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Applications of Smart Grid through Harmonic Current & Reactive Power Compensation

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ABSTRACT

Power factor correction (PFC) is a mandatory functionality of electronic products in the industrial and commercial market in order to mitigate grid harmonics and operate a power system economically. Since the load characteristics of most PFC applications such as home appliances, battery chargers, switched mode power supplies and other digital products support unidirectional power flow, the general ac-dc boost converter with step-up chopper is considered a popular topology. This is because they are low cost, simple, and their performance is well-proven. Its main task inside the system is to maintain dc-link voltage constantly in order to feed loads at different power ratings. In addition, it is necessary to control input current with a pure sinusoidal waveform in phase with input voltage. Active power filters (APF) are another approach capable of improving grid power quality. Many research endeavors have included APFs in their circuit topologies and control strategies. Unlike PFC circuits, the APF is a system in itself which provides compensation of harmonics and reactive power in order to reduce undesirable effects from non-linear loads and uncontrolled passive loads in power systems.

KEYWORDS: *AC-DC Boost Converter, Motor, SMPS, Battery etc.*

I. Introduction

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilization. A passenger lift in a modern building equipped with a Variable Voltage-Variable Speed induction machine drive offers a comfortable ride and stops exactly at the floor level. Behind the scene it consumes less power with reduced stresses on the motor and corruption of the utility mains.

Power Electronics involves the study of Power semiconductor devices their physics characteristics, drive requirements and their protection for optimum utilization of their capacities,

- Power converter topologies involving them,
- Control strategies of the converters,
- Digital, analogue and microelectronics involved,
- Capacitive and magnetic energy storage elements,
- Rotating and static electrical devices,
- Quality of waveforms generated,
- Electro Magnetic and Radio Frequency Interference

Power electronic converters to modify the form of electrical energy (voltage, current or frequency). Power ranges from some milli-watts (mobile phone) to hundreds of megawatts (HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency. The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed.

An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, for example like television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industry the most common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSD's start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power

- AC to DC (rectification)
- DC to AC (inversion)
- DC to DC (chopping)
- AC to AC (transformation)

Conventional drawbacks:

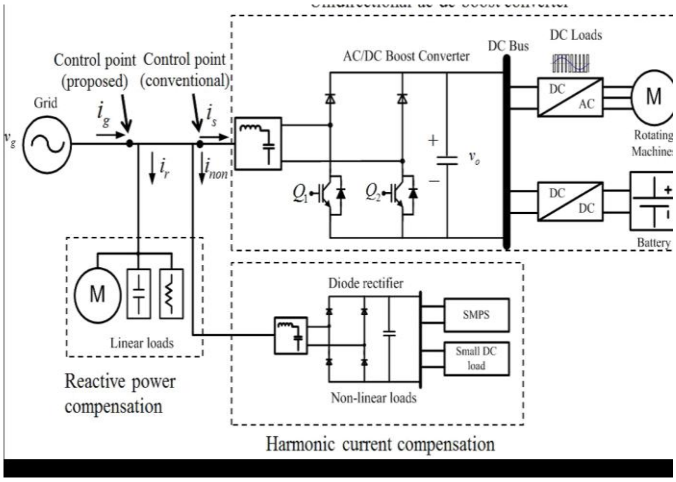
Conventionally, topologies with bidirectional power flow are used for APF applications. Despite their excellent performance, they may not be the best solution to improve the power quality of an entire power system due to high capital and operating costs related to space and installation, as well as their intrinsic power losses. Conventional converters consider the input current to be a purely sinusoidal waveform in phase with the input voltage.

Proposed method:

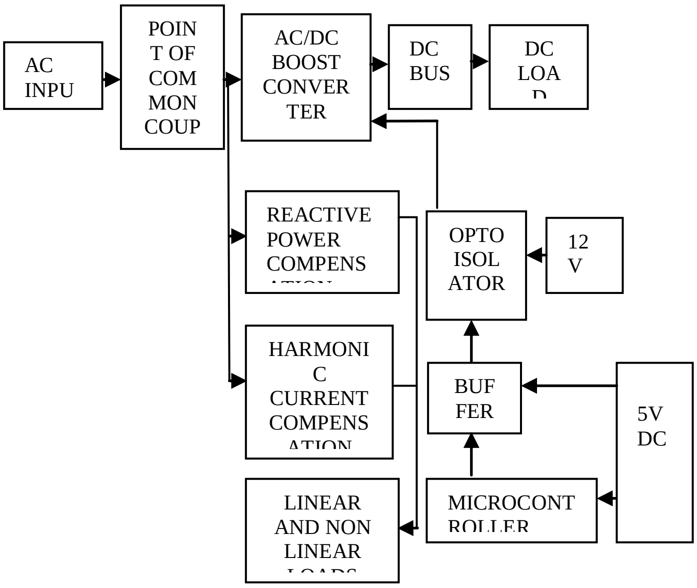
This project introduces a versatile unidirectional ac-dc converter with harmonic current and reactive power compensation. Since numerous unidirectional ac-dc converters can be connected with ac power systems, existing commercial converters possess the ability to improve substantially the stability of ac power systems by compensating harmonic current and reactive power. In this project, the feasibility and limitations of the unidirectional ac-dc converter are explained when it is employed for harmonic current and reactive power compensation, and a control strategy for such functionalities is proposed. he proposed control method can ameliorate harmonic current and reactive power for improved grid power quality as well as regulation of dc-bus voltage. Even though the amount of HCC and RPC is limited compared to APFs, this control strategy can contribute to a more stable power system as more converters capable of HCC and RPC are available at the point of common coupling (PCC) without extra cost. The proposed unidirectional ac-dc converter has three operation modes i.e., PFC, HCC and RPC. Also, both HCC and RPC can be simultaneously used to improve the distortion and the displacement factors of the grid current.

II. Principle operation

The instantaneous dissipated power of a device P = V.I, Thus, losses of a power device are at a minimum when the voltage across it is zero (the device is in the On-State) or when no current flows through it (Off-State). Therefore, a power electronic converter is built around one (or more) device operating in switching mode (either On or Off).



Block diagram:



Block Diagram Description

DC – DC Converter:

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It is a class of power converter. DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply. Additionally, the battery voltage declines as its stored energy is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. Most DC to DC converters also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the output voltage.

DC to DC converters developed to maximize the energy harvest for photovoltaic systems and for wind turbines are called power optimizers.

Electronic:

Linear Mode:

Linear regulators can only output at lower voltages from the input. They are very inefficient when the voltage drop is large and the current is high as they dissipate heat equal to the product of the output current and the voltage drop; consequently they are not normally used for large-drop high-current applications. The inefficiency wastes energy and requires higher-rated and consequently more expensive and larger components. The heat dissipated by high-power supplies is a problem in itself and it must be removed from the circuitry to prevent unacceptable temperature rises. Linear regulators are practical if the current is low, the power dissipated being small, although it may still be a large fraction of the total power consumed. They are often used as part of a simple regulated power supply for higher currents: a transformer generates a voltage which, when rectified, is a little higher than that needed to bias the linear regulator. The linear regulator drops the excess voltage, reducing hum-generating ripple current and providing a constant output voltage independent of normal fluctuations of the unregulated input voltage from the transformer/bridge rectifier circuit and of the load current. Linear regulators are inexpensive, reliable if good heat sinks are used and much simpler than switching regulators. Linear regulators do not generate switching noise. As part of a power supply they may require a transformer, which is larger for a given power level than that required by a switch-mode power supply. Linear regulators can provide a very low-noise output voltage, and are very suitable for powering noise-sensitive low-power analog and radio frequency circuits. A popular design approach is to use an LDO, Low Drop-out Regulator that provides a local "point of load" DC supply to a low power circuit.

Switched-mode conversion:

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient than linear voltage regulation. This efficiency is beneficial to increasing the running time of battery operated devices. The efficiency has increased since the late 1980s due to the use of power FETs, which are able to switch at high frequency more efficiently than power bipolar transistors, which incur more switching losses and require a more complicated drive circuit. Another important innovation in DC-DC converters is the use of synchronous rectification replacing the flywheel diode with a power FET with low "on resistance", thereby reducing switching losses. Before the wide availability of power semiconductors, low power DC to DC converters of this family consisted of an electro-mechanical vibrator followed by a voltage step-up transformer and a vacuum tube or semiconductor rectifier or synchronous rectifier contacts on the vibrator. Most DC-to-DC converters are designed to move power in only one direction, from the input to the output. However, all switching regulator topologies can be made bi-directional by replacing all diodes with independently controlled active rectification. A bi-directional converter can move power in either direction, which is useful in applications requiring regenerative braking. Drawbacks of switching converters include complexity, electronic noise (EMI / RFI) and to some extent cost, although this has come down with advances in chip design. DC-to-DC converters are now available as integrated circuits needing minimal additional components. They are also available as a complete hybrid circuit component, ready for use within an electronic assembly.

Magnetic:

In these DC-to-DC converters, energy is periodically stored into and released from a magnetic field in an inductor or a transformer, typically in the range from 300 kHz to 10 MHz. By adjusting the duty cycle of the charging voltage, the amount of power transferred can be controlled. Usually, this is applied to control the output voltage, though it could be applied to control the input current, the output current, or maintain a constant power. Transformer-based converters may provide isolation between the input and the output. In general, the term "DC-to-DC converter" refers to one of these switching converters. These circuits are the heart of a switched-mode power supply. A converter may be designed to operate in continuous mode at high power, and in discontinuous mode at low power. The Half bridge and Fly-back topologies are similar in that energy stored in the magnetic core needs to be dissipated so that the core does not saturate. Power transmission in a fly-back circuit is limited by the amount of energy that can be stored in the core, while forward circuits are usually limited by the I/V characteristics of the switches. Although MOSFET switches can tolerate simultaneous full current and voltage, bipolar switches generally can't so require the use of a snubber (or two). High-current systems often use multiphase converters, also called interleaved converters. Multiphase regulators can have better ripple and better response times than single-phase regulators. Many laptop and desktop motherboards include interleaved buck regulators, sometimes as a voltage regulator module.

Capacitive:

Switched capacitor converters rely on alternately connecting capacitors to the input and output in differing topologies. For example, a switched-capacitor reducing converter might charge two capacitors in series and then discharge them in parallel. This would produce an output voltage of half the input voltage, but at twice the current (minus various inefficiencies). Because they operate on discrete quantities of charge, these are also sometimes referred to as charge pump converters. They are typically used in applications requiring relatively small amounts of current, as at higher current loads the increased efficiency and smaller size of switch-mode converters makes them a better choice. They are also used at extremely high voltages, as magnetic would break down at such voltages.

Electromechanical

A motor-generator or dynamotor set may consist either of distinct motor and generator machines coupled together or of a single unit motor-generator. A single unit motor-generator has both rotor coils of the motor and the generator wound around a single rotor, and both coils share the same outer field coils or magnets. Typically the motor coils are driven from a commutator on one end of the shaft, when the generator coils output to another commutator on the other end of the shaft. The entire rotor and shaft assembly is smaller in size than a pair of machines, and may not have any exposed drive shafts. Motor generators can convert between any combination of DC and AC voltage and phase standards. Large motor-generator sets were widely used to convert industrial amounts of power while smaller motor-generators were used to convert battery power to a high DC voltage, which was required to operate vacuum tube (thermionic valve) equipment.

Electrochemical:

A further means of DC to DC conversion in the kilowatts to megawatts range is presented by using redox flow batteries such as the vanadium redox battery, although this technique has not been applied commercially to date.

Step-down: A converter where output voltage is lower than the input voltage (like a Buck converter).

Step-up: A converter that outputs a voltage higher than the input voltage (like a Boost converter).

Continuous Current Mode:

Current and thus the magnetic field in the inductive energy storage never reach zero.

Discontinuous Current Mode:

Current and thus the magnetic field in the inductive energy storage may reach or cross zero.

Noise:

Since all properly designed DC-to-DC converters are completely inaudible, "noise" in discussing them always refers to unwanted electrical and electromagnetic signal noise.

RF noise:

Switching converters inherently emit radio waves at the switching frequency and its harmonics. Switching converters that produce triangular switching current, such as the Split-Pi, forward converter in continuous current mode, produce less harmonic noise than other switching converters. Linear converters produce practically no RF noise. Too much RF noise causes electromagnetic interference (EMI).

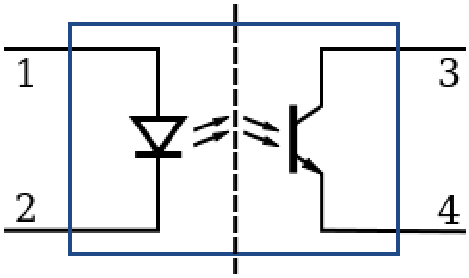
Input noise:

If the converter loads the input with sharp load edges, electrical noise can be emitted from the supplying power lines as RF noise. This should be prevented with proper filtering in the input stage of the converter.

Output noise:
The output of a DC-to-DC converter is designed to have a flat, constant output voltage. Unfortunately, all real DC-to-DC converters produce an output that constantly varies up and down from the nominal designed output voltage. This varying voltage on the output is the output noise. All DC-to-DC converters, including linear regulators, have some thermal output noise. Switching converters have, in addition, switching noise at the switching frequency and its harmonics. Some sensitive radio frequency and analog circuits require a power supply with so little noise that it can only be provided by a linear regulator. Many analog circuits require a power supply with relatively low noise, but can tolerate some of the less-noisy switching converters.

Opto-isolator:

In electronics, an opto-isolator, also called an opto-coupler, photo coupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits by using light. Opto-isolators prevent high voltages from affecting the system receiving the signal. Commercially available opto-isolators withstand input-to-output voltages up to 10 kV and voltage transients with speeds up to 10 kV/μs. A common type of opto-isolator consists of an LED and a phototransistor in the same opaque package. Other types of source-sensor combinations include LED-photodiode, LED-LASCR, and lamp photo-resistor pairs. Usually opto-isolators transfer digital signals, but some techniques allow them to be used with analog signals.

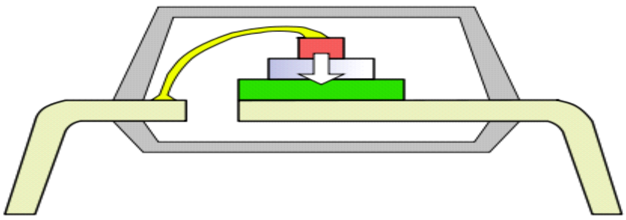


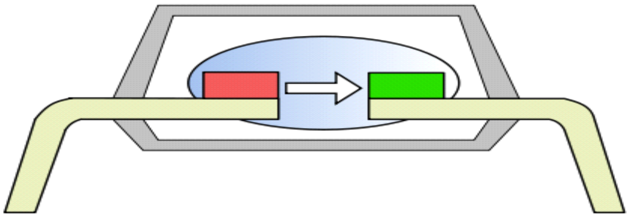
Working Principle:

An opto-isolator contains a source of light, almost always a near infrared light-emitting diode, that converts electrical input signal into light, a closed optical channel and a photo sensor, which detects incoming light and either generates electric energy directly, or modulates electric current flowing from an external power supply. The sensor can be a photo resistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR) or a triac. Because LEDs can sense light in addition to emitting it, construction of symmetrical, bidirectional opto-isolators is possible. An opto-coupled solid state relay contains a photodiode opto-isolator which drives a power switch, usually a complementary pair of MOSFETs. A slotted optical switch contains a source of light and a sensor, but its optical channel is open, allowing modulation of light by external objects obstructing the path of light or reflecting light into the sensor.

Electric Isolation:

Electronic equipment and signal and power transmission lines can be subjected to voltage surges induced by lightning, electrostatic discharge, radio frequency transmissions, switching pulses and perturbations in power supply. Remote lightning strikes can induce surges up to 10 kV, one thousand times more than the voltage limits of many electronic components. A circuit can also incorporate high voltages by design, in which case it needs safe, reliable means of interfacing its high-voltage components with low-voltage ones. The main function of an opto-isolator is to block such high voltages and voltage transients, so that a surge in one part of the system will not disrupt or destroy the other parts. Historically, this function was delegated to isolation transformers, which use inductive coupling between galvanicallys isolated input and output sides. Transformers and opto-isolators are the only two classes of electronic devices that offer reinforced protection — they protect both the equipment and the human user operating this equipment. They contain a single physical isolation barrier, but provide protection equivalent to double isolation. Opto-isolator specifications published by manufacturers always follow at least one of these regulatory frameworks. An opto-isolator connects input and output sides with a beam of light modulated by input current. It transforms useful input signal into light, sends it across the dielectric channel, captures light on the output side and transforms it back into electric signal. Unlike transformers, which pass energy in both directions with very low losses, opto-isolators are unidirectional and they cannot transmit power. Typical opto-isolators can only modulate the flow of energy already present on the output side. Unlike transformers, opto-isolators can pass DC or slow-moving signals and do not require matching impedances between input and output sides. Both transformers and opto-isolators are effective in breaking ground loops, common in industrial and stage equipment, caused by high or noisy return currents in ground wires. The physical layout of an opto-isolator depends primarily on the desired isolation voltage. Devices rated for less than a few kV have planar construction.

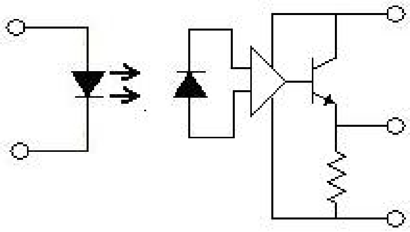




The sensor die is mounted directly on the lead frame of its package .The sensor is covered with a sheet of glass or clear plastic, which is topped with the LED die. The LED beam fires downward. To minimize losses of light, the useful absorption spectrum of the sensor must match the output spectrum of the LED, which almost invariably lies in the near infrared. The optical channel is made as thin as possible for a desired breakdown voltage. For example, to be rated for short-term voltages of 3.75 kV and transients of 1 kV/μs, the clear polyimide sheet in the ASSR-300 series is only 0.08 mm thick. Breakdown voltages of planar assemblies depend on the thickness of the transparent sheet and the configuration of bonding wires that connect the dies with external pins. Real in-circuit isolation voltage is further reduced by creepage over the PCB and the surface of the package. Safe design rules require a minimal clearance of 25 mm/kV for bare metal conductors or 8.3 mm/kV for coated conductors. Opto-isolators rated for 2.5 to 6 kV employ a different layout called silicone dome. Here, the LED and sensor dies are placed on the opposite sides of the package; the LED fires into the sensor horizontally. The LED, the sensor and the gap between them are encapsulated in a blob, or dome, of transparent silicone. The dome acts as a reflector, retaining all stray light and reflecting it onto the surface of the sensor, minimizing losses in a relatively long optical channel. In double mold designs the space between the silicone blob and the outer shell is filled with dark dielectric compound with a matched coefficient of thermal expansion.

Photodiode opto-isolators:

Diode opto-isolators employ LEDs as sources of light and silicon photodiodes as sensors. When the photodiode is reverse-biased with an external voltage source, incoming light increases the reverse current flowing through the diode. The diode itself does not generate energy; it modulates the flow of energy from an external source. This mode of operation is called photoconductive mode. Alternatively, in the absence of external bias the diode converts the energy of light into electric energy by charging its terminals to a voltage of up to 0.7 V. The rate of charge is proportional to the intensity of incoming light. The energy is harvested by draining the charge through an external high-impedance path; the ratio of current transfer can reach 0.2%. This mode of operation is called photovoltaic mode. The fastest opto-isolators employ PIN diodes in photoconductive mode. The response times of PIN diodes lie in the sub nanosecond range; overall system speed is limited by delays in LED output and in biasing circuitry. To minimize these delays, fast digital opto-isolators contain their own LED drivers and output amplifiers optimized for speed.



These devices are called full logic opto-isolators: their LEDs and sensors are fully encapsulated within a digital logic circuit. The Hewlett-Packard 6N137/HPCL2601 family of devices equipped with internal output amplifiers was introduced in the late 1970s and attained 10 MBd data transfer speeds. It remained an industry standard until the introduction of the 50 MBd Agilent Technologies 7723/0723 family in 2002.The 7723/0723 series opto-isolators contain CMOS LED drivers and a CMOS buffered amplifiers, which require two independent external power supplies of 5 V each. Photodiode opto-isolators can be used for interfacing analog signals, although their non-linearity invariably distorts the signal. A special class of analog opto-isolators introduced by Burr-Brown uses two photodiodes and an input-side operational amplifier to compensate for diode non-linearity. One of two identical diodes is wired into the feedback loop of the amplifier, which maintains overall current transfer ratio at a constant level regardless of the non-linearity in the second (output) diode. The proposed configuration consists of two different parts. One of them transfers the signal, and the other establishes a negative feedback to ensure that the output signal has the same features as the input signal. This proposed analog isolator is linear over a wide range of input voltage and frequency. Solid-state relays built around MOSFET switches usually employ a photodiode opto-isolator to drive the switch. The gate of a MOSFET requires relatively small total charge to turn on and its leakage current in steady state is very low. A photodiode in photovoltaic mode can generate turn-on charge in a reasonably short time but its output voltage is many times less than the MOSFET's threshold voltage. To reach the required threshold, solid-state relays contain stacks of up to thirty photodiodes wired in series.

Filter:

In this method capacitor acts as filter. Electronic filters are analog circuits which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. Electronic filters can be:

- Passive or active
- Analog or digital
- High-pass, low-pass, band-pass, band-stop
- Discrete-time or continuous-time
- Linear or non-linear
- Infinite impulse response (IIR type) or finite impulse response (FIR type)

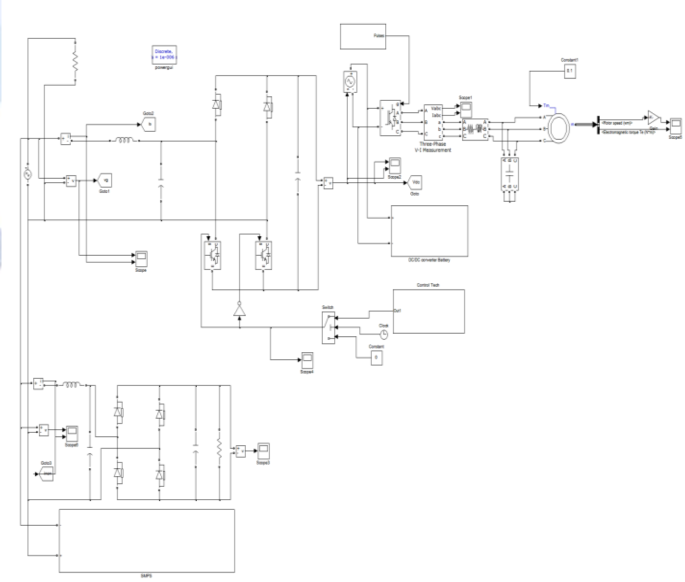
The most common types of electronic filters are linear filters, regardless of other aspects of their design. See the article on linear filters for details on their design and analysis.

Motor:

The motor used in this paper acts as both dc and ac motor. The outcome from DC as 12V and 50V came from AC. An electric motor is an electrical machine that converts electrical energy into mechanical energy. The reverse of this would be the conversion of mechanical energy into electrical energy and is done by an electric generator. In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy. Found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives, electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as from the power grid, inverters or generators. Small motors may be found in electric watches. The largest of electric motors are used for ship propulsion, pipeline compression and pumped-storage applications with ratings reaching 100 megawatts. Electric motors may be classified by electric power source type, internal construction, application, type of motion output, and so on. Electric motors are used to produce linear or rotary force (torque), and should be distinguished from devices such as magnetic solenoids and loudspeakers that convert electricity into motion but do not generate usable mechanical powers, which are respectively referred to as actuators and transducers.

Buffer:

By using buffer along with micro-controller, it is possible to reduce the effect of 'back EMF' or '**Spiking Effect**'. The capacity of any micro-controller is to sink or source current up to 25mA and its ports gets damaged if it is more. So buffer protects ports of micro-controller getting damaged. And it is possible to get appropriate data trans-receiving by using buffer in micro-controller



Simulation circuit diagram

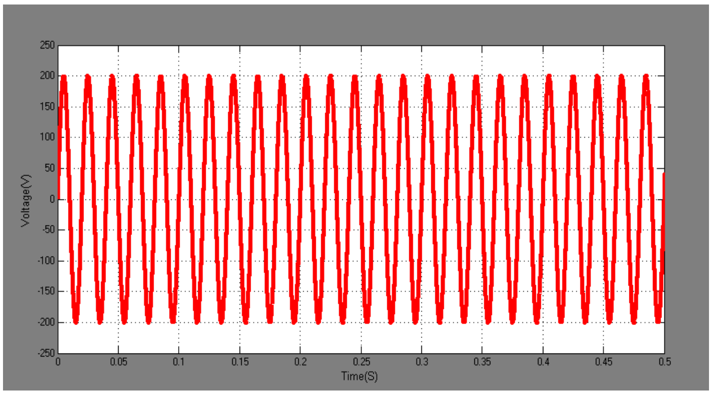
III. SIMULATION RESULTS

In order to investigate the effectiveness and performance of the proposed control method for a unidirectional ac-dc boost converter, a 2kW bridgeless PFC converter model, a nonlinear load with 80% THD and a linear load with 0.8 PF are implemented in MATLAB/Simulink. For the evaluations of performances, the three converter operation modes are simulated: 1) HCC mode, 2) RPC mode, 3) combined operations of HCC and RPC

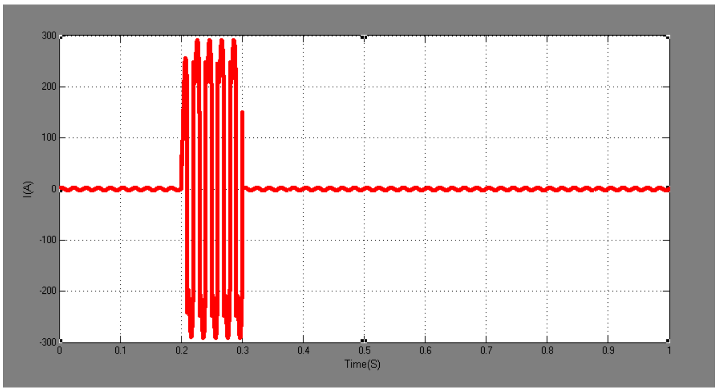
A. Harmonic Current Compensation

Fig. 12 shows the simulation results in HCC mode when a single-phase rectifier as a nonlinear load with 80% THD of the current is connected to the unidirectional ac-dc boost converter at the PCC. The PFC operation begins with a 200V dc-bus voltage reference while the current THD is 3% and the PF is unity. However, the grid THD is polluted with the harmonic current from the nonlinear load, resulting in 17% THD. At 0.2s, the operation mode of the converter is changed from PFC to HCC. It can be observed that the grid current is a nearly sinusoidal waveform with 3% THD as a result of canceling the load harmonic current, but this also causes distortion of the converter current.

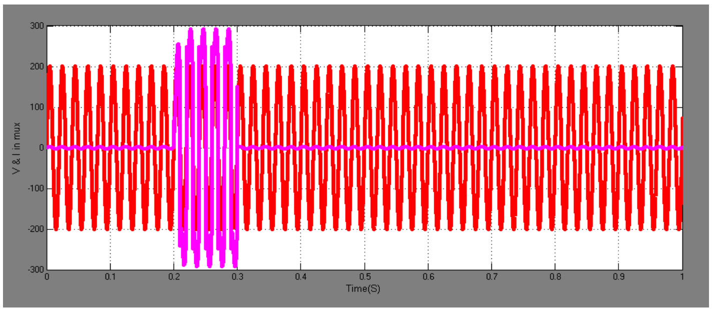
Voltage



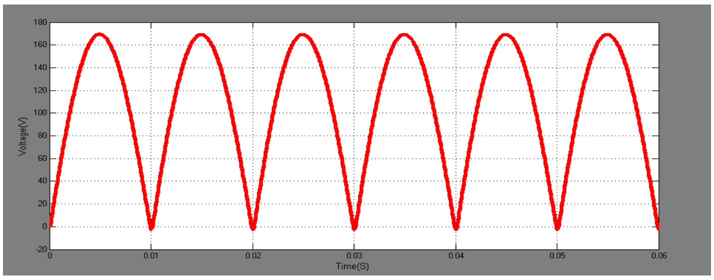
Current



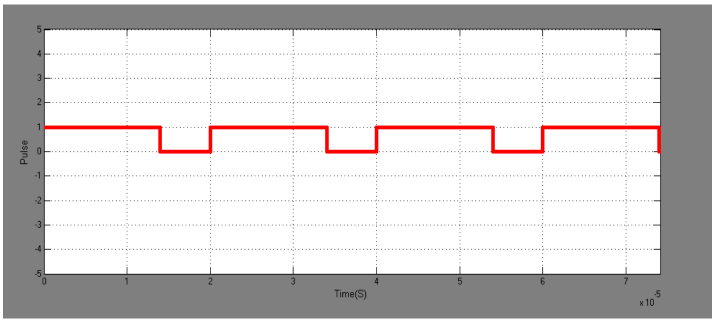
Voltage and current in MUX



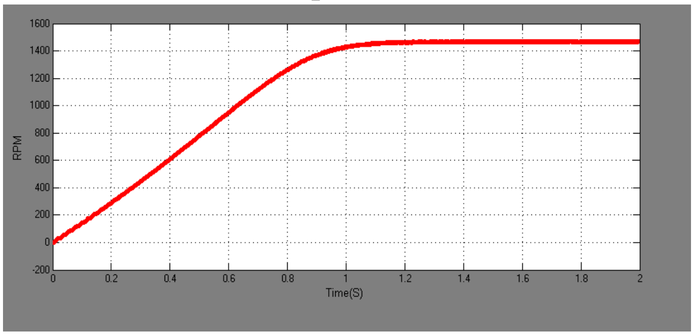
DC Link



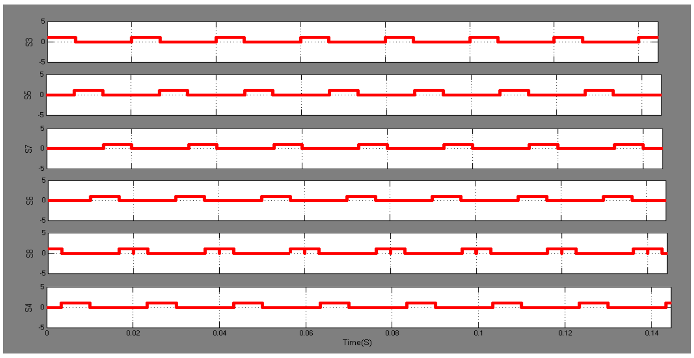
Pulses



Speed



Gate pulses for inverter



SUMMARY OF EXPERIMENTAL RESULTS

Mode	Items	[illegible] converter		Load1 (nonlinear)	Load2 (linear)	Grid	
		Conv.	Proposed			Conv.	Proposed
HCC	*P* (W)	695	695	165	N/A	905	905
	Q (Var)	-20	-125	145	N/A	160	50
	THD (%)	2.7%	17.1%	82.0%	N/A	15.5%	4.5%
	P.F	0.994	0.961	0.559	N/A	0.964	0.989
RPC	*P* (W)	695	695	N/A	330	1067	1067
	Q (Var)	-20	300	N/A	-262	-262	75
	THD (%)	2.7%	5.1%	N/A	0.86%	1.89%	3.93%
	P.F	0.994	0.908	N/A	0.779	0.963	0.992
HCC + RPC	*P* (W)	695	695	490		1225	1225
	Q (Var)	-20	360	-295		-290	90
	THD (%)	2.7%	16.2%	24.3%		11.2%	4.0%
	P.F	0.994	0.870	0.824		0.960	0.992

IV. Conclusion

Since numerous unidirectional converters are connected with ac power systems, existing unidirectional ac-dc boost converters can possess the ability to improve substantially the stability of ac power systems by maximizing the functionalities of aggregated unidirectional ac-dc boost converters. In this paper, the control method of the unidirectional ac-dc converter has been presented to enhance the grid power quality through HCC and RPC. The effectiveness of the proposed control method was validated through simulation and experimental results showing improved power factor and total harmonic distortion of the grid. At the same time, it should be noted that due to the inherent limitations of the unidirectional ac-dc converter, the grid current can be distorted unintentionally when operating in RPC mode. Hence, the amount of reactive power injected from an individual converter to the grid should be restricted.

V. References

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