Modular Active Frontend Rectifier Using Sepic Converter In Motor Drive Applications

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Abstract- *The increased applications of non-linear loads and reactive loads make harmonic distortion and over loading of power transmission and distribution networks, a phenomenon that is occurring quite often and the effects of which cannot be ignored since almost all the power transmission and distribution newline network components are affected. More harmonics result in more losses, lower efficiency, and newline more electric energy to be produced and correspondingly more pollution and particularly more carbon dioxide put in to the atmosphere. Lower harmonics and lower reactive power in transmission networks makes not only an economic sense but also a direct solution for sustainable development. Till now the traditional method of current harmonic reduction involved passive filters LC, parallel-connected to the grid, neither convenient nor economical. However, an attractive alternative to this solution is now commercially available based on power electronics in the form of active PFC front ends and active power filters (APFs). The control strategies have been very complex and specific to each application. In order to further reduce the generated low order harmonics, a dc-link current modulation scheme and its phase shift values of multi-drive systems have been optimized. Analysis, simulations and experiments have been carried out to verify the proposed method.*

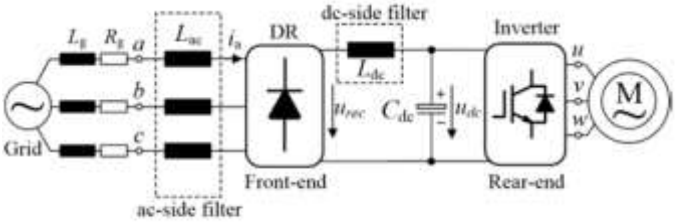
Keywords- Active filter, adjustable speed drive, electronic inductor, harmonic elimination, rectifier.

I. INTRODUCTION

Modern power electronics have revolutionized the course of motor drive industry by introducing the Adjustable Speed Drive (ASD) technology (also known as Variable Speed Drives (VSD) or Frequency Converters (FC)). An ASD improves energy efficiency of a system by controlling the speed of motor at an optimal speed and/or torque. Hence, the energy consumption of the motor is reduced from full power to a partial power for the same performance (i.e., speed and/or torque). However, ASD systems have witnessed as one of the major sources of harmonics, which may deteriorate the grid power quality. From a power quality point of view, the generation of current harmonics from an ASD system has become a major concern as they may lead to high losses and stability issues in the grid.

In electrical terms, power quality can be defined as the ability of the power grid to supply clean and stable power that is always available, has a pure noise free sinusoidal wave shape and is always within voltage and frequency tolerances. Power quality is in fact, a set of electrical boundaries that allow equipment to function in its intended manner without significant loss of performance or life expectancy. IEEE standard 1159 defines power quality as ―The concept of powering and grounding sensitive equipment in a manner that is suitable for the operation of that equipment‖.

Power quality and reliability are growing concerns for most businesses and institutions in today's world. Information depended organizations such as stock exchanges, online trading, banking and insurance firms can end up in heavy financial losses if data or communications are disrupted due to poor quality of power. Quality of power is also very important in reliable and safe operation of healthcare equipments like life- support and monitoring devices. Semiconductor industry, plastics industry, textile industry, glass industry etc. are all heavily dependent on quality power. In fact, no business or institution today is immune from the impact of power problems. When the quality of the electrical power supplied to the installed equipment is deficient, performance degradation results.



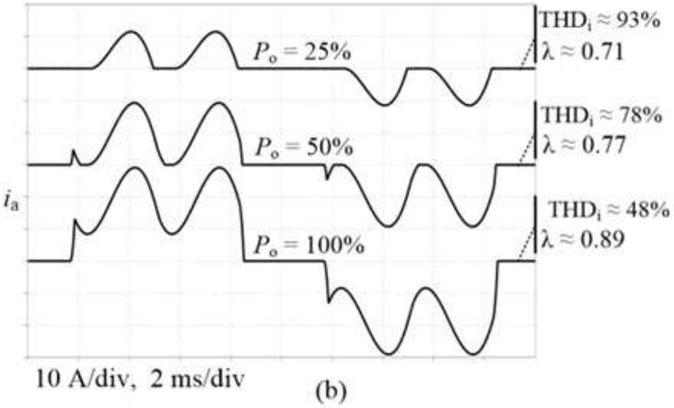


Figure 1 Standard adjustable speed drive system with double stage conversion

The remainder of this dissertation is organized in the following fashion: In Chapter 2, a review of the published work on existing work is presented. Chapter 3, describes the proposed system design in detail. Chapter 4 the results were compared and the performance of the model and the technique were discussed. In Chapter 5, summarizes the main contributions of the research.

II. LITERATURE REVIEW

Modern power electronics have revolutionized the course of motor drive industry by introducing the Adjustable Speed Drive (ASD) technology (also known as Variable Speed Drives (VSD) or Frequency Converters (FC)). An ASD improves energy efficiency of a system by controlling the speed of motor at an optimal speed and/or torque. Hence, the energy consumption of the motor is reduced from full power to a partial power for the same performance (i.e., speed and/or torque). However, ASD systems have witnessed as one of the major sources of harmonics, which may deteriorate the grid power quality. From a power quality point of view, the generation of current harmonics from an ASD system has become a major concern as they may lead to high losses and stability issues in the grid [1], [2].

Typically, the majority of three-phase motor drive applications are equipped with a double-stage power converter. As Fig. 1(a) shows, the first stage employs a three-phase line commutated rectifier such as diode-rectifier (DR) or Silicon Controlled Rectifier (SCR) to perform AC to DC conversion and a voltage source inverter to convert DC back to AC at the demanded voltage and frequency. As it can be seen, an intermediate circuit known as DC-link exist between the front-end rectifier and rear-end inverter. The DC-link filter (i.e., *Ldc* and *Cdc*) not only improved the input current quality, but also provides a smoother current and voltage for powering the rear-end inverter. Thereby, the rear-end side (inverter and load) are decoupled from the front-end side through the dc-link filter.

This configuration (i.e., Fig. 1(a)) provides a unidirectional power flow and is the most common topology employed in industrial and commercial drives. Employing line commutated rectifier at the front-end stage imposes high level of input current harmonics. Although many harmonic mitigation solutions have been introduced [3], [4], most ASD manufacturers are still using conventional passive filtering technique (e.g., using inductor at ac-side or dc-side as shown in Fig. 1(a)) as a simple, reliable and an effective solution to some extent [4].

With the global shift towards energy saving, more ASD systems are adopted as an energy efficient solution. However, the undesirable effect of generated harmonics can be substantially elevated when the number of industrial drives is increased at the Point of Common Coupling (PCC). Therefore, more advanced filtering method is required rather than using passive inductors (Fig. 1 (a)). Notably, a proper arrangement of these nonlinear loads can contribute to an effective harmonic mitigation [5]-[8]. In fact, this idea was first introduced in multi-pulse rectifiers using phase-shifting transformers [10]. Many ASD manufacturers advocate the use of 12-pulse or 18-pulse phase-shifting transformer, mainly because of its simplicity and reliability [10], [11].

Transformer-based multi-pulse rectifiers significantly impair the power density of ASD systems and are costly. In addition, their performance depends on the load profile. For instance depending on the output power level a 12-pulse rectifier system can obtain a Total Harmonic Distortion (THDi) in the range of 10% < THDi < 15% [7], [10], [11]. In the real-world situation, most ASD systems operate in partial loading conditions depending on the application demands, locations and even safety margins. Operating at partial loading conditions adversely affect the ASD system THDi as the effective impedance of the passive filter is proportional to the load current (output power). Therefore, the input current THDi and power factor (λ) will be worsened when the rectifier is partially loaded. Fig. 1(b) exemplifies the input current waveforms of a conventional ASD system under different loading conditions when the passive filter inductor is placed at the dc-side. In practice the inductance value is selected in the range of 3-5% (e.g., *L*dc = 2 mH) [12]. Thus, maintaining the THDi and the power factor (λ) independent of the load profile is very beneficial.

Notably, although most ASD applications generate energy during deceleration and braking, but feeding back this energy to the grid not necessarily justify the use of regenerative rectifiers in an ASD system. This is due to the fact that a regenerative rectifier accounts for more active components comparing with a standard rectifier unit. Also, the nominal motor performance is not equal to the regenerated energy as oversizing of motors is a common practice. Finally, the more often the motor is operated in regenerative mode the more energy is fed back to the grid. Therefore, situations during a load cycle where energy is generated must be considered. Thereby, considering the above mentioned three facts, utilizing regenerative rectifier in conventional ASD applications is not common [13], [14].

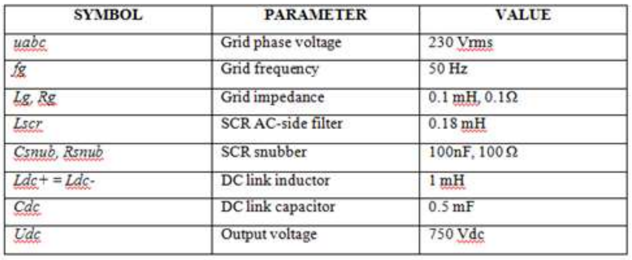
In this paper an electronic phase-shifting method (transformer-less) is proposed based on having multiple line-commutated rectifiers. The proposed topology has a common dc-bus, which makes it suitable for single and multi-drive configuration especially for medium and high power applications where employing a phase-shifting transformer is quite bulky. In addition, a current modulation technique at the dc-link using Electronic Inductor (EI) technique is employed which substantially improves the input current quality. The proposed technique is an enhanced method based on previous introduced strategies by the authors in [5]-[8], [12], [15]. The introduction of a common dc-bus in this method makes the performance of the system independent of the load profile. The proposed controller and topology have been analyzed and simulated in order to verify the proper operation of the multi-rectifier system.

III. SYSTEM DESIGN

In this section the proposed method is first validated through numerical simulations. In practice, to avoid SCR unit failure and to reduce the overvoltage to a reasonable limit, an RC snubber branch is connected across each thyristor. However, the presence of the snubber circuit causes current spikes in the SCR current at the point of commutation. In order to damp the current spikes, small AC-side inductors are placed in series prior to the SCR units (i.e., Lscr). Here, two different cases are considered. In the first case study, the performance of the proposed current control technique in balancing the dc-link currents is analyzed based on the extra added inductors (Ldc-). Secondly, the advantage of the proposed topology in improving the input current quality is Here at the dc-side of each rectifier a dc-dc converter is installed. Controlling the dc-link current by incorporating a dc-dc converter enables to emulate the behavior of an ideal infinite inductor . Fig. 4.1 shows a simplified representation of the proposed method, which the dc-dc converter will operate as a current source. Basically, by controlling the dc-link current at a constant level (i.e., Idc) the input current of each rectifier (i.e., id,a and is2,a) will be a square-wave with 120 degrees conduction applying a phase-shift (αf) using the SCR will generate a multilevel total input current ig,abc.

In fact, by applying a suitable phase-shift to the SCR unit certain harmonic orders (hth) can completely be eliminated (i.e., αf = 180o/h). This has been validated as one of simulation cases in Section III. To achieve the maximum harmonic reduction performance, the current drawn by each rectifier should be at the same level (i.e., ILd = ILs2 = Idc). Since the motors mostly operate at different partial loading conditions, having a common dc-bus and controlling the dc-link current can ensure such behavior. However, having a phase-shift of the controlled rectifier changes the rectified voltage ($u$rec,sM) and makes the controlling of all rectifiers at same current level quite challenging due to presence of circulating currents. The proposed solution applies a passive method in order to minimize the circulating current. The passive method is based on utilizing extra inductors at negative dc-link leg of each rectifier (i.e., Ldc-). The operation modes can be generally analyzed as two modes, which is Mode I where both units have the same input voltage while in the second mode the rectifiers are connected to different input voltages

Table I. Parameters of the Multi-Rectifier System



SYMBOL	PARAMETER	VALUE
uabc	Grid phase voltage	230 Vrms
fg	Grid frequency	50 Hz
Lg, Rg	Grid impedance	0.1 mH, 0.1Ω
Lscr	SCR AC-side filter	0.18 mH
Csnub, Rsnub	SCR snubber	100nF, 100 Ω
Ldc+ = *Ldc-*	DC link inductor	1 mH
Cdc	DC link capacitor	0.5 mF
Udc	Output voltage	750 Vdc

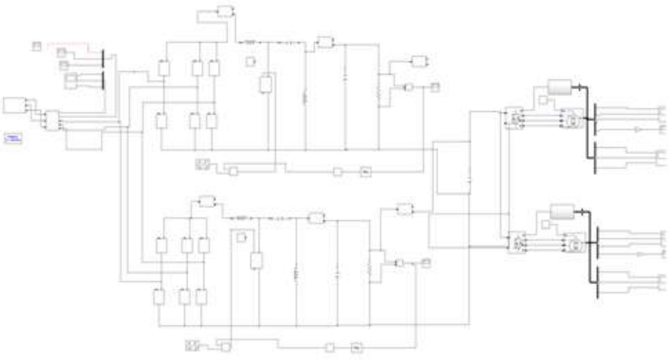


Fig 2 Circuit diagram of SEPIC based Selective Harmonics reduction method

The operation modes are briefly explained for two parallel-connected rectifier units as shown in Fig.2. The operation modes can be generally analyzed as two modes, which is Mode I where both units have the same input voltage while in the second mode the rectifiers are connected to different input voltages.

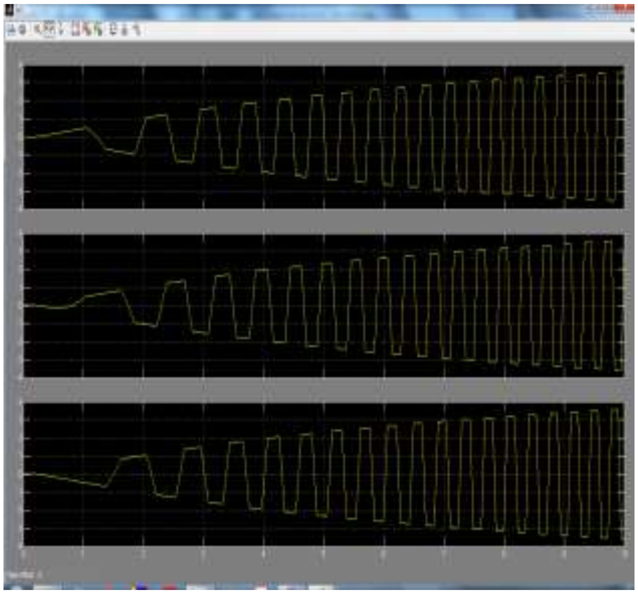


Fig2 Simulation Result for BLDC BACK EMF

Fig.2 demonstrates the performance of the implemented prototype applying the proposed harmonic elimination technique. As it can be seen from, utilizing only phase-shifted current control technique the 5th harmonic component is significantly damped. . Provides comparative results based on the measured harmonic distribution of the total input current waveform of, In general, the obtained experimental results are in close agreement with the numerical simulation as illustrated in Figures.

IV. RESULT AND DISCUSSION

The electronic phase-shifting technique has the advantage of being simple and cost-effective compared with the current modulation technique in which additional voltage sensors are required for the synchronization purpose. However, applying only phase shift cannot improve the input current quality as much as when it is combined with the modulation technique. But the performance of the system in improving the input current quality is highly dependent on the number of the connected rectifier units as well. Therefore, the performance of the phase-shifted flat current control can be comparable with the modulated current control technique if enough number of rectifiers is connected in parallel. In order to show this dependency, optimizations are conducted for having up to seven parallel rectifier units based on the minimum achievable THDi and different power factors. A switched-capacitor-based dual-switch dc–dc converter with a high-boost voltage gain is proposed in this paper. The proposed converter can obtain a high-voltage gain with a small duty cycle, which decreases the voltage stress and the conduction loss on the power switches . This Converter has been optimized for a parallel configuration of line-commutated rectifiers with a common dc-bus voltage used in motor drive application. This feature makes the performance of the system independent of the load profile and maximizes its harmonic reduction ability. In order to further reduce the generated low order harmonics, a dc-link current modulation scheme and its phase shift values of multi-drive systems have been optimized. Analysis, simulations and experiments have been carried out to verify the proposed method. In proposed system dual switch boost converter switching by pid controller. A proportional–integral derivative controller (PID controller or three term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modify lated control. The input power will controlled by converter , which can further reduce the low order harmonics and significantly reduce harmonic distortion.

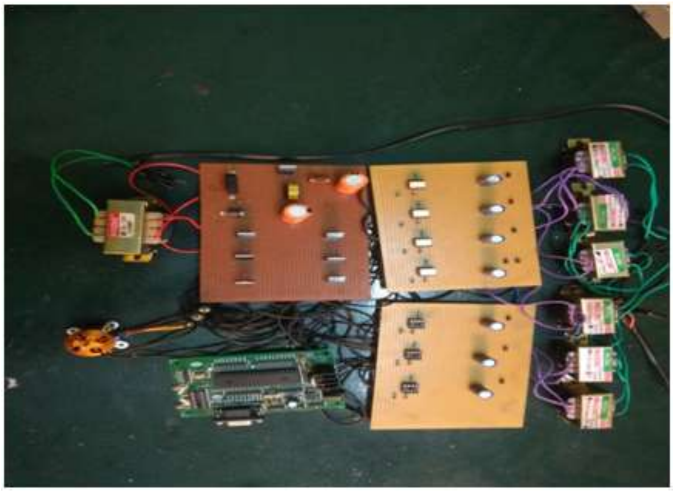


Figure 3 hardware implementation diagrams

The actual process gone through in deciding the rating of the system and setting up of the non-linear load is covered in this. The practical selection criterion for the MOSFETs - the heart of the Shunt HAPF used to assemble the three phase converter block is established. The details of the DSP based control PCB is also given in this chapter. Detailed specification of the proto unit is provided. The parts list of the major components used in the proto unit is also provided. Photograph of the actual proto unit, MOSFET stack and the DSP card are also provided.

In this chapter the power quality tests conducted on the 50kVA dual boost converter, developed and fabricated for this research work, is described. It is found that the developed proposed converter is successful in mitigating the power quality problems created by the harmonics current drawn by the non-linear load based on both IEEE 519 based power quality measure and IEEE 1459 based power quality indices. The compensated grid current waveform has been seen as nearly sinusoidal. It also can be noticed that the waveforms and THD values of the actual implemented system, are matching the findings during simulation. It can be seen that the test results of the practically implemented proto unit and the results of simulation carried out are matching. This is a validation of the design methodology adopted.

The final test results also establish the effectiveness of Switched capacitor based dual switch boost converter for harmonic mitigation in motor drive applications, in mitigation of current harmonics. The performance of the selective harmonic extraction method has also been as per the design requirements. Thus the objectives set for the research work have been fulfilled.

V. CONCLUSION

It is a well established fact that Power Quality is a serious issue faced not only by end users, industries, and utilities but the economy of an entire nation. Harmonics pollution of the grid is a growing concern, due to the proliferation of modern electrical and electronics equipments and modern industrial loads like Variable Speed Drives. Developed design methodology for determining the values and sizing of power components of SEPIC converter, namely A.C filter inductor, A.C filter capacitor, D.C filter capacitor and the power semiconductor switch of the converter, MOSFETs. Developed design procedure for the current controller and voltage controller, to provide optimum harmonics mitigation capability. The objectives set for the research work are successfully achieved. The experimental, simulations and analysis verified the performance of the system which showed that applying the proposed system with electronic phase-shifting (transformer-less) can significantly improve the input current quality compares with the traditional transformer-based rectifier systems.

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