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A Novel Converter Topology for Reactive Power Compensation in Grid under Non-Linear Load Conditions


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Abstract:
The paper presents a novel converter configuration for compensation of power quality issues in grid. The active power filters expand their performance day by day in power quality aspects especially harmonics suppression and reactive power compensation in effective load injection. The proposed controlling technique can mitigate harmonic current and reactive power to improve grid power quality, and to balance of dc-bus voltage. The proposed topology has advantage of harmonic current compensation and reactive power compensation. The performance study is also presented using MATLAB/simulink software.

INTRODUCTION

Due to the intensive use of power converters and other non-linear loads in industry and by consumers in general, it can be observed an increasing deterioration of the power systems voltage and current waveforms [1-3].

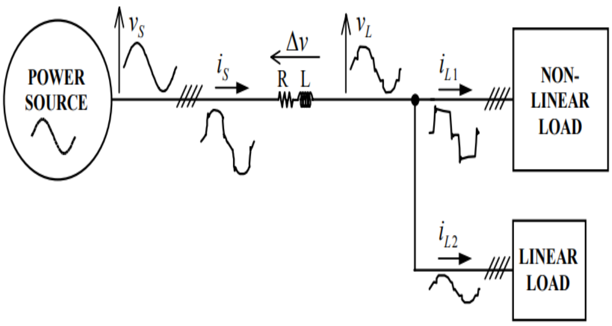

Fig 1: A typical system with combination of linear and non-linear loads

Figure 1 presents a power system with sinusoidal source voltage operating with a linear and a non-linear load. The current of the nonlinear load contains harmonics. The harmonics in the line-current produce a non-linear voltage drop in the line impedance, which distorts the load voltage. Since load voltage is distorted, even the current at the linear load becomes non-sinusoidal.

The presence of harmonics in power lines results in greater power losses in the distribution system, interference problems in communication systems and, sometimes, in operation failures of electronic equipments, which are more and more sensitive since they include microelectronic control systems, which work with very low energy levels [4].

In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, to compensate voltage regulation, and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads [5].

Several technologies, typically having high power capacities, based on power electronics theory have aimed to improve grid power quality and compensate reactive power at the transmission and distribution

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system level. Flexible alternating current transmission systems (FACTS) have been studied by industrial and academic researchers since 1990s [6-7].

Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, flexible ac transmission systems (FACTS) have been developed and represent a new concept for the operation of power transmission systems.

REACTIVE POWER COMPENSATION

In a linear circuit, the reactive power is defined as the ac component of the instantaneous power, with a frequency equal to 100/120 Hz in a 50- or 60-Hz system. The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equals to two times the rated value (50 or 60 Hz). For this reason it can be compensated using Var generators, avoiding its circulation between the load (inductive or capacitive) and the source, and therefore improving voltage stability of the power system. Reactive power compensation can be implemented with Var generators connected in parallel or in series.

Shunt Compensation

Fig. 2 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source V_1, a power line, and a typical inductive load. A current-source device is being used to compensate the reactive component of the load current (I_Q). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated.

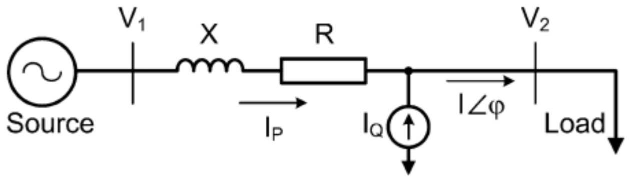

Fig 2: Shunt compensation with a current source

Series Compensation

Var compensation can also be of the series type. Typical series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self-regulated manner, balances a fraction of the line's transfer reactance.

Fig. 3 shows the results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V_2.

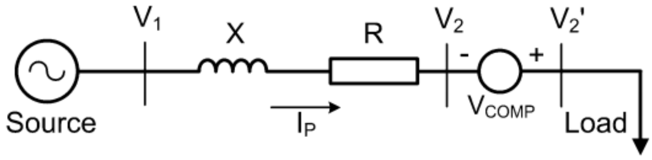

Fig 3: Series compensation with a voltage source.

SYSTEM CONFIGURATION

Fig. 4 shows a prevalent application of unidirectional ac–dc boost converters. Conventional PFC converters consider the input current to be a purely sinusoidal waveform, which is completely in phase with the input voltage. The dual boost PFC converter [23]–[26], often called the bridgeless PFC converter, is one of the most popular unidirectional ac–dc boost converters. The control algorithms of the dual boost PFC converter are almost identical 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 conventional one controls rectified output current.

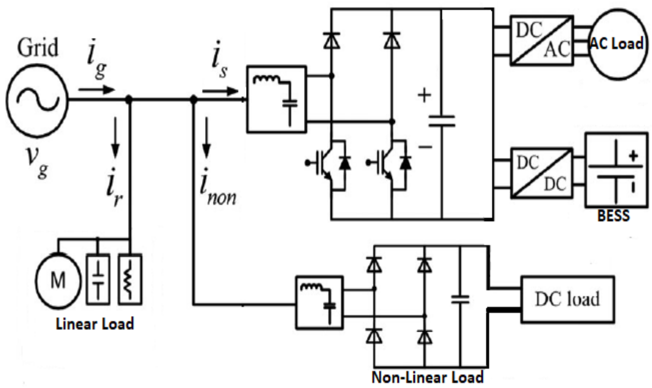

Fig 4: system configuration

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The proposed control method can ameliorate harmonic current and reactive power for improved grid power quality, as well as regulation of dc-bus voltage. The proposed versatile control of unidirectional ac–dc boost 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.

CONTROL STRATEGY

PFC control methods are very common in the related literature, especially those utilizing feedback and feed forward controllers, as shown in Fig. 5. 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.

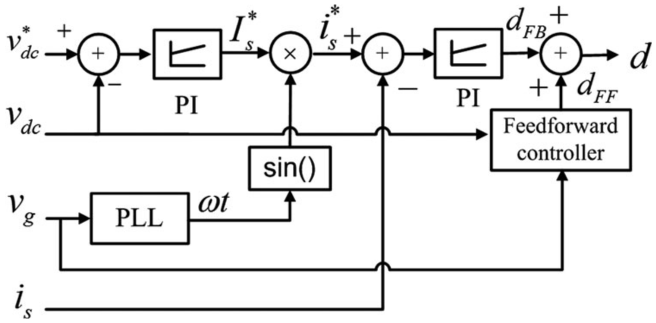

Fig 5: Conventional control algorithm for unidirectional ac–dc boost converters

Therefore, the source voltage can be considered as a rectified voltage, which can be expressed 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.

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.

Assume that the input current from the unidirectional ac–dc boost converter operating in PFC mode is a purely sinusoidal waveform. The grid current *ig* includes *i*hn from a nonlinear load. 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. Therefore, the new current reference for the current controller of the converter is shown in Fig. 6

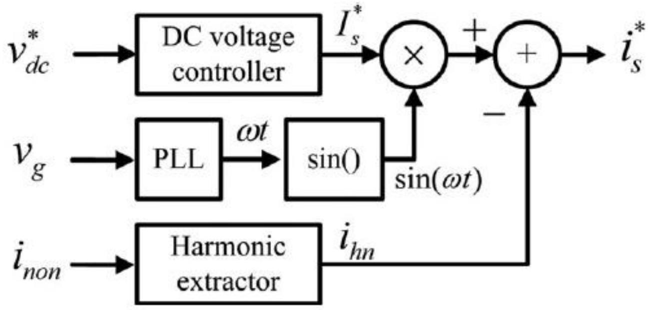

Fig 6: Current reference generator block for HCC

The proposed control strategy of the unidirectional ac–dc converter including a feed forward controller, HCC, and RPC is shown in Fig. 7.

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. 12.

The possible supervisory control strategy for future smart grid applications can be suggested as follows: Analyze grid power quality factors, such as THD and PF; calculate the amount of compensation for harmonic producing components and reactive power; Obtain the available capacities used for HCC and RPC in an individual converter; Determine and distribute HCC and RPC references to an individual converter; Analyze the

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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.

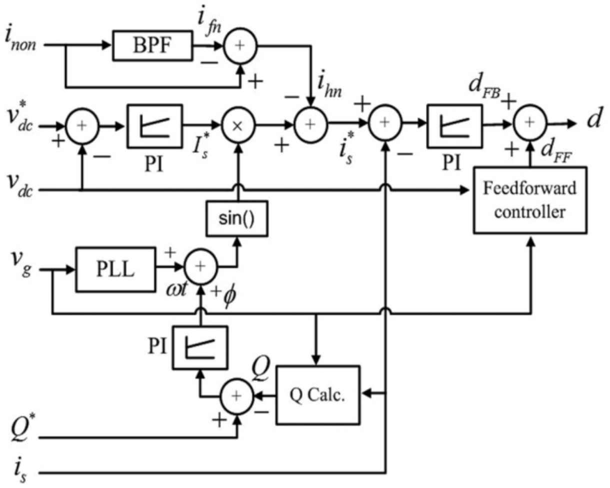
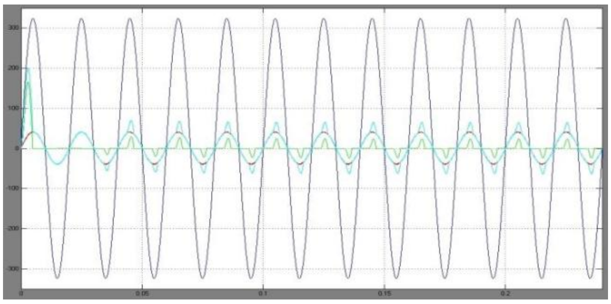


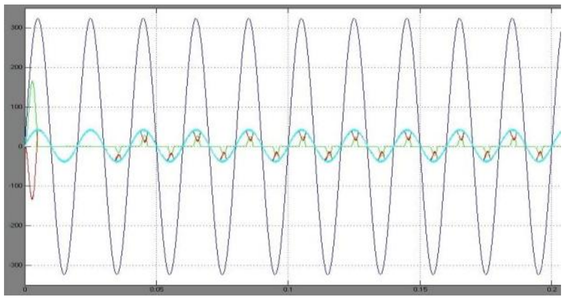
Fig 7: Proposed HCC and RPC control block diagram

SIMULATION RESULTS

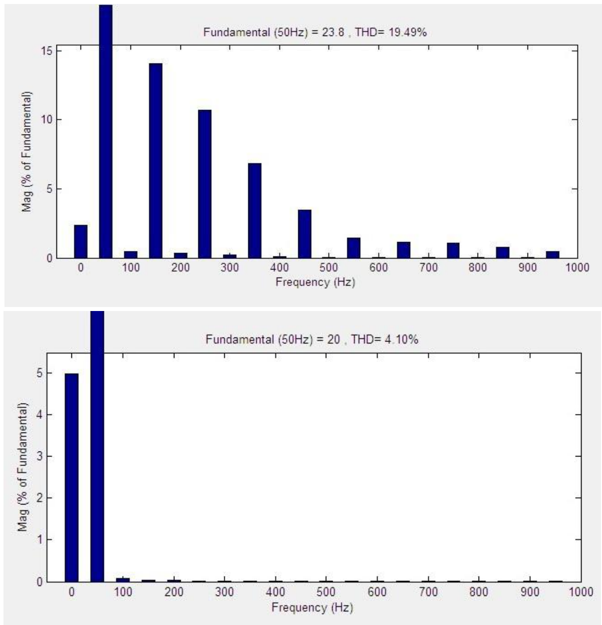
Fig.8 shows the simulation results in HCC mode when an emulated nonlinear load current is connected to the unidirectional ac–dc boost converter operating at the PCC. Before HCC mode is enabled, the grid THD is polluted with the harmonic current from the nonlinear load, resulting in 15.5% THD with a peak-shape waveform as shown in Fig. 8 (a). However, after HCC mode is enabled and the converter current is intentionally distorted, it can be observed that the grid current can be a sinusoidal waveform with 4.1% THD, along with improved power factor as a result of canceling the load harmonic current as shown in Fig. 8 (b) and (c).



(a)



(b)



(c)

Fig 8: Simulation results in HCC mode (a) before HCC, (b) after HCC, and (c) harmonic analysis of the grid current.

Fig.20 shows the simulation results in RPC mode when a passive load consisting of several resistors and capacitors connected to the unidirectional ac–dc boost converter at the PCC which is used as a linear load. Before RPC mode is enabled, the grid power factor decreases due to this capacitive load, even under the unity power factor of the converter as shown in Fig.20 (a). After RPC mode is enabled, it can be observed that the power factor of the grid is improved. as shown in Fig. 20(b). However, the THD of the grid current increases from 1.78% to 6.13% as shown in Fig. 20(c) due to inherent distortions of reactive power current in unidirectional ac–dc boost converters as explained in previous sections.

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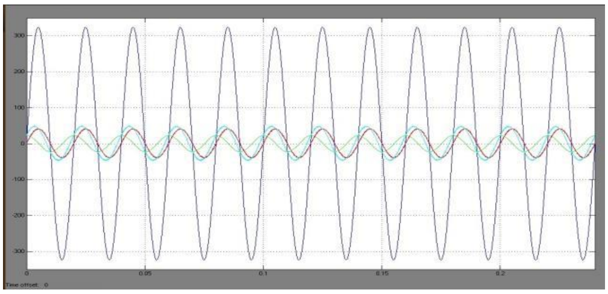
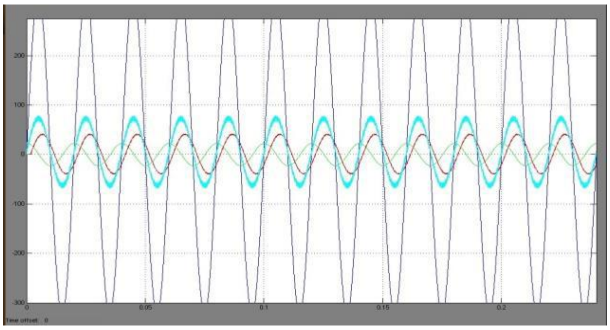


(a)



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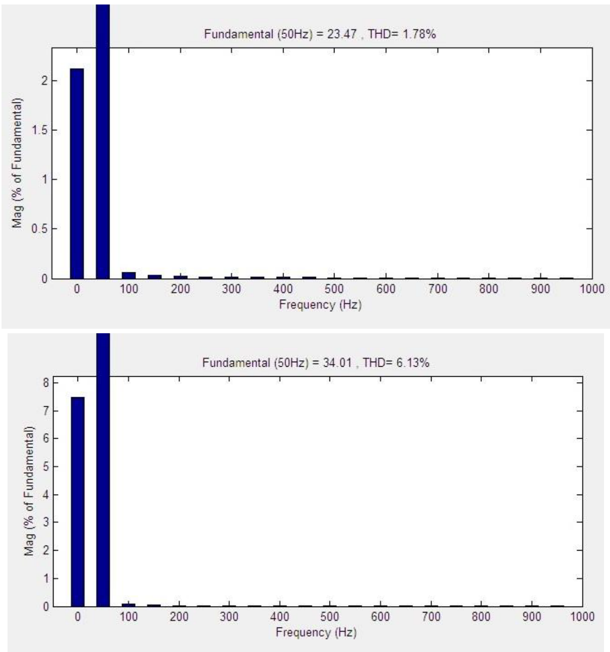
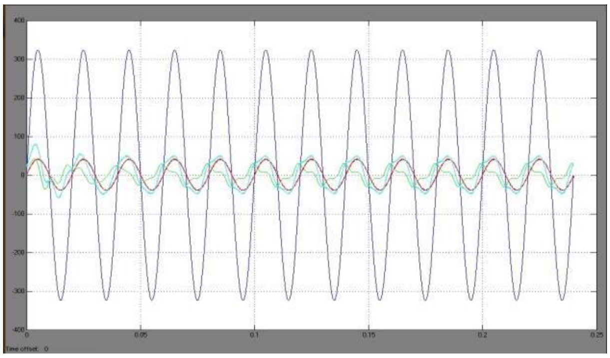


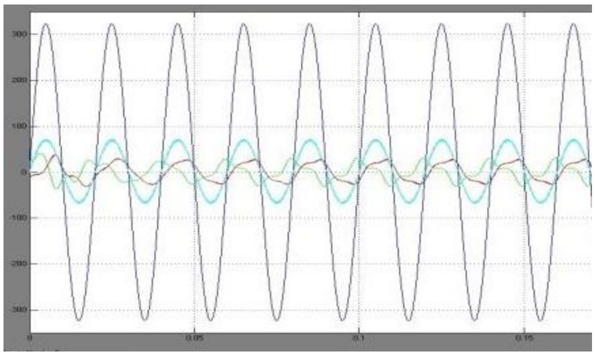
(c)

Fig 9: simulation results in RPC mode (a) before RPC, (b) after RPC, and (c) harmonic analysis of the grid current.

Fig 10 shows the simulation results for combined operations of HCC and RPC when the two loads used. With the implementation of combined mode the THD value reduced to 2.09% from 18.07%.



(a)



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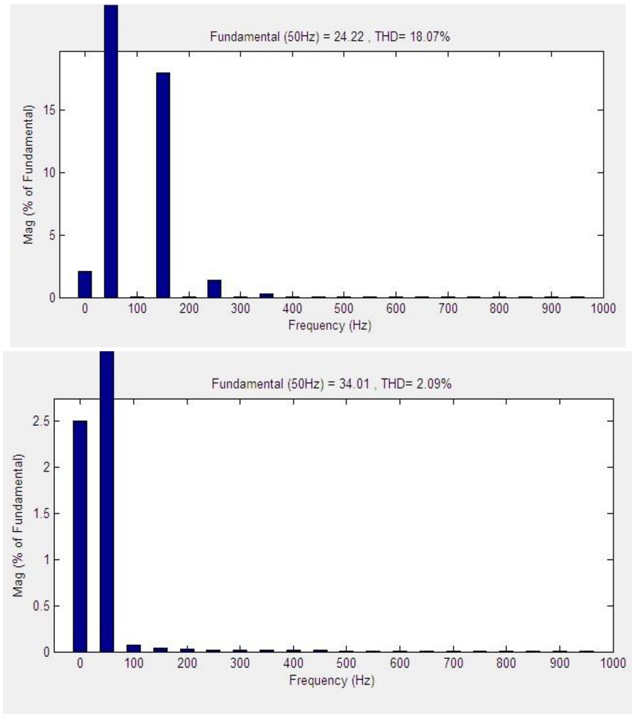

(c)

Fig 10: Simulation results in combined HCC and RPC mode (a) before HCC and RPC, (b) after HCC and RPC, and (c) harmonic analysis of the grid current.

CONCLUSION

In this paper, novel control strategies for the unidirectional ac–dc boost converter have been presented to improve grid power quality through the combination of HCC and RPC. Simultaneously, it can be seen that due to the inherent limitations of the unidirectional ac–dc boost converter, the grid current will be distorted when operating in RPC mode where the THD of capacitive current is worse than that of the inductive current due to extended cusp distortions.

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