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Comparison of Conventional Converter with Three-Phase Single-Stage Ac-Dc PWM Buck-Type Full-Bridge Converter

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Abstract
The main objective of this concept is to examine the operation of fundamental buck-based three-phase single-stage ac–dc full-bridge converters. In this concept, the operation of this fundamental converter is explained and analyzed, and a procedure for the design of its key components is derived and demonstrated with an example and general concluding remarks comparing Buck-Based and Boost Based three Phase single-stage AC to DC full Bridge converters are made.

I. INTRODUCTION

The use of rectifiers in industrial applications started at the era of mercury converters with the electromechanical contact converter. DC machines are common in day to day use. But the supply that we get from power companies is AC. To use those machines AC supply has to be turned into DC supply by the use of a rectifier.
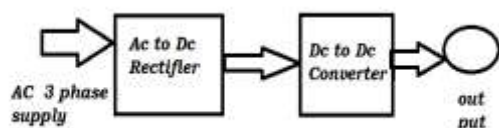

Fig (1) Block Diagram

A further application of the rectifier is driving a DC motor. Speed control in DC motor is an important issue. With time the need of flexible speed control for motor is becoming essential. One way to control the speed of the motor is by varying its input voltage. Thus this project aims on designing a rectifier circuit that can supply a voltage as required and can be adjusted if necessary even after the operation starts.

Three-Phase ac–dc converters usually have two separate and independently controlled switch-mode power converters—a six-switch ac–dc rectifier that performs input power factor correction (PFC) in series with a four-switch transformer-isolated dc–dc full-bridge converter. It is possible to replace the three-phase six-switch front-end ac–dc rectifier with a rectifier that uses only a single active switch to reduce cost and complexity. AC–DC converters with simplified front-end converters, however, still require two separate switch mode converters. As a result, converters that integrate the functions of PFC and isolated dc–dc conversion in a single power converter have been proposed to further reduce cost and complexity.

Most previously proposed three-phase single-stage converters have a boost converter input section. These converters suffer from high input ripple as their input currents are discontinuous with high current peaks, high output ripple due to a lack of an output inductor, and a large low-frequency 360-Hz component at the output due to a lack of a bulk capacitor at the primary-side dc bus.

Although work has been done on boost-based three-phase ac–dc single-stage full-bridge converters. little, if any, work has been done on buck-based three-phase ac–dc single-stage full-bridge converters. As a result, the potential of this type of converter is uncertain as its properties and characteristics are unknown. The source feeds the input of the power converter, which converts the input power to the required form for a load. The load may be DC or AC, single–phase or three–phase, and may or may not need transformer isolation from the power source. The power converter, therefore, can be an AC/DC converter, a DC/DC converter, a DC/AC inverter or an AC/AC converter depending on the application.

II. THREE PHASE SINGLE-STAGE AC-DC PWM BUCK TYPE FULL BRIDGE CONVERTER

Power electronic converters use active semiconductors (e.g. IGBTs) and passive power semiconductors (e.g. diodes) and passive elements (e.g. inductors and capacitors) arranged in circuit structures to convert power from the form available from a source to that required by a load[1]. The power source may be a DC source, a single–phase AC source, or a three-phase AC source with line frequency of 50, 60 or 400 Hz. It may also be an electric battery, a solar panel, an electric

generator or a commercial power supply. The source feeds the input of the power converter, which converts the input power to the required form for a load. The load may be DC or AC, single–phase or three–phase, and may or may not need transformer isolation from the power source. The power converter, therefore, can be an AC/DC converter, a DC/DC converter, a DC/AC inverter or an AC/AC converter depending on the application.

The fundamental buck-based converter that is examined in this paper is shown in Fig. (3), and Fig. (4) shows the reference directions for the most significant converter voltages and currents.
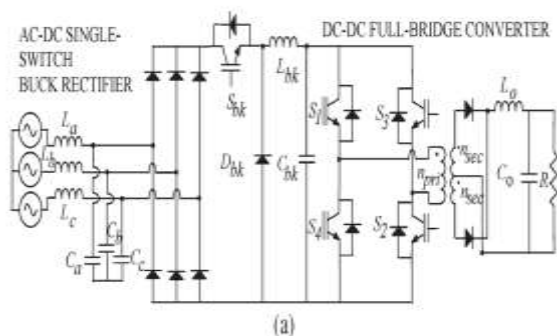

Fig.(2) AC–DC single-switch buck rectifier and dc–dc full-bridge converter.

It has three sections: an input section that consists of a three-phase diode bridge rectifier with a three-phase *LC* filter; a dc-bus section that consists of an inductor, a capacitor, and two diodes; and a full-bridge converter section.

The following should be noted about the general operation of the converter.

1) The full-bridge converter's alternating between freewheeling modes (*S*1 and *S*3 or *S*2 and *S*4) and energy transfer modes (*S*1 and *S*2 or *S*3 and *S*4) is analogous to the turning off and on of the front-end buck switch (*Sbk*) in Fig. (1). The input capacitors charge during the freewheeling modes of the full-bridge section when two top switches or two bottom switches are on and discharge during energy-transfer modes of operation when a diagonally opposed pair of switches are on and energy can be transferred from the input to the output. The PFC occurs naturally, without the need for any input section sensing as long as the input capacitor voltages are discontinuous in all the switching cycles contained in an input line cycle.

2) Capacitor C_{bus} must be disconnected from the rest of the converter when the full bridge is in a freewheeling mode of operation because the input capacitors would not be allowed to charge properly otherwise. The improper charging of these capacitors would result in their voltages not being bounded by a sinusoidal envelope, which would ultimately lead to distortion in the input currents and a lower input power factor.

3) The fact that C_{bus} is disconnected from the converter by the reverse blocking of diode Dbus2when the converter is in a freewheeling mode does not affect the operation of the full bridge as it operates like a pulse width modulated (PWM) full-bridge converter in freewheeling mode, nor does this fact affect the operation of the full bridge when it is in an energy-transfer mode as C_{bus} is connected to the dc bus during such a mode because$D_{bus2}$is forward biased. In other words, the full bridge can therefore operate exactly like a PWM dc–dc full-bridge converter, with whatever control technique is desired (phase-shift PWM, variable switching frequency, etc.).
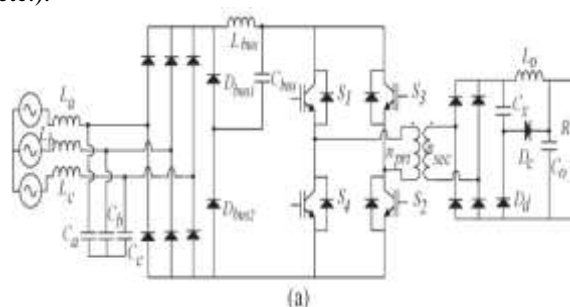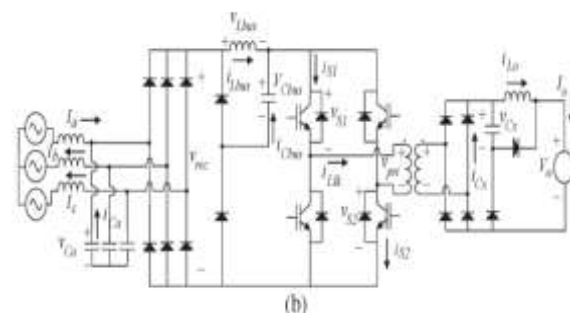

Fig. (3) Buck-type full-bridge converter under study

Fig. (4) . Reference directions for currents and voltages

4) Since $C_{bus}$is disconnected from the new converter whenever a freewheeling mode occurs, it is therefore not in the circuit when the full bridge is exiting a freewheeling mode. As a result, there is no path for any reverse current from the full bridge to flow in the dc bus, and some steps must be taken to address this problem.

5) Although it has been shown in and that the use of variable switching frequency control can improve the input power factor of three-phase buck-based singles witch front-end converters and two-switch single-stage forward converters and that the use of resonant methods in these converters can significantly improve their efficiency,

6) the use of variable switching frequency control and resonant soft-switching methods are not considered in this paper. The reason for this is that they obscure the general properties and

characteristics of buck-based converters so that insight into their true nature is still minimal as all previously proposed three-phase single stage converters have been boost based.

7) The main objective of this paper is to examine the properties and characteristics (both positive and negative) of a simplified or fundamental buck-based three-phase single-stage converter and then make conclusions that can be extended to buck-based three-phase single-stage converters in general.

8) The operation of the fundamental buck-based converter has been therefore simplified considerably by using constant frequency operation and dissipative snubbers (to absorb any reverse current from the full bridge) as a means to simplify the analysis of the converter and to discover the characteristics of the new fundamental buck-based converter. Doing so, however, results in the converter performance being less than optimal (particularly the efficiency), as will be discussed.

9) The converter operation is, however, considered with some zero-voltage–zero-current switching (ZVZCS) method. It is a means to improve the converter efficiency without interfering with the basic operation of the converter .
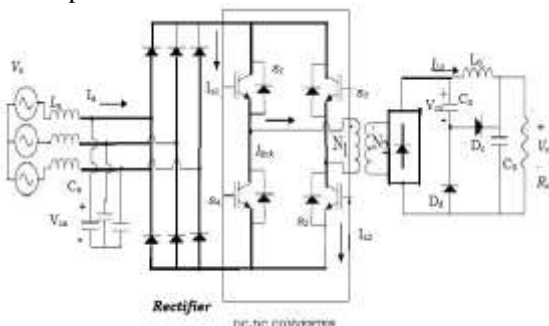
Fig(5) Modified converter

III.   ANALYSIS OF MODIFIED CONVERTER

An analysis of the steady–state characteristics of Modified Converter is needed to determine it operates for any given set of specifications (line–to–line input voltage: *Vll(rms)*, output voltage: *Vo*, output current: *Io*, and switching frequency: *fs*) and for a selected set of parameters (input capacitors: *Ca*, duty ratio of the full–bridge: *D*, transformer turns ratio: *n = npri/nsec*, leakage inductance: *Llk*, auxiliary capacitor: *Cx* and the output inductor: *Lo*). Important converter characteristic graphs can be plotted as a result of the analysis and then used to develop a design procedure, which will be done in the next section of this chapter.

The analysis of Modified Converter presented . In both cases, steady–state operating points for various combinations of parameter values and component values can be determined by checking the net average voltage across an inductor of each

converter. For example, in the case of the converter shown in Fig. 2, the status of the converter is checked by evaluating the average value of the *Lbus* voltage, over a period of 1/6th of a 60 Hz line cycle (an interval of 60º of the fundamental period is used due to symmetries). If the average voltage of L_{bus} is zero for this period, then the converter is in steady–state and a steady–state operating point has been determined. In order to calculate the average value, the instantaneous L_{bus} voltage (*vLbus,k*) waveform during any *k* full–bridge half switching cycle can be found by the difference between the three–phase diode bridge rectifier output voltage and the voltage across capacitor *Cbus* ($vLbus,k = v_{re}c,k − VCbus$). The modal equations help to find the variables v_{rec},k and $VC_{bu}s$. If the average voltage across L_{bus} is not zero, then steady–state operating points can be determined by varying the converter.

IV.   Design Procedure of Modified Converter

The main characteristics of the converter are the instantaneous input capacitor voltage *vCa*, peak switch voltage stress *Vs(pk)* and instantaneous transformer primary current *iLlk,k*. These characteristics depend on the selection of the duty ratio *D*, turns ratio *n*, input capacitor *Ca*, leakage inductor *Llk* and auxiliary capacitor *Cx*. .

The procedure is demonstrated below with an example. The converter is designed for the following specifications: Line–to–line input voltage = 220 V, output voltage = 48 V, maximum output current = 40 A, switching frequency = 25 kHz. The procedure is iterative given the interdependency of the key parameters. Only the final iteration is presented in the design example.

a. Selection of Turns Ratio *n*

Two factors must be considered when picking a value for n. The first factor is the ability of the converter to regulate the output DC voltage as specified (*Vo* = 48 V). This is not possible if *n = npri/nsec* is too high. The second factor is the reflected load current to the transformer primary side, which should be low. If n is too small, then *iLlk* may not be sufficiently extinguished before *S2* or *S3* is turned off (when the converter exits a freewheeling mode) and a longer freewheeling time is needed to apply the counter voltage across *Llk*. This is not desirable since if too much freewheeling time is needed, *D* of the converter must be decreased and the converter will not be able to produce the desired *Vo*.

b.   Determination of Duty Ratio *D* and Input Capacitors *Ca = Cb= Cc*

If *D* is too small, then the power transfer mode is shortened and the converter's operation is affected in two ways. First, the converter may not be able to

provide therequired *Vo*. Second, there may be insufficient time for the input capacitors to fully discharge, which would result in their voltages not being fully discontinuous so that low frequency harmonics will appear in the input currents. This problem may be avoided if *Ca* = *Cb* = *Cc* is chosen to be very small, which would ensure that the input capacitors do fully discharge. Doing so, however, would also result in excessively high values of *VCa(pk)* and therefore peak switch voltage *Vs(pk)*, as *Vs(pk)* = √3*VCa(pk)*.

If *D* is too large, then the time allocated for the input capacitors to charge up will be inadequate and therefore partial charging will result. As a result, the input capacitors will not store sufficient energy to transfer to load during the power transfer modes, which ultimately affect the converter's voltage regulation.

A value of *n* = 2.5 was selected in the previous step. As *D* should not be too small or too large, a value of *D* = 0.5 is considered.   .

Whether the required correct *Vo* can be achieved by this operating point must be confirmed; if *Vo* < 48, then *D* must be increased and *Ca* should be selected accordingly. In this the selected *Ca* charges to a peak voltage of 400 V; since *Vs(pk)* = √3*VCa(pk)*, therefore *Vs(pk)* = 693 V. With the values of *n* = 2.5, *D* = 0.5 and *Ca* = 220 nF that are chosen above the diode rectifier output voltage can be determined to have an average value of approximately *Vrec(avg)* = 250 V from *vrec,k* determined from the analysis, which is a triangular pulse train, then determine its average value. If the current of *Lo* is continuous *Vo*. which is sufficiently close to the required *Vo* = 48 V, so that values of *n*, *D* and *Ca* can be set. The converter's operation with these values and its ability to satisfy the regulatory standards must be confirmed with a "check" stated at the end of the design procedure.

c. Determination of Leakage Inductance *L*$_{lk}$ and Auxiliary Capacitor *Cx*

The values of *L*$_{lk}$ and *Cx* are critical parameters that affect the auxiliary circuit's ability to reduce transformer primary current. In addition to its impact on the auxiliary circuit, *L*$_{lk}$ also affects the *vCa,k* waveform because there is a direct resonant interaction between *L*$_{lk}$ and *Ca* when *Ca* discharges. The smaller *L*$_{lk}$ is, the quicker *Ca* discharges as the resonant cycle is reduced; however, *iL*$_{lk}$,k also decreases faster due to the counter voltage that is placed on *L*$_{lk}$ by *Cx*. If *iL*$_{lk}$,k drops to a level that is less than the current coming out of the diode bridge rectifier (*ibus,k*) and switch *S1* (or *S4*) has not been turned off by the end of Mode 3, then *Ca* will begin to charge prematurely by part of *Ia,k* before it has been fully discharged. If *Ca* is not fully discharged, then low frequency harmonics may be introduced

into *Ia,k*. *L*$_{lk}$ should not be too large, however, as this will slow down the rate of decrease of *iL*$_{lk}$,k too much when the converter is in a freewheeling mode of operation. Since *iL*$_{lk}$,k must ideally be dropped to zero before the converter exits this mode and enters a power transfer mode, this means that the amount of time allowed for a freewheeling mode to occur must be increased so that the current can be extinguished. Doing so, however, limits *D*, and then the converter will not be able to provide the required *Vo*. *C*$_x$ is a critical parameter because it sets the counter voltage that is available to extinguish *iL*$_{lk}$,k and it helps determine the minimum duration of the freewheeling modes of operation. If *C*$_x$ is too small, it will not have enough energy in it to discharge *L*$_{lk}$ during the freewheeling mode, thus *iL*$_{lk}$,k will not be properly extinguished. However, if *C*$_x$ is selected to be too large, unnecessary conduction will reduce the overall efficiency.
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d. Determination of Input Inductors *La* = *Lb* = *Lc*

Determination of the input inductors for Modified Converter is same as it was for reference Converter

V.   Features of Single-Stage Full-Bridge Type Converters Reference Converter

1. Peak Switch Current Stress

The switches in Modified Converter can be directly exposed to the sum of the current coming from the input inductors and the discharging current of the input capacitors. The switches in Reference Converter are only exposed to the current coming out of the DC bus capacitor. Since the current that comes out of the diode bridge rectifier has peaks that the current that comes of the DC bus capacitor of Reference Converter does not, the peak switch current stress of the switches in Modified Converter is greater than that of the switches in Reference Converter. From the experimental prototypes, it was found that the peak switch current stress for Reference Converter was approximately 30 A while that for Modified Converter was approximately 40 A.

2. Output Ripple

Reference Converter has a bulk capacitor across its DC bus that Modified Converter does not have. Even though this capacitor is disengaged from the bus whenever the converter enters a freewheeling mode, nonetheless, it helps to filter out the low 360 Hz component that is contained in the front–end bridge rectifier output voltage. As a result, this component is not present in the output of the converter as it is for Modified Converter This 360 Hz ripple can be removed from Modified Converter if bulkier filtering is used at its output.

3. Hold–Up Time

The presence of a bulk capacitor in Reference Converter means that the Reference Converter as hold–up time capability if needed. Hold–up time is defined as the amount of time that a converter can provide the required output after the input AC voltage has been lost and may be needed if the converter is operating in a power system without battery back–up. In the case of Reference Converter , energy stored from *Cbus* can help maintain the required output voltage in the case of a loss of input AC voltage, whereas Modified Converter cannot do so because it does not have a bulk capacitor.

VI.   Modified Converter

1. Peak Switch Voltage Stress

The switches in Modified Converter can have lower peak switch voltage stress than those of Refernce Converter . This is because the peak switch voltage stress of Reference Converter #1 is the sum of the output voltage of the front–end diode bridge rectifier and the voltage across the DC bus capacitor *Cbus* while the peak switch voltage stress of Modified Converter is equal to just that of the diode bridge rectifier output voltage. From the experimental prototypes, it was found that the peak switch voltage stress for Modified Converter was approximately 700 V while that for Refernce Converter was approximately 1000 V.

2. Input Power Factor

The ability of both converters to provide sinusoidal input currents with minimal distortion is dependent on the ability of their input capacitors to operate with fully discontinuous voltages through the input line cycle. The smaller the input capacitor value is, the quicker these capacitors can discharge, increasing the likelihood of fully discontinuous voltage operation. Decreasing the input capacitor value, however, increases the peak voltage across a capacitor, which in turn, increases the peak voltage stress of the converter's switches. There is, therefore, a compromise that must be made between input power factor and peak switch voltage stress.

In the case of Modified Converter it is easier to make this compromise as it has, inherently, less switch peak voltage stress than Reference Converter so that Modified Converter can be made to operate with a better input power factor than Reference Converter.

3. Efficiency

Modified Converter has a direct path of power transfer from the output of the front–end bridge rectifier to the input of the full–bridge. In Reference Converter, energy must be transferred from the converter's input section to its DC bus section before it is transferred to its full–bridge section. Moreover,

Reference Converter has current that freewheels in the DC bus that Modified Converter does not when the converters are in a freewheeling mode of operation. it was found that Modified Converter had a maximum efficiency of 83% that Reference Converter had a maximum efficiency of 80% and that Modified Converter was approximately 2.5% − 3% more efficient throughout the load range.

VII.   Simulation Results

The fig (6) shows the simulation circuit of comparison of conventional converter with three phase single-stage ac-dc pwm buck-type full-bridge converter, Fig(7) shows the input current and voltage of the supplyof converter, Fig(8) shows the voltage across the input capacitor voltage ,fig (9) shows the thee phase rectifier voltage buck converter, fig(10) shows the output voltage across the load ofbuck type full bridge converter
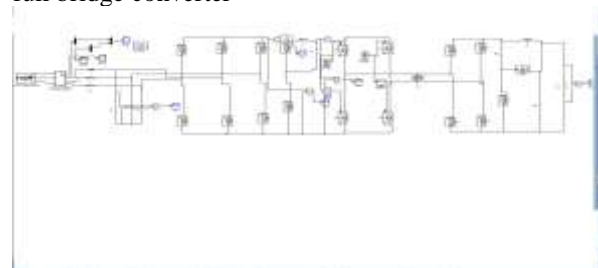
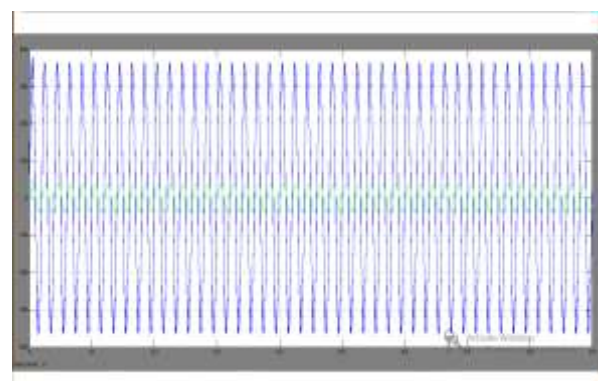**Fig(6) Simlinke circuit of Modified buck type converter**

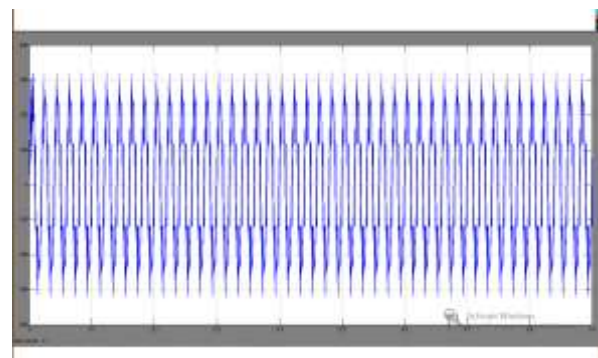**Fig (7) supply voltage and current of the converter**

Fig (8) voltage across the input capacitor of the converter
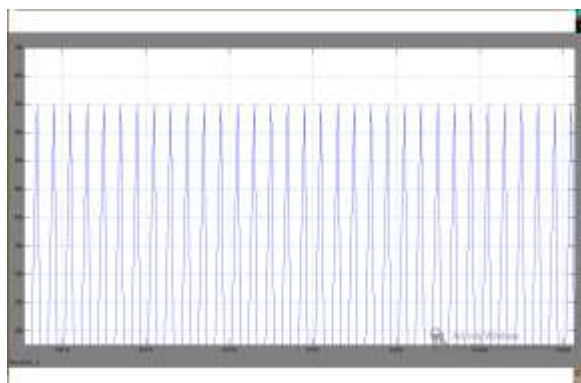
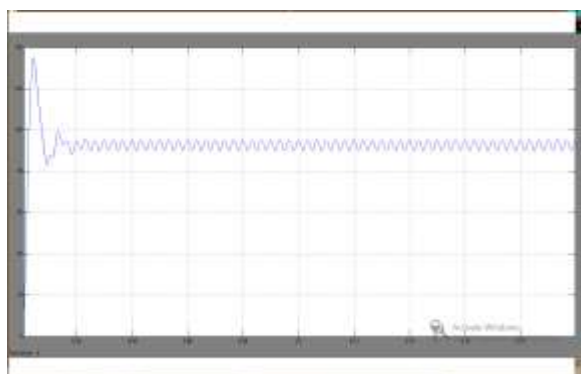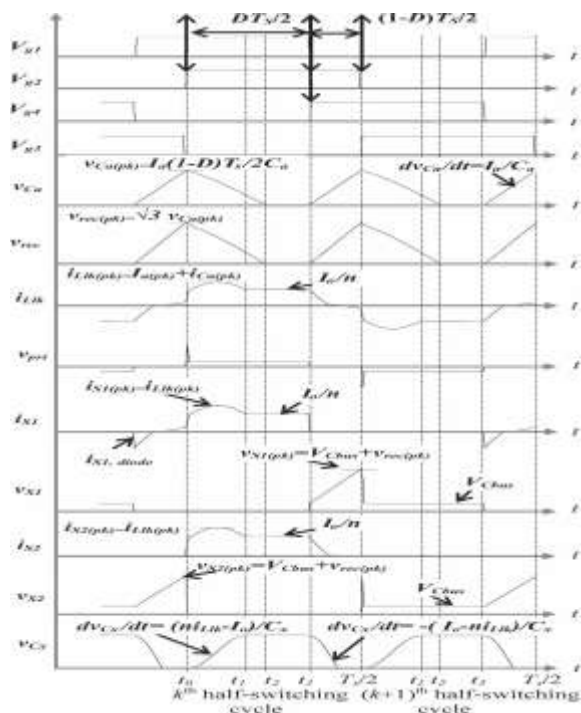**Fig (9) voltage across the rectifier(Vrect)**

Fig (10) output voltage across the load

Fig(11).Waveforms of full bridge buck type converter

VIII.   CONCLUSION

The three-phase single-stage converters have a boost converter input section. These converters suffer from high input ripple as their input currents are discontinuous with high current peaks, high output ripple due to a lack of an output inductor, and a large low-frequency 360-Hz component at the output due to a lack of a bulk capacitor at the primary-side dc bus.

Converters that are based on buck converters do not have these drawbacks as they have inductive–capacitive filtering in their input and output sections and can be implemented with a bulk capacitor at their dc bus. The properties and characteristics of these converters, however, are unknown, and their potential has thus not been developed. The main objective of this project has been therefore to examine a buck-based three-phase single stage converter in its simplest form—with fixed frequency PWM operation and with no soft-switching circuitry—to gain insight into the nature of buck-based converters.

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