An Extensive Review on Six-Leg Single-Phase to Three-Phase Converter

Sachin Lokhande[1], Prof. Ajeet Verma[2]

[1]M-Tech Research Scholar, [2]Research Guide

Department of Electrical Engineering, SCOPE College Bhopal

Abstract: The switched mode dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide applications like power supplies for personal computers, office equipments, appliance control, telecommunication equipments, DC motor drives, automotive, aircraft, etc. A new single phase to three phase converter topology for different industries is presented Phase converter, include this investigation , is a new technology that supplies three phase power from a single phase source to power inductive, resistive and capacitive loads with distinct advantages over any existing converter technology. The converter consists of DC power supply, integrated gate drive IC, and a DSP to generate the switching signals. The switching signals generated are a unique version of selective harmonic elimination, which produces a consistent starting point for the switching functions, independent of the number of harmonics eliminated. Electronic power processing technology has evolved around two fundamentally different circuit schemes: duty-cycle modulation, commonly known as pulse width modulation (PWM), and resonance. The PWM technique processes power by interrupting the power flow and controlling the duty cycle, thus, resulting in pulsating current and voltage waveforms. The resonant technique processes power in a sinusoidal form. This investigation presents a survey on Six-Leg single-phase to three-phase converters.

Keywords: Pulse Width Modulation (PWM) Techniques, Variable Frequency Drives (VFDS), Rotary Phase Converters, Static Phase Converters, Six-Leg Transformerless (SLTL) Topology, Six-Leg Transformer-Based (SLTB) Topology.

I. INTRODUCTION

In many technical applications, it is required to convert a set voltage DC source into a variable-voltage DC output. A DC-DC switching converter converts voltage directly from DC to DC and is simply known as a DC Converter. A DC converter is equivalent to an AC transformer with a continuously variable turns ratio. It can be used to step down or step up a DC voltage source, as a transformer.

With available devices and circuit technologies, PWM converters have been designed to operate generally at 30-50-kHz switching frequency. In this frequency range, the equipment is deemed optimal in weight, size, efficiency, reliability and cost. In certain applications where high power density is of primary concern, the conversion frequency has been chosen as high as several hundred kilohertz. With the advent of power MOSFET'S, devices switching speed as high as tens of megahertz is possible. Accompanying the high switching frequency, however, are two major difficulties with the semiconductor devices, namely high switching stress and switching loss. For a given switching converter, the presence of leakage inductances in the transformer and junction capacitances in semiconductor devices causes the power devices to operate in inductive turn-off and capacitive turn-on. As the semiconductor device switches off an inductive load, voltage spikes are induced by the sharp di/dt across the leakage inductances, On the other hand, when the switch turns on at high voltage level, the energy stored in the device's output capacitances, 0.5 CV2, is trapped and dissipated inside the device. Furthermore, tum-on high voltage levels induces a severe switching noise known as the Miller effect which is coupled into the drive circuit, leading to significant noise and instability

The day by day increase in electronics consumers and the rigid occurrence of mains rectification circuits inside the electronic devices dominants the cause of mains harmonic distortion. Some form of ac to dc power supply are used within the construction of most modern electrical and electronic apparatus and for each half cycle of the supply these supplies take pulses of current. Considering for single apparatus (a domestic television, for example) the amount of reactive power drawn may be small, but for bulk, may be 100 or more TVs the reactive power utilization from the same supply phase causing a flow of substantial amount of reactive current and hence harmonics generation. The advancement in power electronic converters reduces the weight and size and simultaneously the performance and function of such converters preferable for industrial

II. SYSTEM MODEL

A wide variety of commercial and industrial electrical equipment requires three-phase power. Electric utilities do not install three-phase power as a matter of course because it costs significantly more than single-phase installation. As an alternative to utility installed three-phase, rotary phase converters, static phase converters and phase converting variable frequency drives (VFD) have been used for decades to generate three-phase power from a single-phase source.

A phase converter is a device that converts electric power provided as single phase to multiple phase or vice-versa. The majority of phase converters are used to produce three phase electric power from a single-phase source, thus allowing the operation of three-phase equipment at a site that only has single-phase electrical service. Phase converters are used where three-phase service is not available from the utility, or is too costly to install due to a remote location. A utility will generally charge a higher fee for a three-phase service because of the extra equipment for transformers and metering and the extra transmission wire.

A. Rotary and Static Phase Converters: Phase converters provide 3-phase power from a 1-phase source, and have been used for decades. The simplest type of old technology phase converter is generically called a static phase converter. This device typically consists of one or more capacitors and a relay to switch between the two capacitors once the motor has come up to speed. T

Figure 1. Static Converter

Figure 2. Rotary Converter

B PWM: The commonly used control methods for dc-dc converters are pulse width modulated (PWM) voltage mode control, PWM current mode control with proportional (P), proportional integral (PI), and proportional integral derivative (PID) controller. These conventional control methods like P, PI, and PID are unable to perform satisfactorily under large parameter or load variation. Therefore, nonlinear controllers come into picture for controlling dc-dc converters. The advantages of these nonlinear controllers are their ability to react suddenly to a transient condition. The different types of nonlinear controllers are hysteresis controller, sliding mode controller, boundary controller, etc.

C. Six-Leg Transformerless (SLTL) Topology: There is a strong trend in PV inverter technology to use transformer-less grid-connected topologies. Transformer-less topologies eliminate the Line Frequency Transformer from grid-connected PV systems. This results in reduced cost, physical size and weight of the inverter. The other advantage is an increase in the overall power efficiency and improved power factor at light loads. The other challenge introduced by transformer-less topologies, is the danger of direct current (dc) injection in to the grid. Reduced weight, size and volume of the PV systems. Absence of the transformer means reduced transformer losses and thus improved efficiency of the system by 1-2%. no inductive reactance contribution from the transformer, thus improved power factor for low loading reduced cost of the PV application since the transformer is eliminated.

Figure 3. Six-Leg Transformer-Based (SLTB) Topology

Six-Leg Transformer-Based (SLTB) Topology:

Figure 4. Six-Leg Transformer-Based (SLTB) Topology

Nonlinear Loads: The distortion normal electric current waveform due to the nonlinear loads creates harmonics in AC distribution systems. Nonlinear loads arise for variable resistance i.e. resistance varies for each sine wave of the applied voltage, causing in a series of positive and negative pulses, In AC-DC system, the connected equipment to the DPS desires some kind of power conditioning, rectification in general, which creates a non-sinusoidal line current because of the non-linear input characteristic.

Figure 5. Linear Load Sine Wave

D. Control Methods: Many control methods are used for control of switch mode dc-dc converters and the simple and low cost controller structure is always in demand for most industrial and high performance applications. Every control method has some advantages and drawbacks due to which that particular control method consider as a suitable control method under specific conditions, compared to other control methods. The control method that gives the best performances under any conditions is always in demand.

- PI Control: PI control strategy the current loop and compensating current error amplifier are not required as for the cases of traditional linear control method for DC converter. Since, the DC converter operates in two modes, for one cycle the steady state time integral of the inductor voltage can be;
- Nonlinear Control: The DC converter always needs extensive operating conditions and fast response, which is satisfactorily impossible by conventional PWM current mode controller. The nonlinear controllers offer control backing in this regards. In comparison to the conventional current mode controllers the nonlinear controller is able to provide:
  - ✓ Comparable fast dynamic responses
  - ✓ Inherent robust features with fixed operating frequency
  - ✓ Stable for large operating range
  - ✓ Least deviation of settling time over wide operating range
  - ✓ Low overshoots voltage relatively over wide operating range

Variable Frequency Drives: Variable frequency drives (VFDs) are designed primarily to control the speed of AC motors, but can be adapted to function as phase converters. They also have some problems with power quality. While a phase converter will supply a 3-phase output at the same frequency as the input voltage from the power line, a VFD has the ability to create voltages that vary in frequency. A VFD has an input rectifier (either 4 or 6 semiconductor diodes) which charge up a DC link capacitor. Three pairs of semiconductor switches are also connected to the DC link capacitor. Each switch pair is connected in series and has connections to the two capacitor terminals.

Figure 6. Electrical scheme of the VFD and Simplified block-diagram of the VFD

The center connection of each switch pair is connected to one of the output terminals. If the top switch is on, the output terminal will be connected to the top or positive terminal of the link capacitor. If the bottom switch is on, then the output terminal will be connected to the bottom or negative terminal of the DC link capacitor. Each of the three output terminals is connected to one of the leads of a 3-phase induction motor.

E. Digital Phase Converters: Digital phase converters are a recent development in phase converter technology that utilizes proprietary software in a powerful microprocessor to control solid state power switching components. This microprocessor, called a digital signal processor (DSP), monitors the phase conversion process, continually adjusting the input and output modules of the converter to maintain perfectly balanced three-phase power under all load conditions. Like rotary and static phase converters, a digital phase converter generates a third voltage, which is added to L1 and L2 of single-phase service to create three-phase power. There the similarity ends. A process called double-IGBT conversion generates the third voltage. Double conversion means that AC power from the utility is converted to DC, then back to AC. The power switching devices used in this process are insulated gate bipolar transistors (IGBT). The input module, or rectifier, consists of IGBTs in series with inductors. Operating at a switching frequency of 10 kHz, the IGBTs are controlled by software in the DSP to draw current from the singlephase line in a sinusoidal fashion, charging capacitors on a constant voltage DC bus. Because the incoming current is sinusoidal, there are no significant harmonics generated back onto the line as there are with the crude rectifiers found in most VFDs. The electronic power factor correction on the input module also corrects the power factor of any inductive loads so that the utility sees a system that operates at near unity power factor. The power factor correction makes digital phase converters very efficient and utility friendly.

The output module, or inverter, consists of IGBTs that draw on the power of the DC bus to create an AC voltage. A voltage created by power switching devices like IGBTs is not sinusoidal. It is a pulsewidth-modulated (PWM) waveform very high in harmonic distortion. This PWM voltage is then passed through an inductor/capacitor filter system that produces a sine wave voltage with less than 3% total harmonic distortion (standards for computer grade power allow up to 5% THD). By contrast, VFDs generate a PWM voltage that limits their versatility and makes them unsuitable for many applications. Software in the DSP continually monitors and adjusts this generated voltage to produce a balanced three-phase output at all times. It also provides protective functions by shutting down in case of utility over-voltage and under-voltage or a fault. With the ability to adjust to changing conditions and maintain perfect voltage balance, a digital phase converter can safely and efficiently operate virtually any type of three-phase equipment or any number of multiple loads. The solid state design results in a relatively small package with no moving parts except for small cooling fans. The converters are very efficient, operating at 95-98% efficiency. When the converter is energized with no load, it consumes very little power. Digital phase converters are a patented technology developed by Phase Technologies, LLC, who is the only manufacturer of true digital phase converters

III. LITEARTURE REVIEW

SR.NO.	TITLE	AUTHORS	YEAR	METHODOLOGY
1	Harmonic injection scheme for harmonic reduction of three-phase controlled converters	A. M. Eltamaly	2018	Third harmonic current injection technique
2	A High Step-Down Isolated Three-Phase AC-DC Converter	Z. Zhang, A. Mallik and A. Khaligh	2018	The single-stage three-phase isolated ac-dc converter topology utilizing SiC MOSFETs
3	Investigation of Zero Sequence Circulating Current Suppression for Parallel Three-Phase Grid-Connected Converters Without Communication	J. Wang, F. Hu, J. Weidong, W. Wang and Y. Gao	2018	The mechanisms and characteristics of ZSCC in two parallel three-phase GCCs are firstly investigated
4	Design of three phase interleaved DC/DC boost converter with all SiC semiconductors for electric vehicle applications	S. Öztürk	2017	The design of a SiC semiconductor based three phase interleaved boost converter
5	Three-phase interleaved boost DC/DC converter with high voltage gain and reduced nominal value on power devices	S. H. Hosseini, M. Maalandish, T. Jalilzadeh and S. Ghasemzadeh	2017	A new interleaved boost dc-dc converter
6	A three phase high frequency link PWM converter using soft switching techniques	R. J. Vince and H. S. Manjula,	2017	A Rectifier-type High Frequency Link (RHFL) PWM converter to achieve low input to three phase high output with reduced switching losses
7	Three-phase converter based on reduced redundant power processing concept	R. Velasco-Reyes, R. Loera-Palomo, M. A. Rivero-Corona, F. S. Sellschopp-Sánchez and J. A. Morales-Saldaña	2017	The model and control strategy of a converter to incorporate a three-phase rectifier and a DC-DC converter,
8	Three-phase bridgeless boost PFC converter with variable duty cycle control	D. C. Morais, F. J. M. de Seixas, L. S. C. e Silva and C. P. João	2017	The analysis and simulation of the three-phase bridgeless boost converter with variable duty cycle control

A. M. Eltamaly, [1] High harmonics in supply currents of three-phase controlled/uncontrolled converters are creating many problems to the power system and customers at point of common coupling. Third harmonic current injection technique is an excellent option for harmonic reduction of these converters. Minimum total harmonic distortion (THD) for any firing angle of controlled converter is function in phase-angle and amplitude of harmonic injection current that can be controlled by single-phase controlled converter and boost converter, respectively. A novel scheme with three bidirectional switches and single-phase controlled converter to circulate the injection current to supply currents has been introduced. This novel scheme is compared to the state-of-the-art system using zigzag transformer. A novel mathematical analysis showing the optimum values for components on the harmonic injection path at minimum THD and the corresponding efficiency for the reported scheme and state-of-the-art scheme is introduced. Two lab prototypes for these two schemes have been implemented, discussed, and compared to show the benefits of using the new reported scheme. The results show the superiority of the new reported scheme.

Z. Zhang, A. Mallik and A. Khaligh, [2] In this investigation , a single-stage three-phase isolated ac-dc converter topology utilizing SiC MOSFETs is reported for power rectification with a stepped-down output voltage. Unlike the conventional two-stage [front-end power factor correction (PFC) stage and isolated dc-dc stage] ac-dc converters, the full/half bridge structure in dc-dc stage is eliminated in this structure. The high-frequency pulsating voltage is obtained directly from the PFC stage and is applied across the high-frequency transformer, leading to a more compact design. In addition, there is an advantage of zero voltage switching (ZVS) in four PFC MOSFETs connected to the high-frequency tank, which is not achievable in the case of a conventional two-staged ac-dc converter. A sine-pulse width modulation (PWM)-based control scheme is applied with the common-mode duty ratio injection method to minimize the current harmonics without affecting the power factor. An LC filter is used after the PFC semistage to suppress the line-frequency voltage ripple. Furthermore, the intermediate dc-link capacitor value can be greatly reduced through no additional ripple constraints. Experimental and simulation results are included for a laboratory prototype, which converts 115-V, 400-Hz three-phase input voltage to 28-V dc output voltage. The experimental results demonstrate a power factor of 0.993 with a conversion efficiency of 95.4%, and total harmonic distortion (THD) as low as 3.5% at 2.1-kW load condition.

J. Wang, F. Hu, J. Weidong, W. Wang and Y. Gao, [3] The parallel three-phase grid-connected converters (GCCs) with common DC and AC buses can increase the system power level effectively. However, zero sequence circulating current (ZSCC) will occur inevitably. In this investigation , the mechanisms and characteristics of ZSCC in two parallel three-phase GCCs are firstly investigated based on three typical cases. From the analysis, it found that not all ZSCC can be suppressed. Generally speaking, ZSCC caused by inconsistent modulation voltages between modules can not be effectively handled. And ZSCC caused by different injected zero sequence voltages (ZSVs) or asynchronous carriers can be suppressed. Based on theoretical analysis, identical ZSV injection and carrier synchronization methods without communication are thus reported to suppress ZSCC at the source, which are easy to be implemented without adding any hardware. Finally, the theoretical analysis and the effectiveness of the reported methods on ZSCC suppression are well verified by experiments.

S. Öztürk, [4] The design of a SiC semiconductor based three phase interleaved boost converter has been presented. The reported SiC based converter has 27 kW output power and 201.6 V–650 V input-output voltage ratings to be used in Electric Vehicle (EV) applications. The reported SiC based converter has been compared with the Si IGBT based converter used in Toyota Prius (3rd Generation) Hybrid Electric Vehicle (HEV) in terms of the efficiency, converter size and power density. The validity of the reported converter has been verified with the computer simulation results. The analytical loss calculations have been made for both converters with the commercial Si and SiC power semiconductors. The passive component sizes has been reduced by %40, and the total converter efficiency of %98.75 has been achieved by using the interleaved operation and SiC devices. The reported converter thus found to be quite convenient to use in EV applications.

S. H. Hosseini, M. Maalandish, T. Jalilzadeh and S. Ghasemzadeh, [5] In this investigation , a new interleaved boost dc-dc converter is presented for PV applications. The reported between the phases for increasing the output voltage converter consists of three-phase which are parallel connected to each other. There are voltage multiplier units. By increasing the voltage multiplier units (by connecting the series together), the output voltage will be more increase. In addition, the nominal value of the power components is reduced. Therefore, the voltage stress of switches and diodes for various duty cycles is low and so, the efficiency is high. One of the other advantages of the reported converter input current ripple is low with the utilization of interleaving techniques. These advantages cause the reported converter to be a good candidate for PV panels. To illustrate the merits of reported converter, comparison results with other converters are provided.

Also, theoretical analysis for two stages with operating at 25kHz is provided.

V. R. J. Vince and H. S. Manjula, [6] This investigation proposes a typical form of a three phase Rectifier-type High Frequency Link (RHFL) PWM converter to achieve low input to three phase high output with reduced switching losses. In RHFL converter a soft-switching mechanism based on zero-voltage-zero-current-switching (ZVZCS) principle is implemented for the front-end isolated dc/dc converter of an isolated three-phase rectifier-type high-frequency-link bidirectional power converter. The reported soft-switching scheme is valid for various load conditions with bidirectional power flow.

R. Velasco-Reyes, R. Loera-Palomo, M. A. Rivero-Corona, F. S. Sellschopp-Sánchez and J. A. Morales-Saldaña, [7] There is a constant development in power switching converters that can be controlled in a simple way and that can fulfill specific requirements in the energy processing. This work develops the model and control strategy of a converter to incorporate a three-phase rectifier and a DC-DC converter, through the reduced redundant power processing approach. The reported converter is able to achieve a Unity Power Factor and a regulated DC voltage, the resulting converter can be useful in the power extraction from a wind turbine. Along the work it is demonstrated that the alternating current stage control is independent from the DC stage control. This is confirmed by simulations where the converter operation and the control are verified.

D. C. Morais, F. J. M. de Seixas, L. S. C. e Silva and C. P. João, [8] The boost bridgeless converters operating in discontinuous-conduction-mode can offer both stages, rectification and elevation of voltage in high frequency, also can offer better efficiency when compared to the traditional single-switch one. Some these advantages are inherent to the converter operating mode, as the zero-current-switching during the turn-on of the switches, the simplicity of control system and the lower cost. However, the discontinuous-conduction-mode operation with constant duty cycle control leads to a high harmonic content of current in low frequency, limiting the converters applications by exceeding the limits imposed by international standards, for example by exceeding the harmonics requirement presented in IEC 61000-3-2. This investigation presents the analysis and simulation of the three-phase bridgeless boost converter with variable duty cycle control. The principle of operation of the reported converter is detailed and results of simulation shown the increase of the power factor by reducing the harmonic distortion of the input current.

IV. PROBLEM IDENTIFICATION

The transfer of electrical power from power grid to the consumer-end is possible with low cost and high efficiency since Power Electronic Converter designed is leading with sophisticated appropriate control technique. Realistically, completely eliminating harmonics would be very challenging and overpriced. Understanding of the choices and their relevant costs for balancing the real harmonic load in contradiction of the cost of the solution is the vital factor. For the minimization of the actual harmonic loads there are numbers of selections offered, but should be studied deliberately because of the combined expenditure and usage of extra copper, is enhancing increase in deficient. All the negative effects of line current distortion needs for setting limits for the line current harmonics of joined equipment to the distribution network. The power factor correction is referred as the minimization of the line current harmonic. Keeping the harmonic content to a minimum level. The effect of harmonic and its problems on power system is observed as significant and hence Electricity regulatory commissions and utilities.

V. CONCLUSION

Almost every electronic equipment are of distinct power rating and the amazing demands of power sources for such equipment acts tense and great task to the power engineer. AC-DC active PFC converters system introduces the idea of regulated DC bus bar voltage. On power distribution and management this fulfils to the higher current desires and the dynamic characteristics of AC-DC system. For specific applications like power sources to telecom and computer servers, biomedical equipment and aeronautical engineering it is too humbling while considering high efficiency, high power density and fast dynamic response etc. DC converters are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklifts trucks, and mine haulers. They provide high efficiency, good acceleration control and fast dynamic response. They can be used in regenerative braking of DC motors to return energy back into the supply. This attribute results in energy savings for transportation systems with frequent steps. DC converters are used in DC voltage regulators; and also are used, with an inductor in conjunction, to generate a DC current source, specifically for the current source inverter.

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