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# Single Phase Step-UP AC Voltage Regulators with High Frequency Link

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**Abstract:** ***In this paper a step-up ac voltage regulators with high-frequency link are proposed. It consists of input LC filter, energy-storage inductor, input cycloconverter, high-frequency transformer, output cycloconverter and output filtering capacitor. In the proposed topology the regulators can convert an unstable sinusoidal voltage with high with high to a stable sinusoidal voltage with the same frequency and low distortion. The results of proposed regulators have advantages of high-frequency galvanic isolation, bidirectional power flow, high efficiency, and high reliability.***

**Keywords:** AC voltage regulators, cycloconverter, high frequency link (HFL), phase-shifting control strategy, step-up

## 1. Introduction

In this paper, circuit configuration of single phase step-up ac voltage regulators with HFL(high frequency link) is proposed. The proposed ac regulators are targeted at a new type of regulated sinusoidal ac power supplies, and electronic transformers in which isolation and/or bidirectional power flow are needed. Studies on step-up converter were limited to dc– dc and ac–dc converters. Studies on ac–ac converters were mainly limited to nonisolated ac–ac converters and ac–dc–ac converters. The nonisolated ac–ac converters, such as thedirect matrix converter [4], the pulse-width modulation (PWM) ac chopper [5], and the soft switched ac-link buck–boost ac–ac converter [6] have the features of single or two stages power conversion, low-voltage transmission ratio no need of intermediate dc energy-storage component, etc. The ac–dc–ac converters, such as the indirect matrix converter [7], the ac–dc–ac converter with low-frequency link [8], and the ac–dc–ac converter with high-frequency link (HFL), have the features of two or three stages power conversion, low or high voltage transmission ratio, high line power factor (LPF), and intermediate dc energy-storage component, etc. A step-up/step-down ac voltage regulator with HFL was proposed and investigated in [9]. In [9], the kind of ac voltage regulator has the features of simple circuit, discontinuous current mode (DCM), and is suitable for low capability field.
The project comprises of AC voltage regulators have a constant voltage ac supply input and incorporate semiconductor switches which vary the rms voltage impressed across the ac load. These regulators fall into the category of naturally commutating converters since their thyristor switches are commutated by the alternating supply. This converter turn-off process is termed line commutation. The regulator output current, hence supply current, may be discontinuous or non sinusoidal and as a consequence input power factor correction and harmonic reduction are usually necessary, particularly at low output voltage levels. A feature of direction conversion of ac to ac is the absence of any intermediate energy stage, such as a dc link. Therefore ac to ac converters are potentially more efficient but usually involve a larger number of switching devices.

Transformer with low cost and easy availability of ferrite core material has helped in the implementation of high-frequency link power transformation. The electronic transformer utilizes power electronic converters, along with a high-frequency transformer to obtain overall size and cost advantages over a conventional transformer. High frequency link transformers are used to provide contactless power transfer and galvanic isolation between the source and the load. The main requirement of the high frequency transformer is to match the voltage levels of the source and the load. Also, it provides the isolation between the input and the output. High frequency ac link transformer also reduces the size reduces the weight of the transformers.

Single phase to single phase cycloconverters are consists of back-to-back connection of two full-wave rectifier circuits. Cycloconverter consists of back-to-backconnection of two full-wave rectifier circuits. Due to many advantages cycloconverters are used in many industrial applications like cement mill drives, ship propulsion drives, rolling mill drives, scherbius drives, □ore grinding mills, and mine winders

## 2. Proposed AC–AC Converter

The proposed topology is a s shown in Fig(2.1) as the figure suggests , the topology contains input *LC* filter, energy-storage inductor, input cycloconverter, high-frequency (HF) transformer, output cycloconverter and output filtering capacitor Cf.

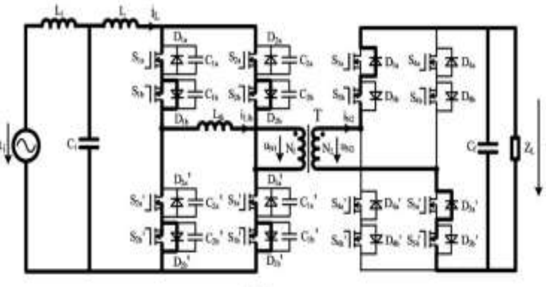


**Figure 2:** Circuit of full bridge-full bridge mode converter

The ac voltage regulators in my work can convert one kind of sinusoidal voltage with unstable magnitude and high total harmonic distortion (THD) to another kind of sinusoidal voltage with the same frequency, stable magnitude and low distortion.

When energy is transferred from source to load, the low frequency (LF) sinusoidal inductance current $i_L$ with HF ripple is modulated into bipolarity three-state HF pulse current $i_1$ by the input cycloconverter. After galvanic isolation and current matching of the HF transformer, $i_1$ is demodulated into unipolarity three-state LF pulse current by the output cycloconverter, then filtered into high-quality sinusoidal voltage $u_o$. High LPF are obtained by inductor $L$ and filter at input side.

## 3. Control Principle

Taking full bridge-full bridge mode circuit topology as an example, shown in Fig. 2a. The instantaneous voltage feedback strategy with phase-shifted control is introduced in the proposed regulator. When the input voltage or the load varies, the output voltage will keep stable by adjusting the duty cycle $D$.

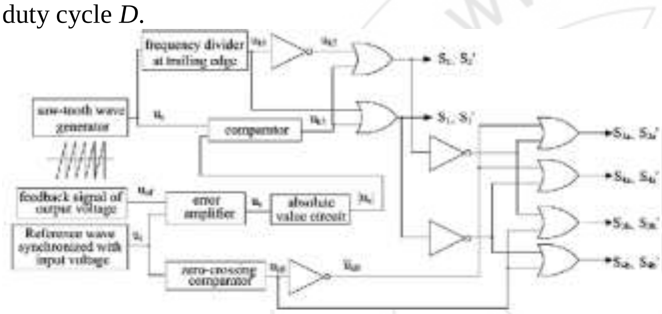



**Figure 3:** Control block diagram instantaneous voltage feedback strategy with phase-shifted control of the proposed regulator

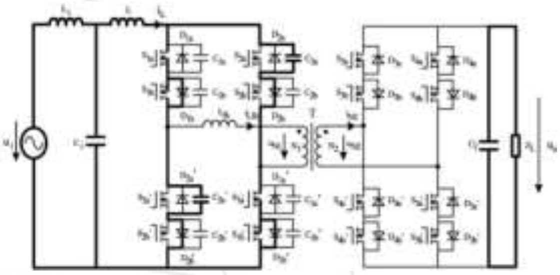
In Fig. 3, the error voltage signal $u_e$ is obtained from the voltage amplifier by comparing the feedback signal $u_{of}$ of output voltage with the reference signal $u_r$ synchronized with input voltage $u_i$ . The PWM signal $u_{k3}$ is generated by comparing the absolute value of $u_e$ with the saw-tooth wave $u_c$. The signal $u_{k0}$ is obtained by comparing $u_r$ with zero. The signal $u_{k1}$ is obtained from $u_c$ by frequency divider circuit at trailing edge. The signal $u_{k2}$ is the logical negation of $u_{k1}$ . $T_s$ is HF switching period, and $T_{on}$ is the conduction time of $S_1$ ($S\__1$) in $T_s$ . There is 180◦ difference between the two driving signals of $S_1$ ($S\__1$), $S_2$ ($S\__2$) in the input cycloconverter. The duty cycle of $S_1$ ($S\__1$) and $S_2$ ($S\__2$) are both greater than 0.5. The common conduction time $T_{com}$ in $T_s$ /2 is $T_{com}$ = ($T_s$ /2)$\theta$/180◦. Thus, the duty cycle of the converters is $D = T_{com}/(T_s/2) = \theta/180$◦ (1) where $\theta$(0<$\theta$<180◦) is the corresponding angle of the common conduction time $T_{com}$ of every pair of power switches.

## 4. Operating States

There are 14 operating modes in one switching period. Taking into consideration half switching period, operation of the converter can be explained using 7 modes and the equivalent circuit for both the modes are shown in figure 3.1b(a-g). Another seven operating stages ($t$ = $t$7–$t$14) are similar to the former ($t$ = $t$0–$t$7 ). The next switching cycle starts at $t$14. On the other three conditions, namely $uo$ > 0 and $iL$ < 0, $uo$ < 0 and $iL$ > 0, $uo$ < 0 and $iL$ < 0, the converter still have fourteen operating states in one switching period, similar to the situations of $uo$ > 0 and $iL$ > 0.

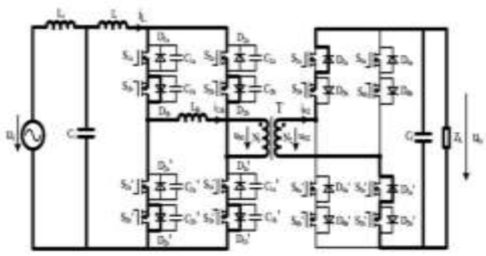
In the proposed work, ac voltage regulators can convert one kind of sinusoidal voltage with unstable magnitude and high total harmonic distortion (THD) to another kind of sinusoidal voltage with the same frequency, stable magnitude and low distortion. When energy is transferred from source to load, the low frequency (LF) sinusoidal inductance current $iL$ with HF ripple is modulated into bipolarity three-state HF pulse current $i1$ by the input cycloconverter. After galvanic isolation and current matching of the HF transformer, $i1$ is demodulated into uni polarity three-state LF pulse current by the output cycloconverter, then filtered into high-quality sinusoidal voltage $uo$. High LPF are obtained by inductor $L$ and filter at input side.

**State 1:**



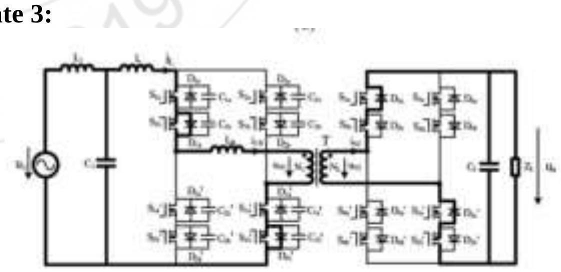
**(a)**

**State 2:**



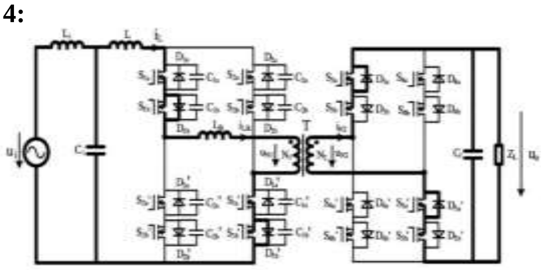
**(b)**

**State 3:**



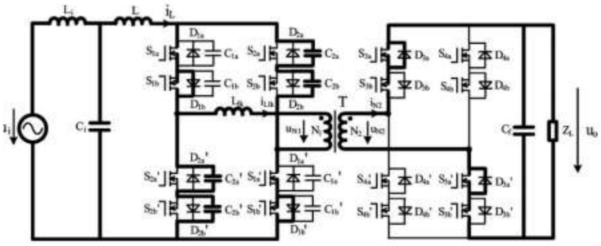
**(c)**

**State 4:**



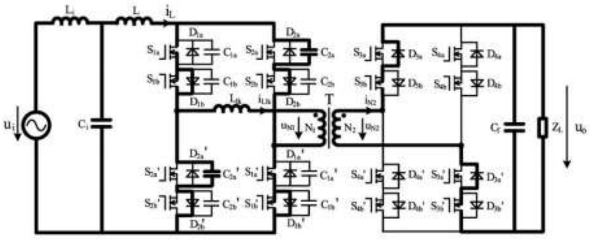
**(d)**

**State5:**



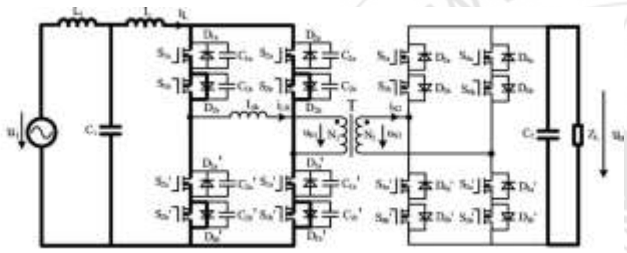
**(e)**

**Mode 6:**



**(f)**

**Mode 7:**



**(h)**

**Figure 3.2 (a-g):** Seven operating states in half-switching period. (a) $t0$ –$t1$ . (b) $t1$ –$t2$ . (c) $t2$ –$t3$. d) $t3$ –$t4$ . (e) $t4$ –$t5$ . (f) $t5$ –$t6$ . (g) $t6$ –$t7$ .

State 1: *At t* = $t0$–$t$ : Switches in the input cycloconverter are on state before $t0$ . The energy-storage inductor is magnetized by the input voltage $ui$ and the load $ZL$ is supplied by the output filtering capacitance $Cf$. At t0 , $S2a$ , $S2b$ , $S\_ 2 a$ , $S\_ 2 b$ are turned OFF with zero-voltage switching (ZVS). $C2a$ , $C\_ 2a$ are charged by $IL$ until the drain–source voltages of $S2a$ , $S\_ 2 a$ reach $UoN1 /N2$ at $t1$.

State 2: *At t* = $t1$- $t1$ , $D3a$ and $D\_ 3a$ turn ON and $Llk$ , $C2a$ , and $C\_ 2a$ begin to resonant; $iL$ lk , $uC$ 2$a$ , and $u\_ C2a$ are given by $iL1\ k = IL - IL \cos \omega1 (t - t1)$ (2) $uC\_ 2\ a = uC2\ a = UoN1/N2 + |z1 \mid IL \sin \omega1 (t - t1)$ (3) where, $\omega1 = 1\_ \sqrt{}2L1kC1$ , $|z2| = \_Llk /(2C1)$. At $t2$ , $iL1\ k = IL$ , $UC\_ 2\ a = UC2\ a = UoN1/N2 + |z1 \mid IL = U1$. After $t1$, ZVS of $S3a$, $S\_ 3\ a$ can be achieved.

State *3: At t* = $t2$–$t3$ : $Llk$ , $C2a$ , $C2b$ , $C\_ 2\ a$ , and $C\_ 2b$ begin to resonant at $t2$ . $iL$ lk , $uC$ 2$a$ , $u\_ C2a$ , $uC$ 2$b$ , and $u\_ C2b$ can be represented as $iL1\ k = IL + (|z1| / |z2|)IL \sin \omega2 (t - t2)$ (4) $uC2\ a = uC\_2\ a = [|z1 \mid IL \cos \omega2 (t - t2) - |z1 \mid IL ] /2 + U1$ (5) $uC2\ b = uC\_2\ b = [|z1 \mid IL \cos \omega2 (t - t2) - |z1 \mid IL ]/2$ (6) where, $\omega2 = 1\sqrt{LlkC1}$ , $|z2| = \_Llk/C1$

The $LC$ damped resonance will fade away at $t3$ for the existence of internal resistance in the circuit. The current of the leakage inductor is equal to $iL$ simultaneously.

State 4: At $t = t3$–$t4$ : $iL$ flows through $S1a$ , $S1b$ ($D1b$ ), $S\_ 1\ a$ , $S\_ 1b$ ($D\_ 1\ b$ ), and the current of second winding flows through $S3b$ , $S3a$ ($D3a$ ), $S\_ 3\ b$ , and $S\_3\ a$ ($D\_ 3\ a$ ). Energy is transferred from the energy-storageinductor to the load.

State 5: At $t = t4$–$t5$: $S3a$ and $S\_ 3\ a$ are turned off with ZVS at $t4$ . $iL$ flows through $S1a$ , $S1b$ ($D1b$ ), $S\_ 1\ a$ , $S\_ 1\ b$ ($D\_1b$ ), the current of the second winding flows through $S3b$ , $D3a$ , $S\_3\ b$ ,$D\_3a$ . Energy is transferred from the energy-storage inductor to the load

State 6: At $t = t5$–$t6$ : $S2a$ , $S2b$ , $S\_2\ a$ , and $S\_2\ b$ are turned ON with ZCS at $t5$ .The energy-storage inductor is magnetized by the input voltage.The current of the second winding flows through $S3b$ , $D3a$ , $S\_3b$ ,$D\_3a$ , and $iL$ lk and is expressed as$iLl\ k = IL - (UoN1/N2 )(t - t5 )/Llk$ (7)where $iL$ lk is decreasing linearly until $iL$ lk reaches zero at $t6$ .

State 7: At $t = t6$–$t7$: From $t6$ , the energy-storage inductor is magnetized by $ui$ and $ZL$ is supplied by $Cf$ .

## 5. Experimental Results

The converter is proposed in the laboratory in order to validate its principle operation and results are simulated in MATLAB 7.10.0 (2010)**.** The simulation model of the proposed system is shown in the fig (5.1). Fig 5.2 (a-d) represents its simulation result, in which input and output voltage values are same.

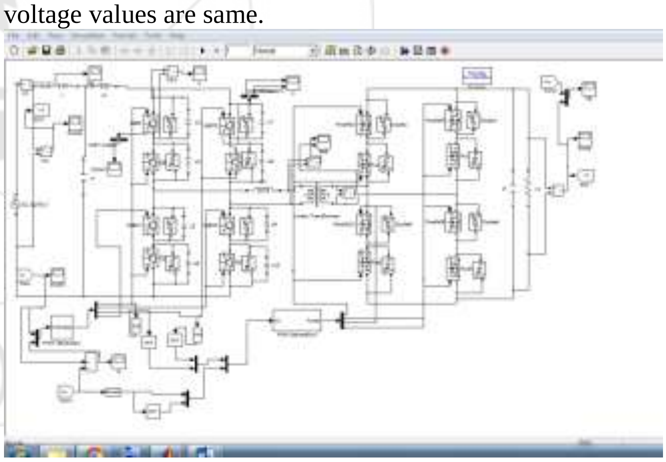
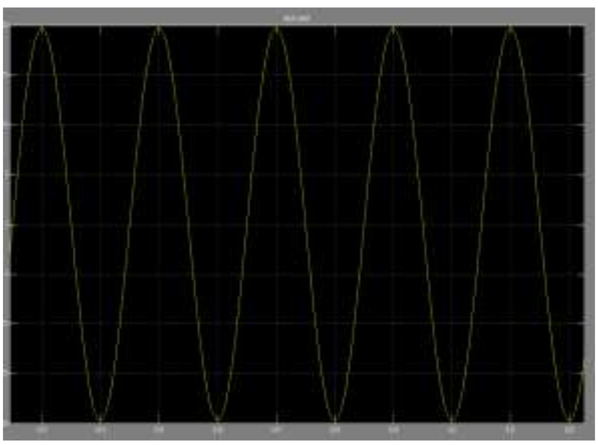
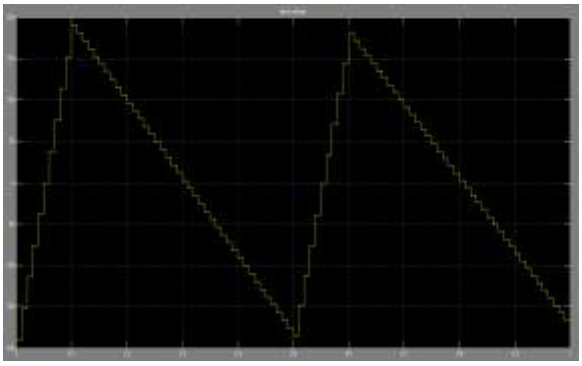


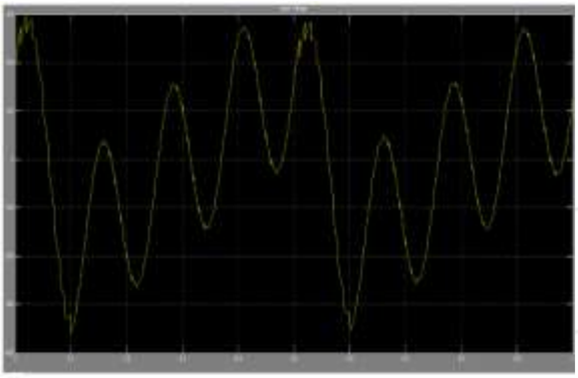
**Figure 5.1:** Simulation model of the converter



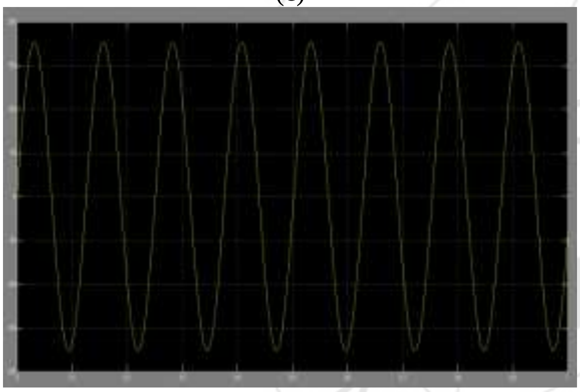
(a)



(b)



(c)



(d)

**Figure 5.2(a-d):** Simulaltion result. (a) Input voltage. (b) Sawtooth waveform (c) Distorted waveform. (d) Output voltage.

## 6. Conclusion

The project proposes a single phase ac voltage regulator topology with high frequency link transformer. The proposed ac voltage regulators with HFL can convert an unstable sinusoidal voltage to a stable sinusoidal voltage with the same frequency and low distortion. This circuit topological family contains seven circuits. Ac voltage regulators using single phase step up ac to ac voltage regulator using high frequency link provides advantages like low switching losses. The size and weight of the converter is reduced using high frequency link transformer.

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