. Proposed system connected linear and non-linear loads.

The motive of this paper is to explore an effective cost power quality allaying solution by utilizing unidirectional converters, even though RPC and HCC contest with the basic purpose and premise of maximizing the power factor. Since, huge number of thee unidirectional converters are present within residential power systems, these unidirectional converters, operating in correspondence, having a high potential as alternative HCC and RPC units and thus, these converters can act in place of larger, more costly HCC and RPC instrument if they obtain these functionalities.

In modern years, few papers have elaborate HCC and RPC functionalities using unidirectional power factor correction (PFC) converters. Few authors broadly viewed battery charger topologies used for EV/PHEV application for providing reactive power support to the grid, but the RPC capability in unidirectional converters was described briefly and any advance analysis was not conducted. The feasibility of HCC functionality using boost converter was offered as a low cost solution, but RPC functionality was not described. The reactive power support capabilities of the unidirectional converter within V2G applications were studied through simulation results, but detailed analysis regarding input current distortions was not performed.

In this paper, the practicability and limitations of the unidirectional ac-dc step-up PFC converter, when it is employed for the HCC and RPC, are discovered. In addition, an outlook for estimating the distortion level of the current under RPC modes is analytically justified. This paper starts with an account of control modes and analysis of local loads for the proposed system in segment II. Experimental or simulation results are presented in order to validate the proposed in segment III. Finally segment IV conclude the paper.

II. OPERATIONAL AND CONTROL MODE

The dual boost PFC converter, commonly called the bridgeless PFC converter, is one of the most noted as unidirectional ac-dc boost converters. The control algorithms of the dual boost PFC converter are almost similar to any conventional ac-dc converter using a diode rectifier and step-up chopper, except that the dual boost PFC converter controls ac input current, while the traditional one controls rectified output current. Fig.1 shows a operable application of unidirectional ac-dc step-up converters. Traditional PFC converters contemplate the input current to be a purely sinusoidal waveform, which is completely in phase with the input voltage. The moved control method can be correction of harmonic current and reactive power for elevated grid power quality, as well as regulation of dc-bus voltage. The proposed versatile control of unidirectional ac-dc step-up converter has three modes of operation, i.e. PFC, HCC, and RPC. Also, both HCC and RPC can operate simultaneously to improve the distortion and the displacement factors of the grid current.

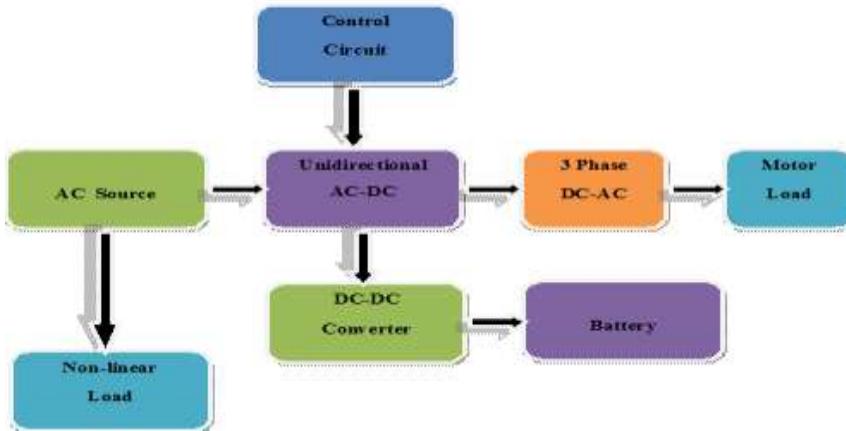


Fig.2.1 Block diagram of unidirectional ac-dc step-up converter

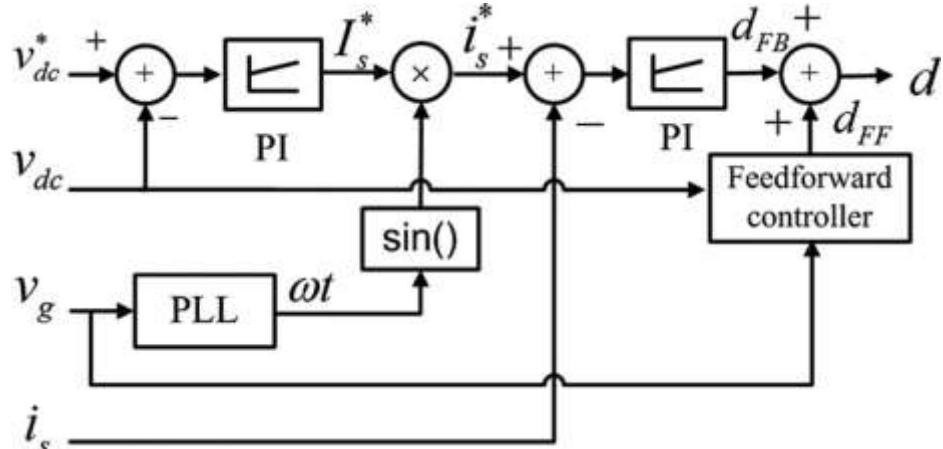


Fig.2.2 Conventional control algorithm for unidirectional ac-dc boost

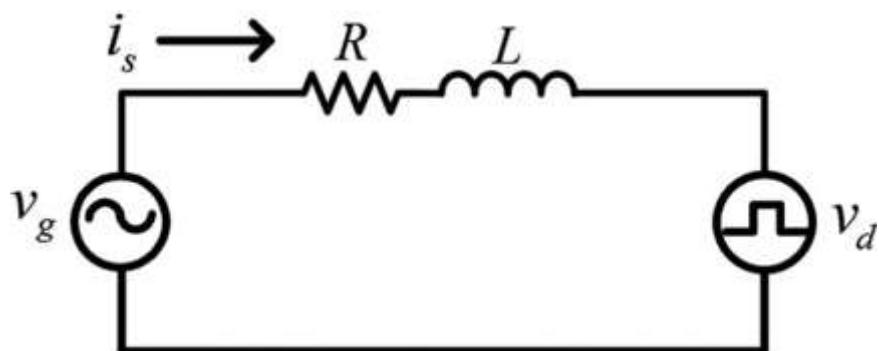


Fig.2.3 Simple circuit diagram during a positive half period of the source voltage.

2.1 Power factor correction control strategy

PFC control methods are very generic in the related literature, especially those exploiting feedback and feed forward controllers, as shown in Fig. 2. Fig. 3 represent a simple circuit diagram of unidirectional ac-dc boost converters with an input inductor L and its parasitic resistor R . Kirchhoff's voltage law with the source voltage v_g , the switch voltage v_d , and the input line current yields to

$$Vg = Ris + L dis/dt + vdd \quad (1)$$

where v_g is the instantaneous value of the source voltage expressed as $Vg \sin(\omega t)$. The switch voltage is always a major factor in determining the waveform of the input current. In other words, when producing a sinusoidal input

current, the switch voltage has to emulate the source voltage identically, with the exact phase difference due to input impedance. The average switch voltage over a switching cycle in continuous conduction mode can be expressed as

$$vd = (1 - d)vdc \quad (2)$$

where d is the average on-time duty ratio of the switches and vdc is the dc output voltage. When the source voltage is in the negative half period, the sign of the input current and switch voltage will be opposite in (1). Therefore, the source voltage can be considered as a rectified voltage, which can be explicit by the absolute sign. This indicates that the bridgeless PFC converter is identical to the general boost converter, using the single switch in rectified dc link, with regard to its operational principle. Combining (1) and (2), and rearranging in terms of d , the duty ratio equation can be obtained as

$$d = \underbrace{\frac{1}{v_{dc}} \left(R i_s + L \frac{di_s}{dt} \right)}_{d_{FB}} + \underbrace{\left(1 - \frac{|v_g|}{v_{dc}} \right)}_{d_{FF}}. \quad (3)$$

Theoretically, the duty ratio in (3) should be generated for the ideal switch voltage as accurately as possible through adequate converter compensators to yield sinusoidal input current. In order to classify the duty ratio d of the system in (3), the feedback duty ratio d_{FB} and the feed forward duty ratio d_{FF} can be considered separately. d_{FB} produces the exact phase difference between the source voltage and the average switch voltage. d_{FF} produces the inverse of the source voltage waveform as the average switch voltage. Hence, the input current tracking is improved and the frequency range for which input admittance acts purely as a resistance can be extended to higher frequencies due to feed forward control.

2.2 Harmonic current compensation

Fig.2.4 shows the current waveform of a typical nonlinear load in a single-phase diode rectifier. Generally, the distorted load current i_{non} can be written in terms of its fundamental i_{fn} and harmonic i_{hn} components as

$$i_{non} = I_1 \sin(\omega_1 t + \theta_1) + \sum_{n=2,3}^{\infty} I_n \sin(n\omega_1 t + \theta_n) \quad (4)$$

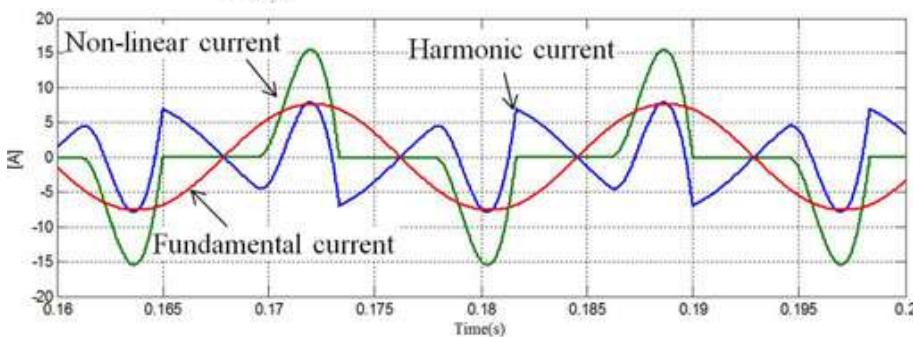


Fig.2.4 Example of nonlinear load current (THD: 80%, PF: 0.705, P: 550 W, Q: 200 Var)

where ω_1 is the line angular frequency and θ_n is the phase difference between the source voltage and input current.

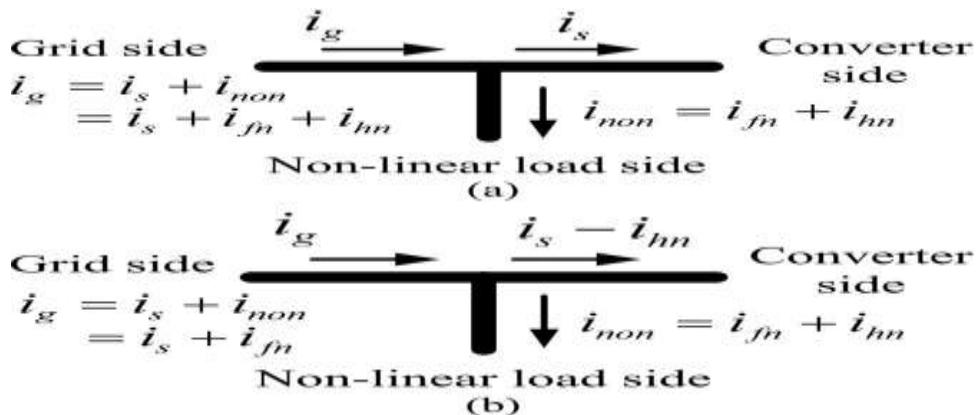


Fig.2.5 Harmonic current flow diagram (a) without HCC and (b) with HCC.

Assume that the input current from the unidirectional ac–dc boost converter operating in PFC mode is a purely sinusoidal waveform. The grid current i_g includes i_{hn} from a nonlinear load as shown in Fig.2.5(a). These harmonics are undesirable and should be removed. If the unidirectional ac–dc boost converter can generate the harmonic current capable of canceling the harmonics of the nonlinear load, the grid current will be comprised of only fundamental components of the converter current and load current as shown in Fig.2.5(b). Therefore, the new current reference for the current controller of the converter from Fig.2.6 can be expressed as

$$i_s^* = I_s^* \sin(\omega t) - i_{hn} \quad (5)$$

Where I_s^* is the magnitude reference provided by the dc-bus voltage controller.

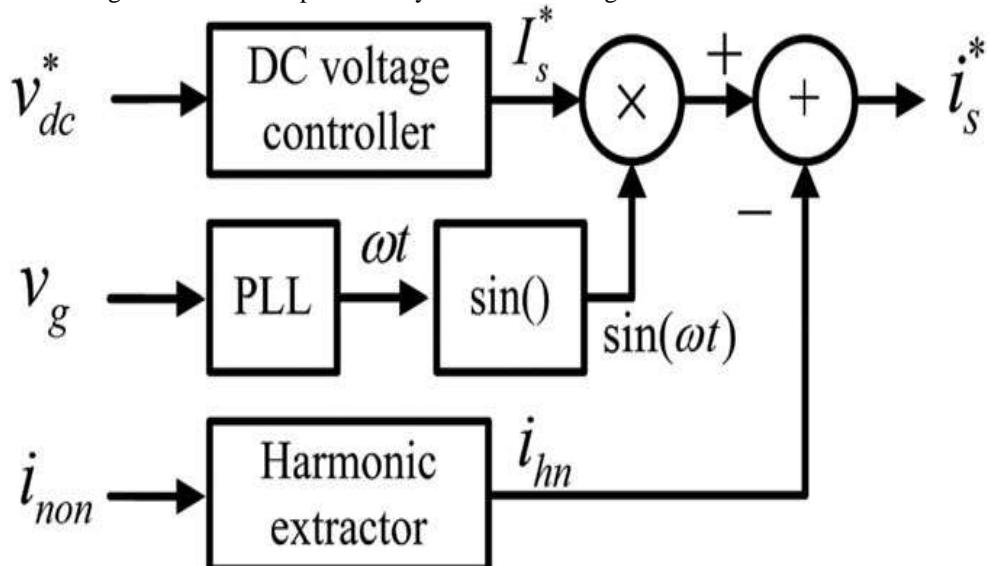


Fig.2.6 Current reference generator block for HCC.

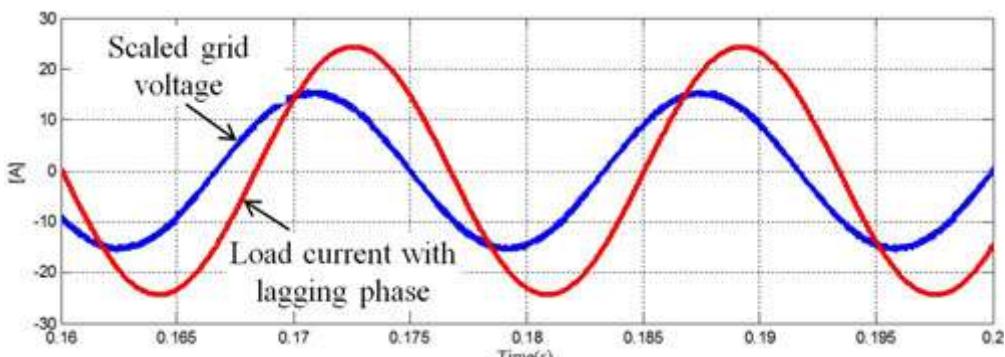


Fig.2.7 Example of linear load current (THD: 0.5%, PF:0.8, active power: 1500 W, reactive power: 1100 Var).

2.3. Reactive power compensation

Unlike nonlinear loads, the current waveform of a linear load is sinusoidal at the frequency of the power system but the power factor can be significantly exacerbated when the load is capacitive or inductive. Fig.2.7 shows the current waveform of a typical inductive load in a single-phase induction motor. The current flow, consisting of the converter current with RPC and the load current i_r consuming reactive power, shown in Fig.2.8,

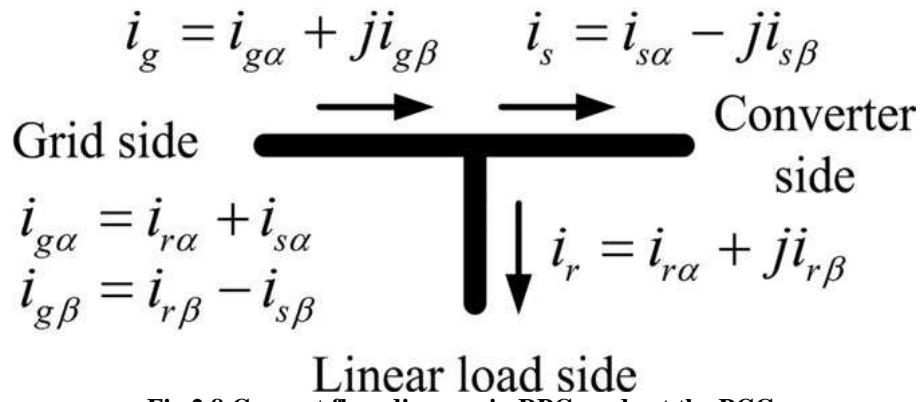


Fig.2.8 Current flow diagram in RPC mode at the PCC.

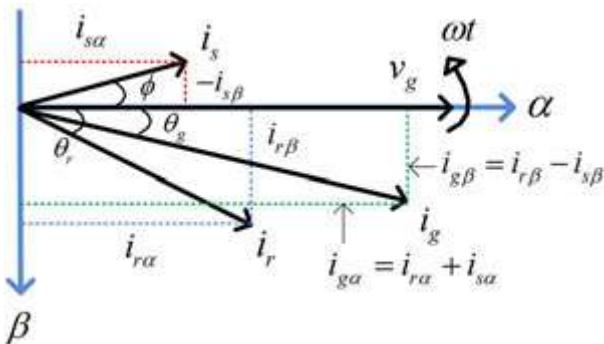


Fig.2.9 Phase diagram of the grid voltage and current during RPC.

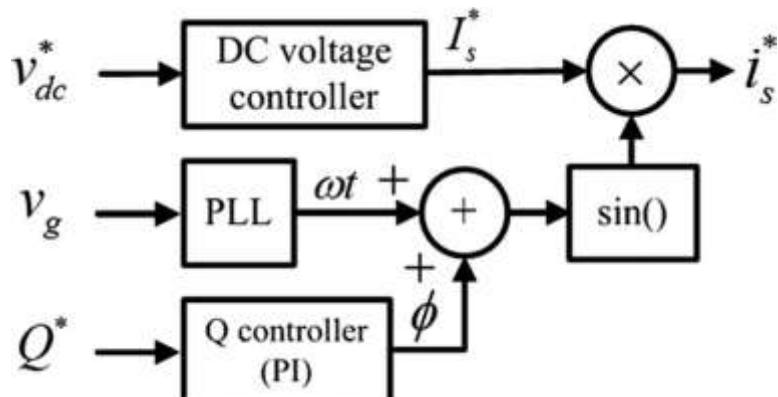


Fig.2.10. Current reference generator block for RPC.

Can be written as,

$$i_s = i_{s\alpha} - j i_{s\beta} \quad (6)$$

$$i_r = i_{r\alpha} + j i_{r\beta} \quad (7)$$

$$i_g = i_{r\alpha} + i_{s\alpha} + j(i_{r\beta} - i_{s\beta}) \quad (8)$$

As a result, the grid power factor at the PCC can be improved by injecting reactive power from the converter as shown in Fig.2.9. However, it should be considered that the input current of the unidirectional converter becomes distorted due to the natural commutation of diodes; thus, the amount of reactive power generated by an individual converter should be restricted. This will be elaborated later in this paper. Since the current waveform of the converter in RPC mode is not sinusoidal, the required phase angle of the current cannot be calculated by a simple reactive power equation. Thus, the phase angle reference

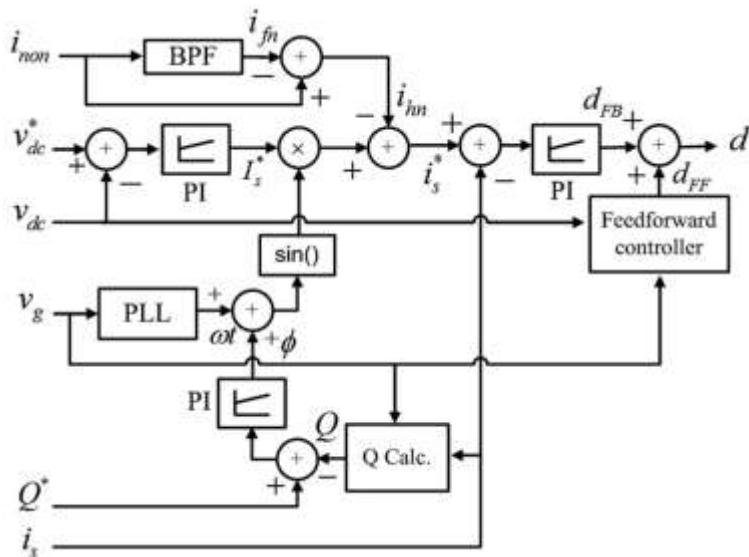


Fig.2.11 Proposed HCC and RPC control block diagram.

To the input converter current needs to be generated by employing a proportional integral compensator as shown in Fig.2.10, and can be represented as

$$\varphi = Kpc(Q^* - Q) + Kic(Q^* - Q)dt \quad (9)$$

$$i^*s = I^*s \sin(\omega t + \varphi) \quad (10)$$

where Kpc and Kic are proportional gain and integral gain of the reactive power compensator, respectively, and φ is the desired phase to be adjusted from the original current reference. It should be noted in (10) that the current magnitude reference I^*s will be adjusted through the dc-bus voltage controller to feed active power to the dc load. The reactive power will be adjusted by changing the phase angle φ . Thus, initially I^*s is determined by the dc-link voltage controller and actual active power will change as result of generating reactive power with respect to the dc link command. However, since I^*s will be updated by the dc link voltage compensator, as the phase angle φ changes, the dc link voltage will be maintained.

2.4. Control strategy for APF functionality

The proposed control strategy of the unidirectional ac–dc converter including a feed forward controller, HCC, and RPC is shown in Fig.2.11. Two control blocks for HCC and RPC have been added to the conventional control algorithm in Fig.2.3. Thus, the final current reference for a versatile control strategy based on (5) and (10) can be expressed as

$$I^*s = I^*s \sin(\omega t + \varphi) - i_{hn}. \quad (11)$$

In addition, it is worthwhile to mention that functionalities of HCC and RPC in unidirectional ac–dc boost converters are available only when these converters supply active power to its dc load. Thus, the current reference able to be used for HCC and RPC is highly dependent on its power rating and its existing loads. Since multiple unidirectional converters may be connected to the power system in residential applications, their RPC capabilities can be maximized by incorporating these aggregated converters as shown in Fig.2.12. And propose block diagram of multiple control of unidirectional ac–dc step-up converter. The possible supervisory control strategy for future smart grid applications can be suggested as follows:

- 1) examine grid power quality factors, such as THD and PF;
- 2) calculate the amount of compensation for harmonic producing components and reactive power;
- 3) enlist the available capacities used for HCC and RPC in an individual converter;
- 4) allocate and distribute HCC and RPC references to an individual converter;
- 5) examine the grid power quality. If the THD of the grid current is above 5%, the level of RPC needs to be reduced, otherwise, the amount of RPC can be increased up to each converter's maximum capacity to achieve unity power factor.
- 6) repeat (1) through (5).

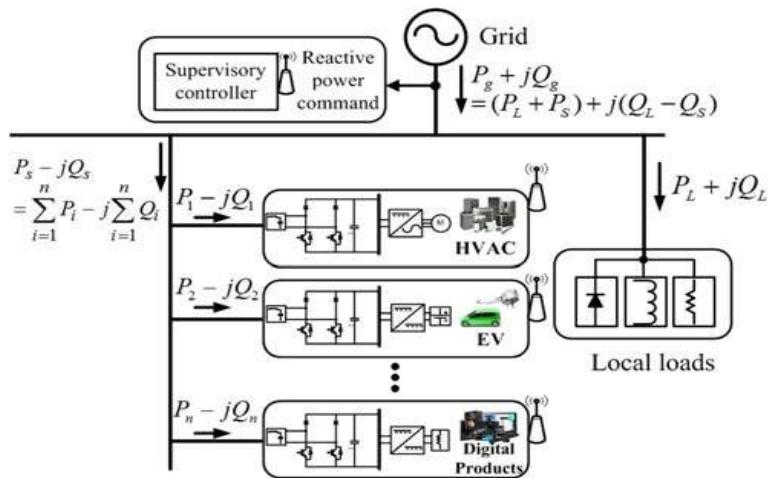


Fig.2.12. RPC using aggregated unidirectional ac-dc boost converters.

Using these steps, the grid power quality can be enhanced, as long as the available converter capacities for HCC and RPC remain.

III. SIMULATION RESULTS

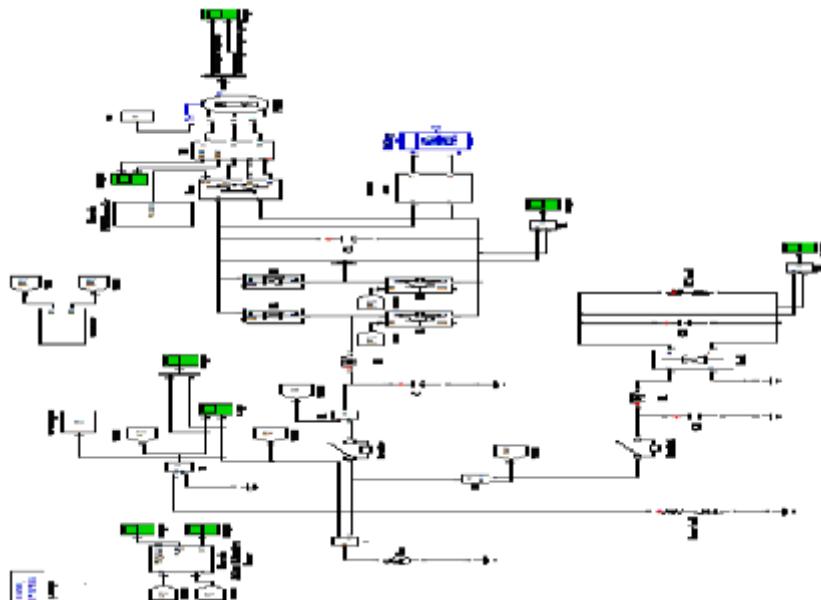


Fig.3.1. Simulation diagram

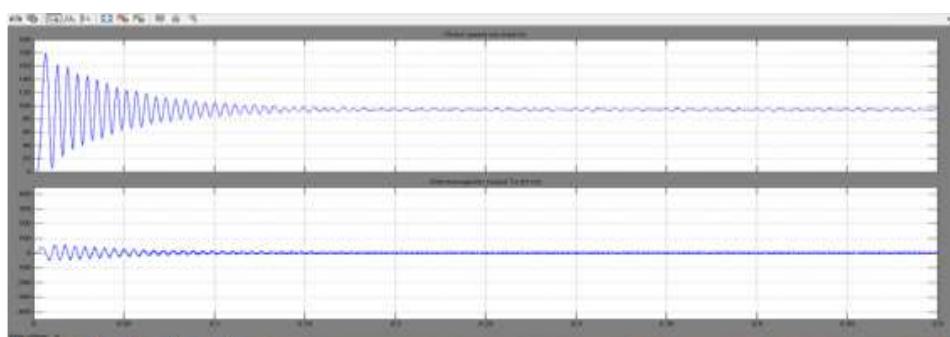


Fig.3.2. Speed and torque of synchronous motor

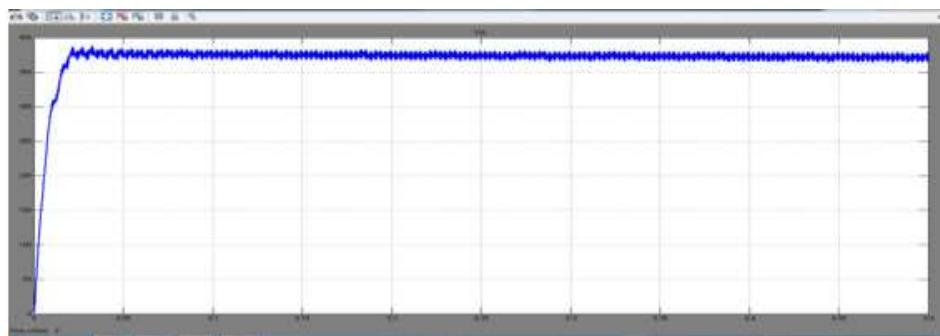


Fig.3.3. Waveform of DC voltage without ac-dc step-up converter

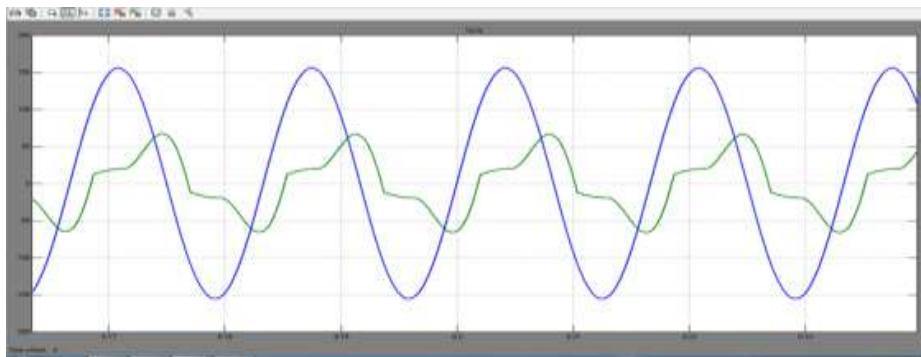


Fig.3.4. Waveform of Input grid voltage and current without ac dc boost converter

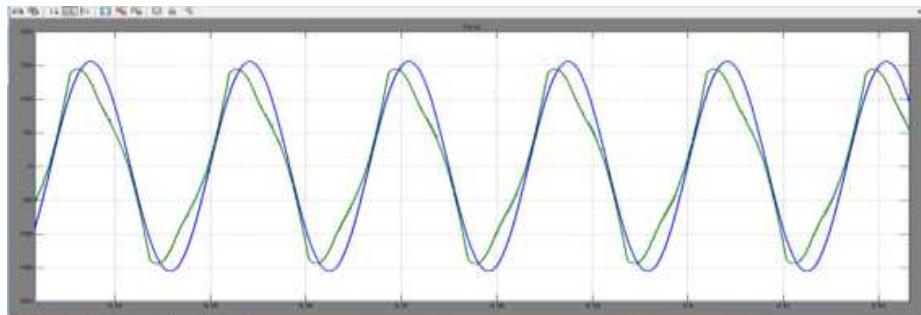


Fig.3.5. Waveform of Input grid voltage and current with ac dc boost converter

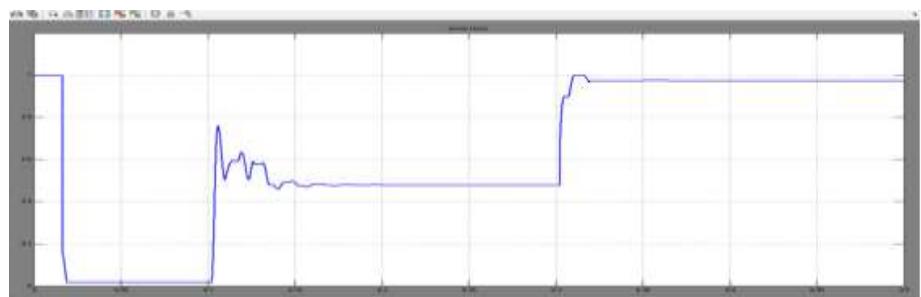


Fig.3.6. Waveform of nearly unity power factor

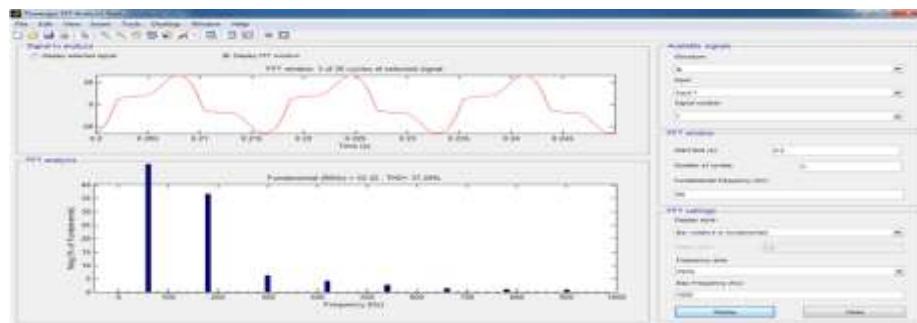


Fig.3.7. Waveform of THD without ac dc boost converter

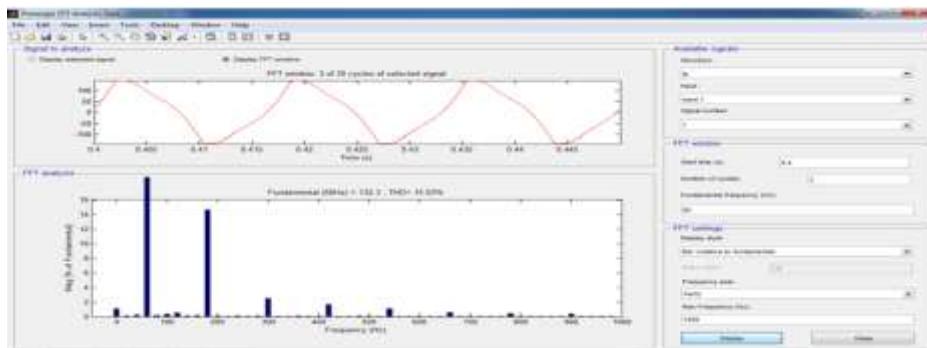


Fig.3.8. Waveform of THD with ac dc boost converter



Fig.3.9. Waveform of Active And Reactive Power

IV. CONCLUSION

Since unidirectional ac-dc step-up converter are already throughout connected with ac power systems, present unidirectional ac-dc step-up converter obtain the ability to improve virtually fastness of ac power systems by maximizing functionalities of aggregated unidirectional ac-dc boost converter. In this review paper multiple control method for unidirectional ac-dc step-up converter have been studied to enhance grid power quality through the combination of HCC and RPC, which can be more economical solution for future grid applications.

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