PULSE WIDTH MODULATION CONTROLLED USING AC CHOPPER VOLTAGE CONTROLLER

Mr. Shailesh Prajapati[1], Mr. Suvas Vora[2], Mrs. Nilam N. Patel[3]
[1]P.G Student (Power System), Electrical engineering Dept., Merchant Engineering College, Basana (Gujarat), India
[2]Lecturer in Electrical engineering Dept., Shree Swminarayan Pollytechnique College, Gandhinagar (Gujarat), India
[3]Assistant Professor, Electrical Engineering Dept., Merchant Engineering College, Basana (Gujarat), India

Abstract: The recent increase in the use of nonlinear loads has caused serious concern for power quality and consequently on the disturbances tolerated by sensitive electronics loads. Currently, most of the line conditioners still rely on thyristor technology (line commutated ac controllers). The absorbed harmonics current present high amplitudes and low frequencies. Due to the emplacement of these harmonics near the fundamental harmonic at the power supply system it is not recommended to use passive filters. Also the size, weight and price of the passive elements could be high. Therefore, direct AC-AC converters with thyristors are placed outside of new electromagnetic compatibility (CEM) standards that limit the admitted perturbations in the power supply system. More, the reactive power absorbed by these converters changes at the same time with the delay control angle. Such conditioners, however, have slow response and need large input-output filters to reduce low-order harmonics. Line-commutated AC controllers can be replaced by pulse width modulation (PWM) AC choppers, which have better overall performance and the above problems can be improved if these controllers are designed to operate in the chopping mode. In this case, the input voltage is chopped into segments and the output voltage level is decided by controlling the duty cycle of the chopper switching function.
Keyword: AC Controllers, AC Chopper, Pulse width modulation, Switching function, Duty cycle

I. INTRODUCTION

Line frequency ac choppers are widely used in applications such as industrial heating, lighting control, soft starting of the induction motor, and speed controllers for fans and pumps. Most of them are phase controlled to control the magnitude of the output voltage. These problems can be improved by modifying the power circuit with freewheeling path or by using the PWM AC chopper. This chopper offers several ad vantages such as sinusoidal input current with unity power factor, Several PWM AC choppers have been articulated in a number of technical papers [5-7]. In the PWM the switching patterns are critical and an alternate path has to be provided for current when both switches are turned off. This alternate path is implemented using additional bilateral. Switches or by using standard switches with RC bypass snubbers [2, 7].In these techniques, the switching losses are very high and as more power capacity is increased, More the power loss of RC bypass snubbers is increased. The power fed to the load can be controlled by simply varying the duty cycle of the PWM signal where the shape of the current is sinusoidal due to the filtering effect of the inductive nature of the load. The AC voltage chopper presents an attractive method for stepping down a given AC voltage level in an efficient and simple way. Conventional types of solid state voltage regulators operate with phase angle control strategy with a capability to control a large amount of AC power with low level control power. However, it suffers from the drawback associated with low order harmonics produced in load voltage and current .Moreover, the switching instant is dependent on load phase angle, thus presenting difficulties in control under varying load condition. These drawbacks could be overcome by using a PWM ac chopper. The growing demand in improving performance of motor drives, there is an increasing need to improve the quality and reliability of the drive circuit. AC-AC converter schemes using pulse width modulation (PWM) are proved to achieve substantial advantages over conventional line-commutated AC controllers. With the increasing availability and power capability of MOSFET'S and IGBT'S switches ,PWM converters can efficiently and economically be used in low and medium power applications. However, the standard ac chopper requires bi-directional switches, with the commutation problem causing a high voltage spike, and is limited to small power applications. The commutation of switches is critical and an alternative current path has to be provided when both switches are turned off. Moreover, with the development of power semiconductor devices, PWM techniques are being increasingly encouraged, will become more sophisticated, and can be divided into two: programmed PWM techniques have been employed extensively for minimization of either selected harmonics or total harmonic distortion (THD). AC choppers are proposed for single-phase and three-phase systems. Since the power circuits of single-phase and three-phase ac choppers use only two and three standard switch modules, respectively, and proper switching operation for solving the commutation problem is achieved,. The ac choppers have the main advantage of sinusoidal output voltage waveform and sinusoidal input current, high efficiency, and significant reduction of filter size. Simulation results show that the PWM ac chopper technique gives good results. The power circuits of the single-phase and three-phase buck-boost ac choppers use only two and three standard switch modules, respectively, and regenerative dc snubbers are attached directly to standard switch modules to absorb energy stored in line stray inductance. The switching policy for solving the commutation problem is achieved.

II. PWM AC CHOPPER METHODOLOGY

In this topic some basic topologies of direct PWM AC choppers are presented. Compared with the phase-controlled AC controllers using thyristors the PWM AC Choppers have important advantages sinusoidal current waveforms, better power factor, faster dynamics and smaller input/output filters. They present high robustness, offer safe commutation and have high efficiency. The chapter describes operational principles and analysis of two basic direct topologies using a very simple DC snubbers consisting of a capacitor only with no discharging resistors. These DC snubbers are directly attached to power commutation cells. Before, PWM AC choppers were made by four quadrants switches. Their application was delayed due to the commutation problems. To assure safe commutation without high voltage spikes, some PWM control principles were developed however; converters robustness depended on the control accuracy and kept high the risk of over voltages and over currents appearance. To increase the converters robustness simple DC snubbers consisting of a capacitor only attached directly to commutation cells were used. In this topic some basic topologies of direct PWM AC choppers are comparatively studied. These have numerous advantages, such as: quasi-sinusoidal current waveforms, better power factor, faster dynamics and smaller input/output filters. PWM AC choppers present high robustness, offer safe commutation and have high efficiency. In phase angle controlled regulators triacs and thyristors pair connected are usually employed as the power control elements of such controllers. Such technique offers some advantages as simplicity and ability of controlling large amount of power economically. However, delayed firing angle causes discontinuity and plentiful harmonics in load current, the size of passive circuit becomes bulky and also a lagging power factor occurs at the ac side even though the load is completely resistive especially when the firing angle is increase. These problems can be improved by modifying the power circuit with freewheeling path or by using the PWM AC Chopper.

III. SINGLE PHASE PWM AC CHOPPER TOPOLOGIES

By the supply mode, PWM AC Choppers are classified in differential and non differential topologies. Both structures are made by two inverter commutation cells with IGBTs bidirectional in current and unidirectional in voltage. DC snubbers is attached directly to commutation cells to absorb the energy stored in line stray inductance. This snubbers has a very simple structure, consisting of a capacitor only with no need for discharging resistors. In differential topology the S2 and S1 switches, the voltage source and the load are serial connected. By moving S2 switch between the voltage source and S1 switch non-differential topology is obtained .This second structure presents the neutral wire continuity advantage. Both converters have the same control, depending on the voltage source Ua sign. In this way, if Ua is positive, S1 and S1c switches are PWM controlled with a constant duty (α) ratio, while S2 and S2c switches are fully turned on. When the sign of the voltage source is changed, the switching pattern is reversed, S2 and S2c being complementary PWM controlled with a constant duty ratio and S1 and S1c are fully turned on. In these switching patterns the current path always exits whatever the inductor current direction. Since two switches are always turned on during the half period of the voltage source the switching loss is significantly reduced. In the buck conversion topology the output voltage is proportional with the duty ratio: $us = \alpha *Ua$ .during one switching cycle, basic PWM AC choppers present three possible operating modes: active mode, freewheeling mode and bypass mode.

A. Differential Topology:

The differential topology of PWM ac chopper consist four bidirectional IGBT switches. Among four switches two turned on for safe commutation. The load always connected across two switches. Circuit performed as a unidirectional independent voltage source.

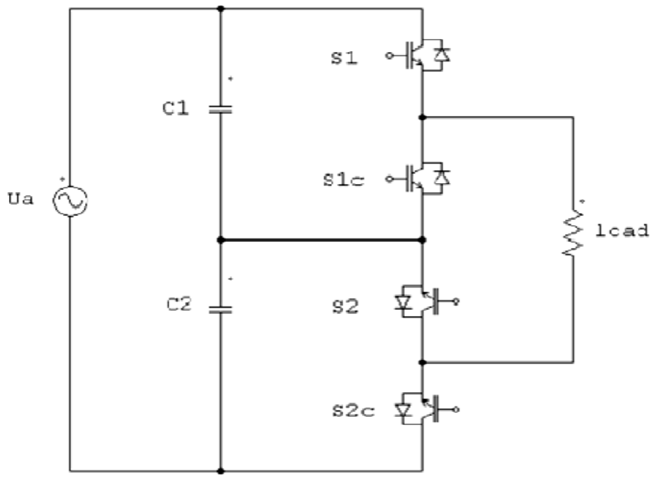


Figure 1 Differential Topology [1]

IV. OPERATING MODES OF PWM AC CHOPPER

A. Active Mode:

The active mode is corresponding to the on-state periods of the chopping switches S1 and S2, where the supply voltage appears across the terminal of the load circuit, forcing current to flow from the supply to the load. During this mode, the inductor current IL Conducts through input and output side and provides output energy. The S1 and S2 switches are turned on and the inductor current IL conducts through S1 and the diode across S2 for IL>0 or S2 and the diode across S1 for IL<0.

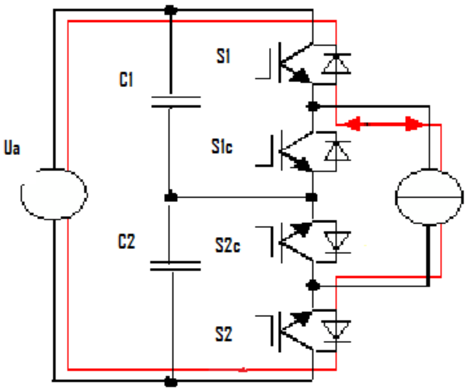


Figure 2 Active Mode [1]

B. Freewheeling mode:

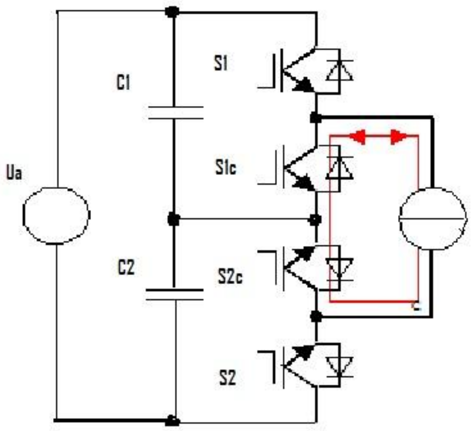


Figure 3 Freewheeling Mode [1]

During the off-state periods of the chopping switchesS1 and S2, the load is isolated from the supply and the load is short-circuited through the freewheeling path, implying that the load voltage is zero. The load current will then naturally decay through the freewheeling switches S1c and S2c connected in parallel with the load terminal for this purpose. This mode is complementary to the active mode. During this mode the switches S1c and S2c are turned on so that the inductor current freewheels through the output side.

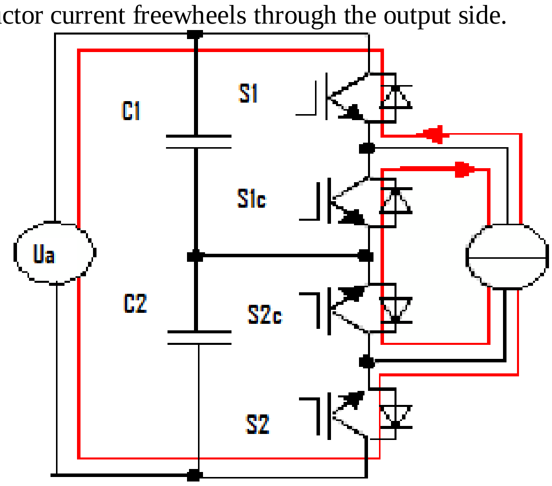


Figure 4 Bypass Mode [1]

C. Bypass mode:

The bypass mode is imposed by non-linear regime of power devices. To avoid commutation problems during dead time, a specific control strategy for this type of conversion was proposed. Two additional switches are turned on for safe commutation in this mode. When the input voltage Ua is positive, the switches S2 and S2c are turned on for safe commutation. During the dead time the inductor current IL conducts in the positive direction through the load, the S2c switch and the diode across S1c. The negative inductor current IL conducts through the voltage source, the S2 switch and the diode across S1.Thus, a current path for the inductor current always exists in every current direction during the bypass mode. The current paths in this mode, for Ua>0, are shown in fig.ure 4 Table 1 presents the output voltage depending on the switches control. The main restrictions for this control are the accuracy and speed for detecting the voltage source sign.

Table 1 Output voltage depending on control

	S1	S1c	S2	S2c		
					Il>0	Il<0
Ua>0	1	0	1	1	Ua	Ua
	0	0	1	1	0	Ua
	0	1	1	1	0	0
Ua<0	1	1	1	0	Ua	Ua
	1	1	0	0	Ua	0
	1	1	0	1	0	0

V. NON DIFFERENTIAL TOPOLOGY

The above circuit showing the non-differential topology of pwm ac chopper. The circuit performed as a unidirectional independent voltage source. The load connected across two switches and capacitor also connected across two switches. Four IGBT switches along with body diodes are used for providing unidirectional voltage and bidirectional current.

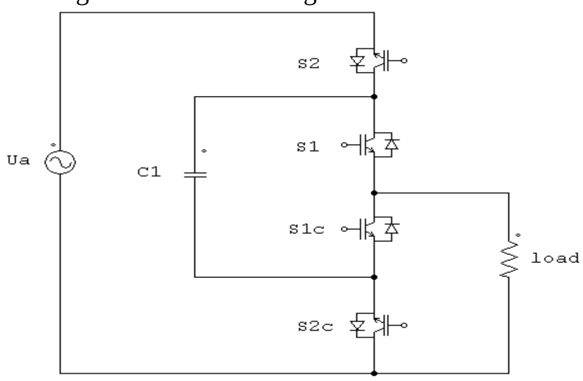


Figure 5 Non differential topology [1]

A. Operating Modes of PWM Non Differential Topology:

Non differential PWM AC Chopper works in three modes.

These are Active Mode, Freewheeling Mode and Bypass Mode. The difference in non differential topology compare with differential topology is that it has a common point for load with the supply and IGBT switch and there is only one capacitor which is connected across two IGBT switch.

B. Active Mode:

The active mode is corresponding to the on-state periods of the chopping switches S1 and S2, where the supply voltage appears across the terminal of the load circuit, forcing current to flow from the supply to the load. During this mode, the inductor current IL Conducts through input and output side and provides output energy. The S1 and S2 switches are turned on and the inductor current IL conducts through S1 and the diode across S2 for $IL > 0$ or S2 and the diode across S1 for$IL < 0$.shown in fig. by red line and the direction shown by arrow in respectively direction.

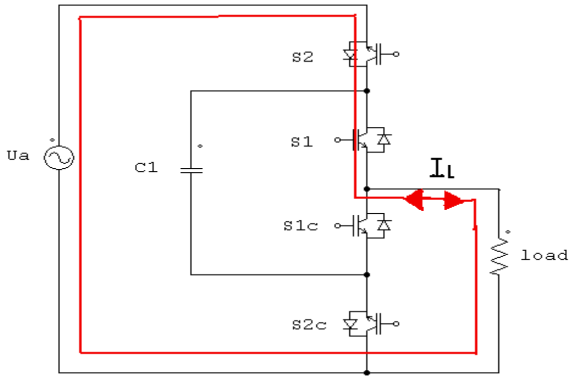


Figure 6 Active Mode [1]

C. Freewheeling Mode:

During the off-state periods of the chopping switchesS1 and S2, the load is isolated from the supply and the load is short-circuited through the freewheeling path, implying that the load voltage is zero. The load current will then naturally decay through the freewheeling switches S1c and S2c connected in parallel with the load terminal for this purpose. This mode is complementary to the active mode. During this mode the switches S1c and S2c are turned on so that the inductor current freewheels through the output side. The direction of current shown in figure 7.

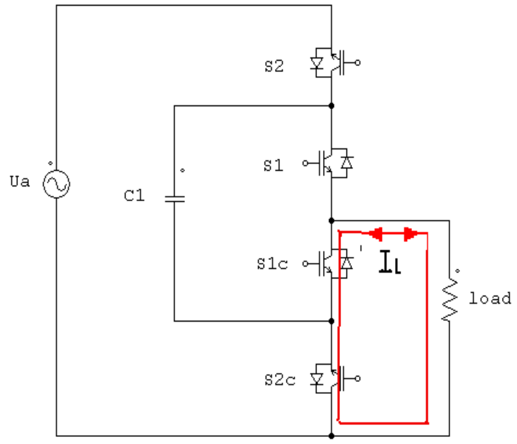


Figure7 Freewheeling Mode [1]

D. Bypass Mode:

The bypass mode is imposed by non-linear behavior of power devices. To avoid commutation problems during dead time, a specific control strategy for this type of conversion was proposed. Two additional switches are turned on for safe commutation in this mode. When the input voltage Ua is positive, the switches S2 and S2c are turned on for safe commutation. During the dead time the inductor current IL conducts in the positive direction through the load, the S2c switch and the diode across S1c. The negative inductor current IL conducts through the voltage source, the S2 switch and the diode across S1.Thus, a current path for the inductor current always exists in every current direction during the bypass mode. The current paths in this mode, for$Ua > 0$, are shown in fig. Table 1 presents the output voltage depending on the switches control.

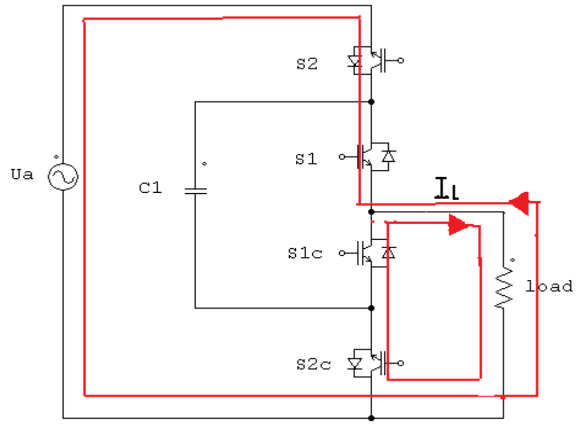


Figure 8 Bypass Mode [1]

VI. THREE-PHASE PWM AC CHOPPER METHODOLOGY

Single-phase topologies structures can be extended for three-phase structures. In the case of differential topology number of commutation cells is two times smaller than the three phase non- differential topology. By adding a third commutation cell to the single-phase topology, a differential three-phase PWM AC chopper is obtained .A snubbers made by only one capacitor is attached directly to each commutation cell. As in the single-phase topology, this structure presents the advantage of using standard commutation cells in two quadrants. The control can be realized by taking into account the current or the voltage source sign. The first control, depending on the current's sing, is realized by having identical duty cycles. In this case only active and freewheeling operation modes are allowed. As a result, there is no indirect energy change similar to a bypass operating mode. Another disadvantage is to determine the current's sign near the passing through zero. In the single-phase topology, the PWM AC chopper operates like a unidirectional voltage chopper. In the second control (depending on the voltage source sign) the three-phase structure operates like two independent unidirectional voltage choppers. It means that the duty cycles can be different, which is an important advantage. In the buck PWM AC chopper for three-phase systems, the switches with the smallest voltage source among three voltage sources are fully turned on. Other switches are modulated with a constant duty ratio. Example, if the voltage of phase a, is the smallest, switches S1 and S1c are fully turned on, while S2, S2c and S3, S3c are complementary switched with a constant duty ratio. The operational modes are the same with the single-phase AC chopper.

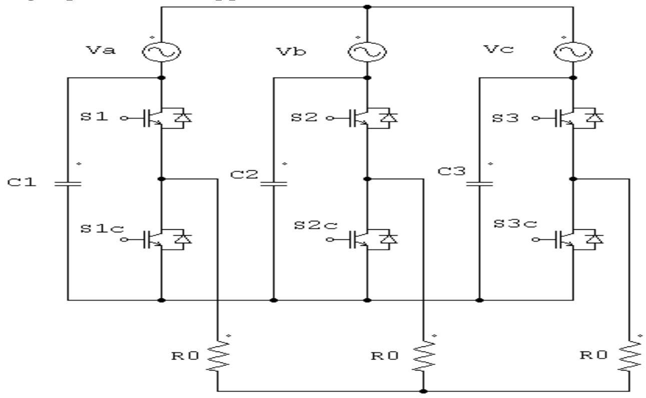


Figure 9 Three phase PWM ac chopper [1]

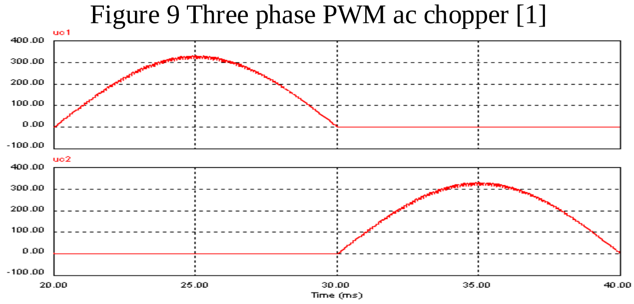


Figure 10 Single-Phase PWM AC Chopper Voltage

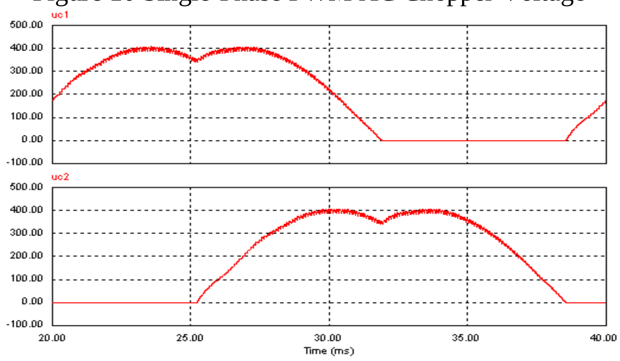


Figure 11 Three-Phase PWM AC Chopper Voltage

A. Operating Modes of 3 Phase PWM AC Choppers:

The three phase PWM ac chopper shown in figure 3. The leg switches corresponding to a minimum voltage among three leg phase voltages Vta, Vtb and Vtc are always turned on without respect to the control strategy for safe commutation. The other switches are modulated according to the duty ratio determined by the control strategy. For example, if the total voltage of the leg `c' is the smallest one, the switches S3, S6 are fully turned on to bypass the inductor current through the input side or output side, depending on its direction during the bypass mode. The switches S1, S2 and S4, S5 are complementarily switched with a constant duty ratio. The operational modes are the same as that of the single phase pwm ac chopper.

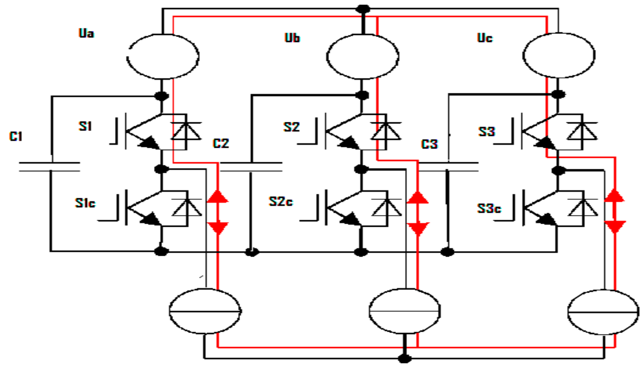


Figure 12 Active Mode [1]

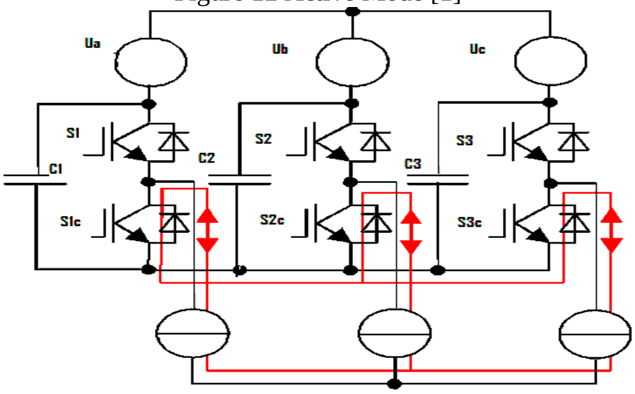


Figure 13 Freewheeling Mode [1]

B. Pulse Width Modulated Switching Scheme:

Pulse-width modulation (PWM) is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only, when switched on. PWM is a comparatively-recent technique, made practical by modern electronic power switches. The term duty cycle describes the proportion of on time to the regular interval or period of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. PWM works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. The triangular waveform Vtri in figure10 is at switching frequency fs, which establishes the frequency with which the chopper switches are switched. The control signal Vcontrol is used to modulate the switch duty ratio and has a frequency f1, which is the desired fundamental frequency of the chopper output voltage.

The amplitude modulation ratio Ma is defined as

$$Ma = Vcontrol/Vtri \quad \ldots.1$$

Where Vcontrol is the peak amplitude of the control signal .the amplitude Vtri of the triangular signal is generally kept constant.

The frequency modulation ratio mf is defined as

$$Mf = fs/f1 \quad \ldots.2$$

Where fs is the carrier frequency and f1 is the modulating frequency. In the chopper the switches are controlled based on the comparison of Vcontrol and V tri.

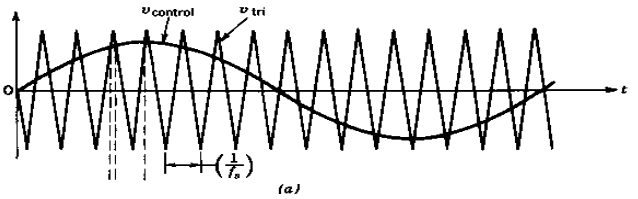


Figure 14 Pulse Width Modulation

C. Filter:
LC circuits are used either for generating signals at a particular frequency, or picking out a signal at a particular frequency from a more complex signal. They are key components in many applications such as oscillator, tuners, filters and frequency mixers. An LC circuit is an idealized model since it assumes there is no dissipation of energy due to resistance. LC circuits are often used as filters; the L/C ratio is one of the factors that determine their "Q" and so selectivity. For a series resonant circuit with a given resistance, the higher the inductance and the lower the capacitance, the narrower the filter bandwidth. In pwm ac chopper circuit Lc filter is using for making chopped output signals to sinusoidal signal as sameas input signal.It is required to design the input filter to reduce the harmonic current and the output filter to reduce the ripple on the output voltage. The cut-off frequency and characteristic impedance formula for LC filter

Cut-Off Frequency

$$F = 1/(2 * PI * SQRT(L * C)) \qquad \ldots.3$$

Characteristic Impedance

$$Z = SQRT(L/C) \qquad \ldots.4$$

VII. SIMULATIONS AND RESULTS

A. Simulation of Single Phase PWM AC Chopper

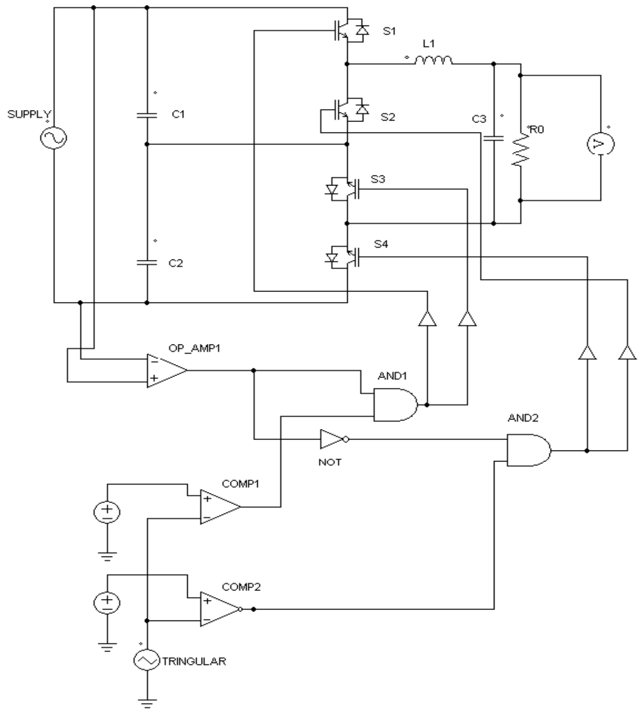


Figure 15 Simulation Diagram of Differential AC Chopper

The simulation performed in PSIM software. The gating pulses for switches are generated by PWM technique. The operation amplifier checking the zero crossing of input voltage waveform and output signal of operational amplifier is Adding with PWM output signals.LC filter doing filtering of chopped signal and providing the pure sinusoidal output signal.

A. Power Supply

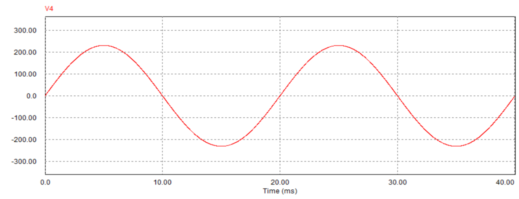


Figure 16 Power Supply

B. PWM gate pulses for IGBT'S:

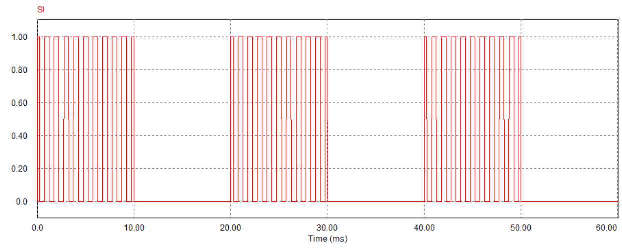


Figure 17 PWM Gate Pulses for Igbt'sFor S1 Switch

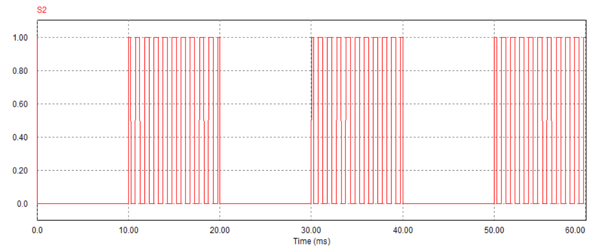


Figure 18 PWM Gate Pulses forIgbt'sfor S2 Switch

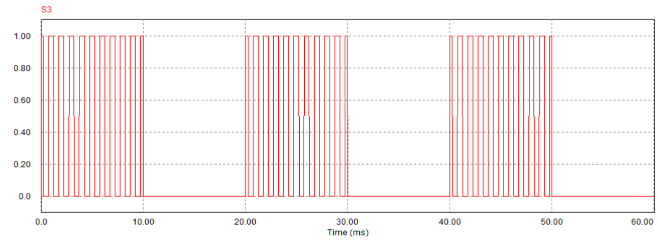


Figure 19 PWM Gate Pulses for Igbt'sFor S3 Switch

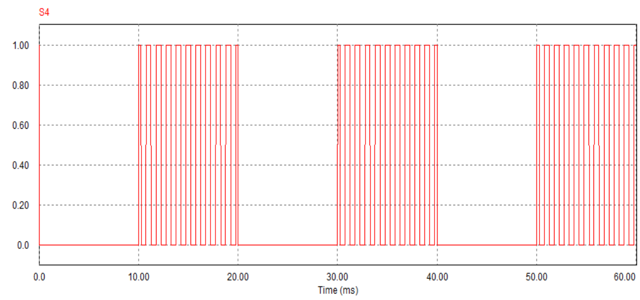
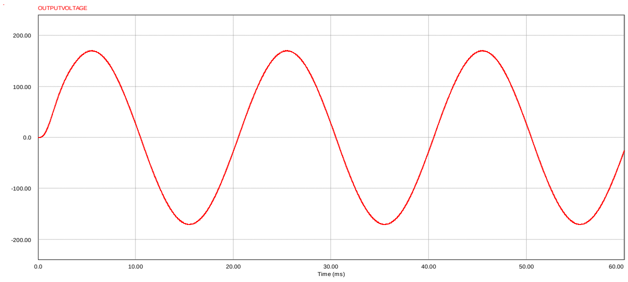
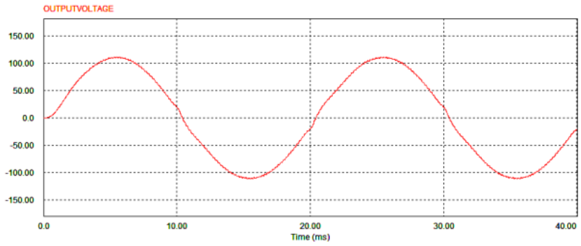


Figure 20 PWM Gate Pulses for Igbt'sFor S4 Switch

C. Output Voltage and Current Waveform of the PWM AC chopper Differential Technolgy:



(A) Output of the simulation of differential PWM AC CHOPPER at 75% duty cycle



(B) Output of the simulation of differential PWM AC CHOPPER at 50% duty cycle

Figure 19 Output Voltage Waveform

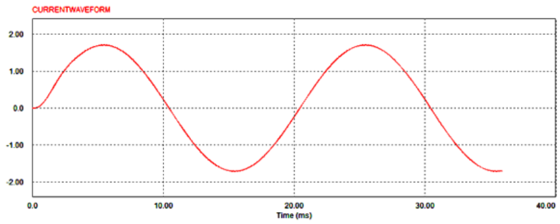


Figure 20 Output Current Waveform

C. Simulation of Non-Differential PWM AC Chopper:

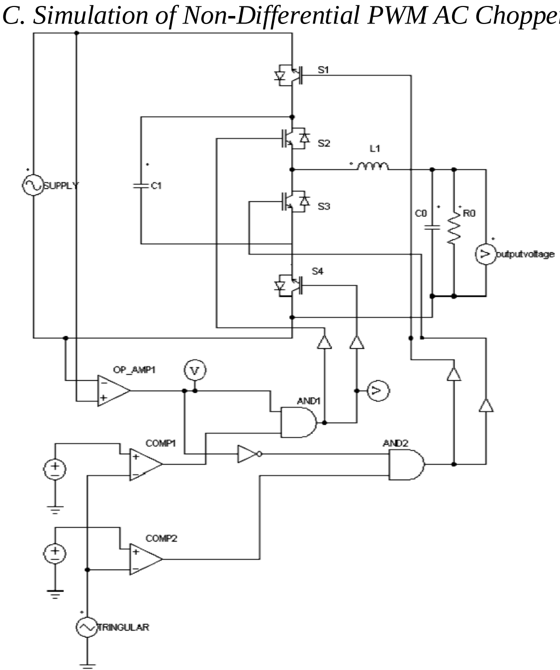


Figure 21 Simulation Diagram Of Non-Differential AC Chopper

D. PWM Gate Pulses For Power Circuit IGBT'S

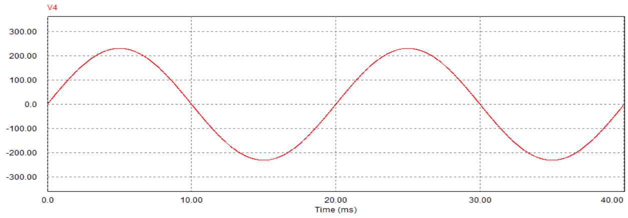


Figure 22 Power Supply

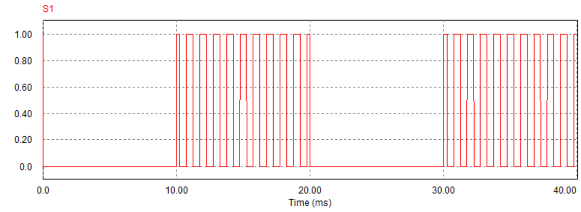


Figure 23 PWM Gate Pulses for Igbt'sFor S1 Switch

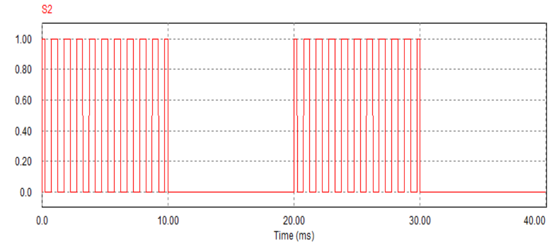


Figure 24 PWM Gate Pulses for Igbt'sforS2 Switch

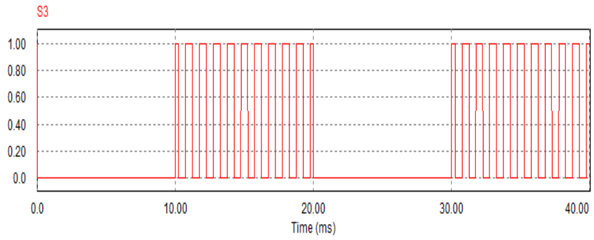


Figure 25 PWM Gate Pulses for Igbt'sFor S3 Switch

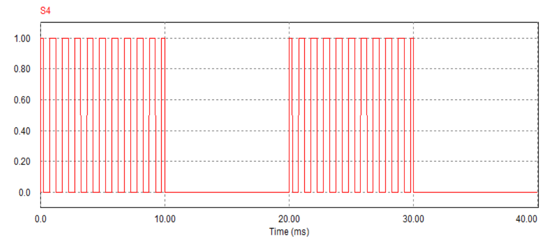


Figure 26 PWM Gate Pulses for Igbt'sFor S4 Switch

E. Output Voltage and Current Waveform of the PWM AC Chopper Non-Differential Topology:

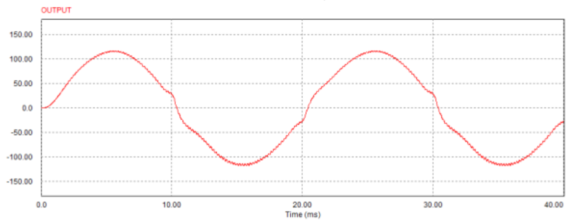


Figure 27 Output voltage waveform (115V) at 0.5 duty cycle

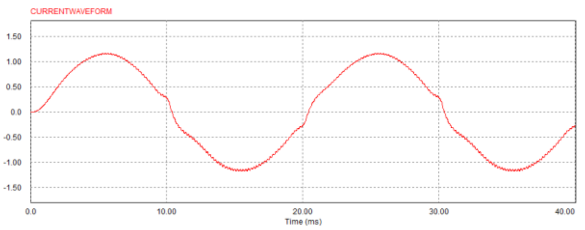


Figure 28 Output Current Waveform

The above figure showing the output voltage waveform of non-differential pwm ac chopper performed in PSIM software at 0.5 duty ratio when input voltage is 230 volts.

Output voltage =duty ratio *input voltage

Here,

Input voltage=230volts

Duty ratio =0.5

Then output voltage =115volts, shown in figure.

Table 2 Parameters used in Simulation

Parameters	**Value**
INPUT VOLTAGE SOURCE	230v
INPUT VOLTAGE FREQUENCY	50HZ
RESISTERS	10ohm
CAPACITERS	1MICROFERAD
SWITCHING FREQUENCY	5KHZ
FILTER	C=5e-6 L=4.404e-2
Duty cycle	0.5
LOAD	100ohm

Table 3 Simulation Results

Parameters	**Value**
OUTPUT VOLTAGE	115v
OUTPUT FREQUENCY	50HZ

VIII. SIMULATION OF THREE PHASE PWM AC CHOPPER IN PSIM

Below figure showing the circuit of three phase pwm ac chopper .Three phase pwm ac chopper consist six IGBT switches with body diode and capacitor across two switches in each leg. The gating pulses are generating by comparing of three sinusoidal sources to triangular source, each sinusoidal source are maintaining 120 degree phase shift and the amplitude is according to our duty ratio.

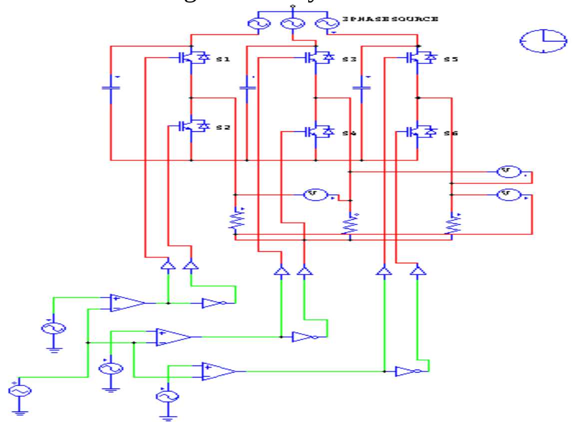
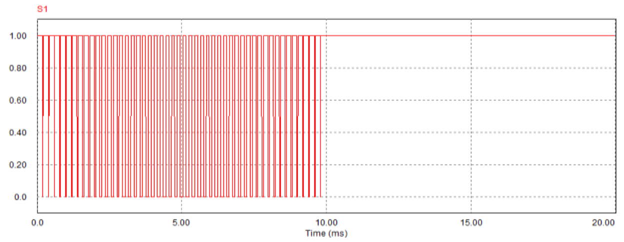
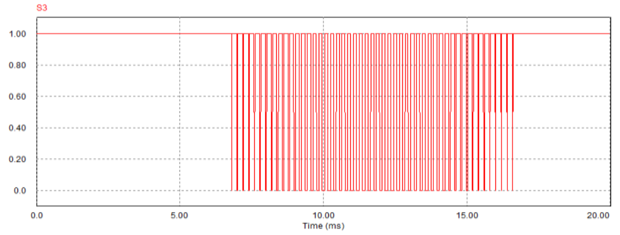


Figure 29 simulation diagram of Three-phase pwm ac chopper

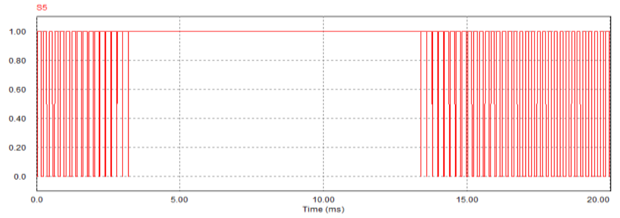
A. GATE PULSES OF ALL SIX IGBT'S:



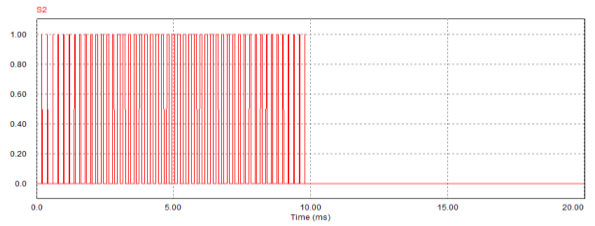
[A]



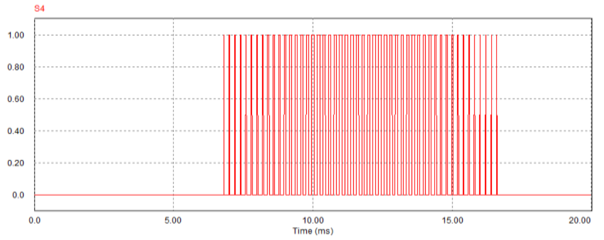
[B]



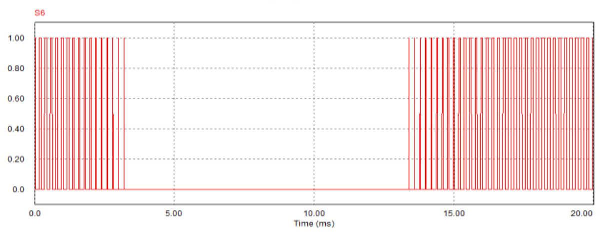
[C]



[D]



[E]



[F]

Figure 30 (a) FOR IGBT 1 SWITCH (b) FOR IGBT 3 SWITCH (c) FOR IGBT SWITCH (d) FOR IGBT 2 SWITCH (e) FOR IGBT 6 SWITCH (f) FOR IGBT 4 SWITCH

B. OUTPUT WAVEFORM OF THREE PHASE PWM AC CHOPPER:

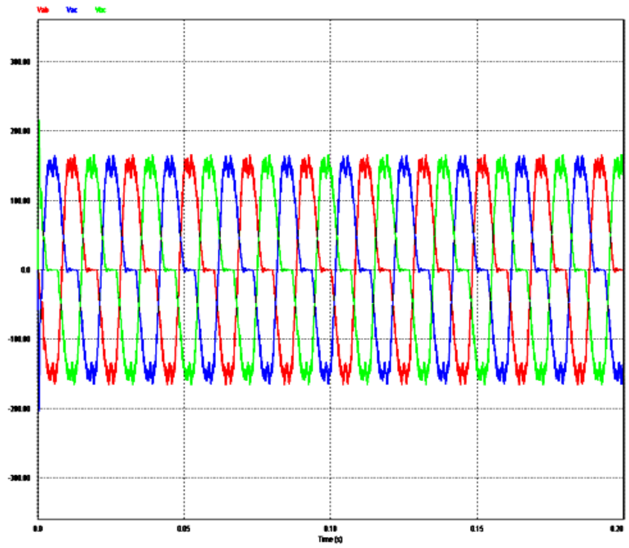


Figure 31 OUTPUT WAVEFORM OF PWM AC CHOPPER

IX. CONCLUSION

In this report, novel PWM ac choppers solving the commutation problem are proposed for single-phase and three-phase systems..Since only 'one switch is modulated and one switch is always turned on during the most half period of the supply voltage, the switching loss is significantly reduced and consequently high efficiency can be approached. Using the polarity of the input voltage and the load current, the switching patterns are decided to make the current path possible whatever the load current and the operation modes are divided into active and freewheeling modes. Advantages of the PWM AC choppers include increased input power factor, fast dynamic, high efficiency, high reliability, high power capacity and it is more economic owing to simple design requirements, less number of switches and low cost. Digital simulation has shown that the proposed circuit gives a good performance. The power circuits of the single-phase and three-phaseac choppers use only two and three standard switch modules. Because proper switching operation for solving the commutation problem is achieved and a high frequency PWM technique is used to control the output voltage, the system is reliable and has provide the pure sinusoidal waveform at output side.

REFERENCES

[1] Dan Floricău, Mariana Dumitrescu, IoanPopa, Sergiu Ivanov, “Basic topologies of direct PWM ac choppers,” Annals of the University of Craiova, Electrical Engineering series no.30,2006

[2] Jong-Hyun Kim, Jang-HyounYoum and Bong-Hwan Kwon, “PWM buck-boost ac choppers for safe commutation,” INT. J. ELECTRONICS, 1999, VOL. 86, NO. 7, 891± 906

[3] Nabil A. Ahmed , Kenji Amei, Masaaki Sakui, “A New Configuration Of Single-Phase Symmetrical PWM AC Chopper Voltage Controller,” Electrical and Electronic Department, Faculty of Engineering, Toyama Uni6ersity, 3190 Gofuku, Toyama 930 - 8555, Japan Received November 1998; accepted 22 March 1999

[4] F.Z.Peng, L.Chen, F.Ahang, “Simple Topologies of PWM AC-AC Converters,” IEEE Trans.Power Electronics Letters,Vol.1,No.1 In March 2003, pp.10-13.

[5] D. H. Jang, J. S. Won, and G. H. Choe, “Asymmetrical PWM method of ac chopper with improved input power factor,” in Proc. IEEE PESC’91, 1991, pp. 838–845.

[6] D. H. Jang, G. H. Choe, “Improvement of Input Power Factor in AC Choppers Using Asymmetrical PWM Technique,” IEEE Trans. On Industrial Electronics. Vol. 42. No. 2, April 1995.

[7] Zbigniew Fedyzac, Ryszard Strzelecki, Grzegorz Benysek, “Single-phase PWM AC/AC Semiconductor Transformer Topologies,” and Applications University Of ZielonaGora, Instute Of Electrical Engineering UI, Podgoma 50,65-246 Zielona Gora, Poland

[8] N. A. Ahmed, K. Amei, and M. Sakui, “Improved circuit of AC choppers for single-phase systems,” in Proc. Energy Conversion Conf. (PCC’97), Nagaoka, Japan, Aug. 3–6, 1997, pp. 907–9012.

[9] N.Burany, “Safe Control of four-Quadrant Switches”, Conf. Record IEEE- IAS Annu. meeting, Vol.1, 1989, pp.1190-1194.

[10] D.Vincenti, J.Hua, P.Ziogas, “Design and implementation of a 25-kVA three-phase PWM ac-ac line conditioner,” IEEE Trans.PowerElectron., vol.9, July 1994, pp.384-389

[11] J.-H.Youm, B.-H. Kwon, “Switching Technique for Current-Controlled AC-to-AC converters,” IEEE Transaction on Industrial Electronics, Vol.46, No.2, pp.309-317, April 1999, pp.85-91.

[12] Sam Ben-Yaakov, YakirHadad, And Noam Diamantstein, “A Four Quadrants HF AC Chopper With No Deadtime,”power electronics laboratory, department of electrical and computer engineering Ben-Gurion university of the negav,P.O.box 653,beer-sheva 84105,ISRAEL.

