Performance Analysis of Single Phase AC-AC Voltage Converter for Compensation of Voltage Issues in Power Distribution System

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***Abstract* - The power quality of the power distribution system is highly concerned with the use of renewable sources, solid-state electronic devices, and power electronic processors. This results in voltage fluctuations, voltage sag, and swell issues. The voltage source converter (dc-to-ac) can resolve these issues but there is a problem with high rating storage devices. The Dual converter (ac-to-dc) will be useful for energy-storing devices but due to complex circuit arrangement and high conversion losses, this converter is not favorable. The direct AC-AC voltage converter is a matter of research due to simple conversion. This paper presents the performance analysis of a single-phase ac-to-ac voltage converter operating in inverting and non-inverting modes with no current commutation problems. The performance analysis of the proposed converter is been done in MATLAB/Simulink 2019b.**

Keywords-Voltage sag and swell, voltage control, inverting mode, non-inverting mode, power distribution system

I. Introduction

Decentralization enables the utilization of distributed energy resources as a component of the power generation system. Components, incorporating the applicable criteria that follow. This technique increases flexibility while decreasing dependency on the traditional power grid. With the vast advantages (DRs) have some technical limitations [1] besides this their growth rate is very fast. They can operate in both conventional (grid) and autonomous (islanding) modes, which is more practical [2]. The functioning of micro-grids in islanding mode has numerous difficulties because of the large use of power electronic devices, and the instability of renewable resource outputs. As a result of the unbalanced and fast load distribution [3], [4]. There are three different types of causes for power system outages: The first is concerned with the demand for reactive power; the second is linked to solid-state electronic equipment; the third is related to properties of renewable energy resources. Voltage harmonics, voltage sag, voltage swells, and voltage fluctuation, are all caused by these types. To address and combat these issues, numerous standards have been developed for effective monitoring and appropriate compensating strategies, these concerns can be resolved

One of the most essential challenges in the power system is voltage sag/swell. Especially for the consumer end's delicate loads. It further exacerbates the problem of line and tripping losses in protective systems. Voltage sag occurs when the line RMS voltage is reduced by 90% to 10%, while voltage swell occurs once the line voltage (V_{Lrms}) is increased. The line voltage (V_{Lrms}) is increased from 110% to 180%, [5]. Under- and over-voltage difficulties are caused by these two issues, respectively. They have the potential to disrupt the industrial process, resulting in a production deficit and financial loss. The most difficult difficulty in today's power distribution environment is maintaining the power standard of a particular voltage at the user end, the use of DVRs at the user end may usually solve these issues.

The power discrepancy from cascaded individual PV converter modules, on the other hand, might cause voltage and system functioning problems [6]. To increase voltage stability, series compensation which is dependent on the FACTS device is implemented as a DVR (dynamic voltage restorer) [7]-[11]. It consists of a VSI converter linked in a series of transmission lines to provide the necessary voltage compensation of power. As mentioned, many control strategies are established for the effective working of DVR presented in [12]. In-phase and pre-sage compensation are given more attention. These techniques, on the other hand, used high-capacity storage devices because their implementation necessitated a large amount of real power injection. For large voltage sags with more time duration, various solutions depending upon the energy optimization principle have been originated [13]-[14]. They lower the demanded injected power while the compensating time, reducing the power of inductors and capacitors. As a result, the above-mentioned solutions exacerbate the problem. Furthermore, they make it easier to regulate the injected voltage without having to worry about power quality issues. In dual converters, the issue of energy-storage devices' limited capacity is tackled (ac to dc). The Dual converter consists of two steps of conversion: the first is the rectification and the second is inversion. They do have the capacity to control voltages as well as frequencies. For a variety of applications, they are achieved with various topologies [15]-[17]. Save the cost and simplify the circuit, the rectification mode is usually implemented with a diode converter. This design limits the variation of input current which is required in many applications. AC-to-DC converters are used for the output conversion stage, and the output voltage and output frequency are regulated using different PWM methods. The dc-link capacitor's existence is the fundamental cause of system failure. This also produces a poor power quality issue in the front-end rectification's input current, resulting in a low input power factor. To solve this difficulty, sophisticated circuit arrangements and switching sequences are used. As a result, because this power conversion scheme is complicated and has large conversion losses and costs, it is not suitable for voltage compensation. Because there are no energy storage devices and dc-link capacitors, one-step ac-to-ac compensation of the voltage designs is much more appealing than dual converters large dc-to-ac converters. In terms of applications, that simply require voltage control, they garner a lot of attention. Thyristors are used as switching devices in traditional ac voltage controllers however, due to excessive harmonics and the cost, their output is badly distorted [9]. Due to present commutation difficulties, they are at risk of short-circuiting their output can only be controlled in unipolar ways. As a result, they can't be used for both voltage sag and swell compensation. To convert the unipolar voltage features of the thyristors to bipolar voltage features, four more thyristors are utilized. Because it increases the overall volume, this method is not practicable. As well as conversion losses it also has a problem with reliability. Another option for bipolar voltage conversion is Z-source converters. They do, however, necessitate the use of snubbed circuits to avoid interference. The issues that have arisen as a result of the current commutation [19]. With bipolar voltage features, secure commutation is achieved [20] the switching cell design is used. A vast number of passive elements and switching devices are used. In the converter topology described in, the switching devices' conduction is lowered. The architecture is made up of six MOSFET and diode pairs, but only two of them are active at any given moment, lowering conduction losses. However, for non-inverting and inverting operations, its gating sequences are asymmetrical. Furthermore, the operating modes are available in buck-boost mode. As a result of the high switching voltages and high currents, the losses are significant of switching. In, a new kind of transportation is introduced [21]. MOSFETs' characteristics of bidirectional current conduction are now unidirectional current conduction features.

To reverse bias the body diode, one more diode connected in series with fast recovery properties is used. Furthermore, their non-identical operation in non-inverting mode and inverting modes forms the switching scheme difficult. The three MOSFET and three diode pairs are used to conduct in all of its operational modes see in Fig. 1, outcomes in substantial conduction losses. Its inversion mode could be achieved only using a buck-boost method, disadvantage of high switching voltage and high current. To lower the switching losses, lower switching voltages, and currents. Although the inverting and non-inverting mode of operation is similar, the conduction loss is similar [21], due to the fact that every operation mode needs three MOSFETs and three diode pairs to conduct.

To mitigate the disadvantages of [21], as a result, this study introduces the ac-to-ac buck topologies Fig. 1 with inverting and non-inverting properties, as well as the conduction of a reduced number of switching devices resulting in a smaller footprint. Its operational modes are all comparable in operation. Its operational modes are all comparable in operation. Because one separate dc voltage is required for each controlled switching device, a minimal number of switching devices gives the reduced losses and costs one gate drive circuit and one source they are more expensive than the controlled switch. The proposed topology's effectiveness is compared with existing schemes for a '0.5' voltage gain. The research found that the proposed topology's switching voltage and switching current are 50 percent lower than the converter as well as the converter's inverting operation in [21]. As a result, conversion losses are reduced. The following is a breakdown of how this article is structured. The proposed topology is demonstrated in Section II, along with its working modes. Establishing the proposed topology researched through simulation is done in Section III. The conclusion is highlighted in Section IV.

II. CONVERTER CONFIGURATION

The proposed topology is depicted in Fig. 1 as an electrical circuit diagram that might be used as DVRs to minimize voltage disruptions in large and small power systems like sags and swell of the voltages. Only six diodes and MOSFET pairs are used, as well as two inductors and two capacitors (C_{in} & C_o). Because the MOSFET has lower on-state resistance, the power MOSFETs are selected as switching schemes.

This issue is solved by adding a fast recovery diode in series. Because it eliminates the problem of current commutation, this configuration also improves the operation reliability. Input power is transmitted from the load via filtering inductor and two diodes and MOSFETs in all operational modes. It also ensures that in a complementary fashion, switching devices were used do not cause current commutation issues. As a result of the lack of these concerns, the demand for blanking time is no longer necessary, and a snubbing circuit is also not required.

High-frequency switching devices have a high switching frequency, therefore input voltage instantaneous value is expected to be quasi constant during each switching period. The proposed topology's working principle is classified into non-inverting and inverting with operating modes in detail.

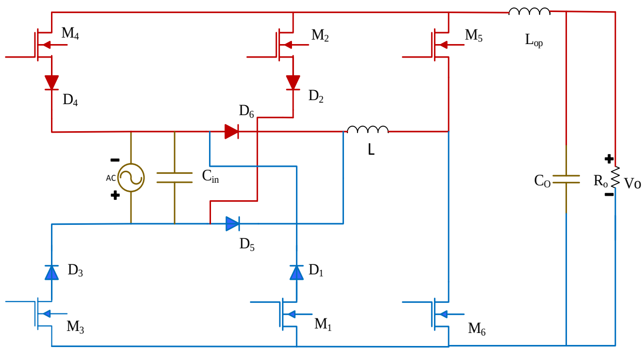

Fig. 1. Converter configuration

A. *Non-inverting mode of Operation*

For voltage sag compensation, the output voltage gain must be positive, therefore it is necessary to add the injected voltage to the input voltage to increase the total voltage to the desired value. Fig. 3(i) shows the lower and higher-frequency switching signals required to obtain in-phase voltage. The switching signals S_1 and S_2 PWM signals with a high frequency that regulate the output voltage is positive and negative input voltages, respectively, through the duty cycle concerning the switching period. The control signals (S_1 to S_6) determine the switching.

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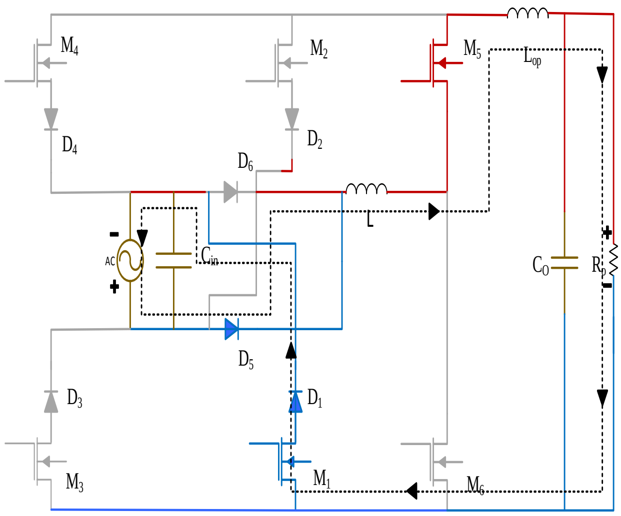
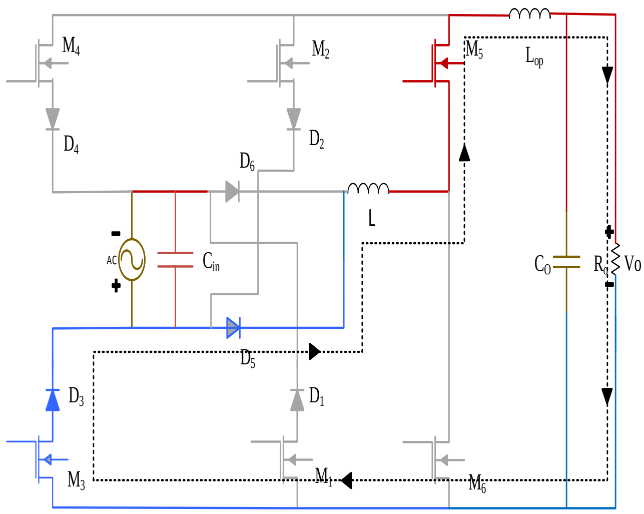
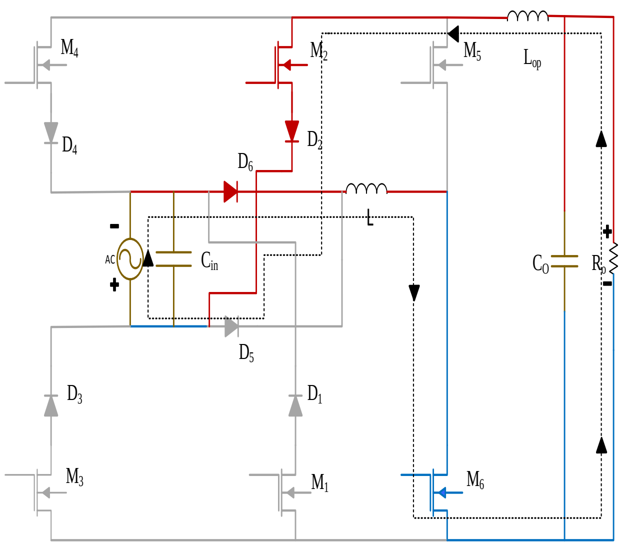


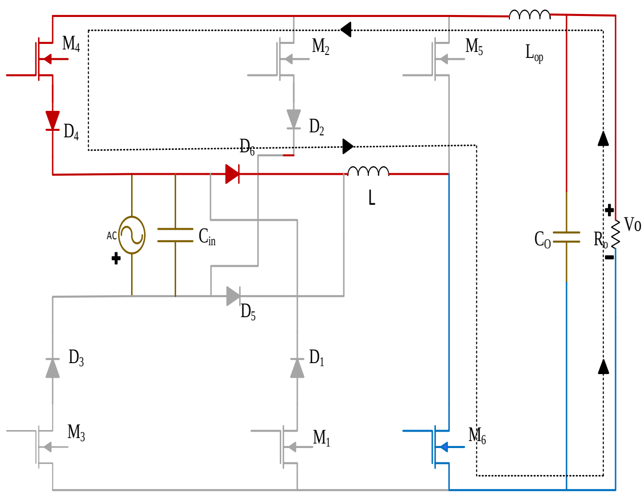
(i)



(ii)



(iii)



(iv)

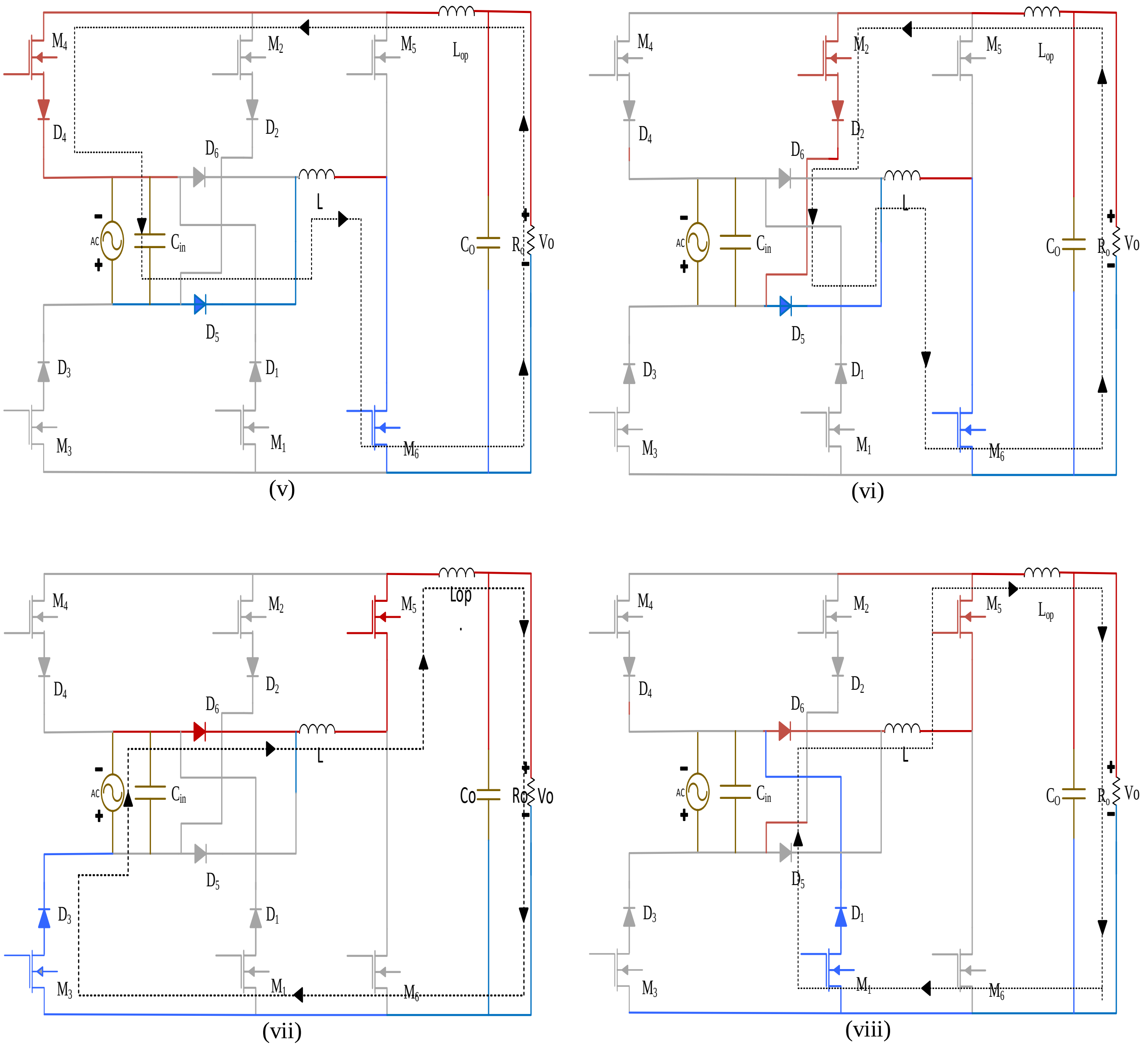


Fig. 2. Highlighted paths of current non-inverting (i) to (iv) & inverting operation (v) to (viii)

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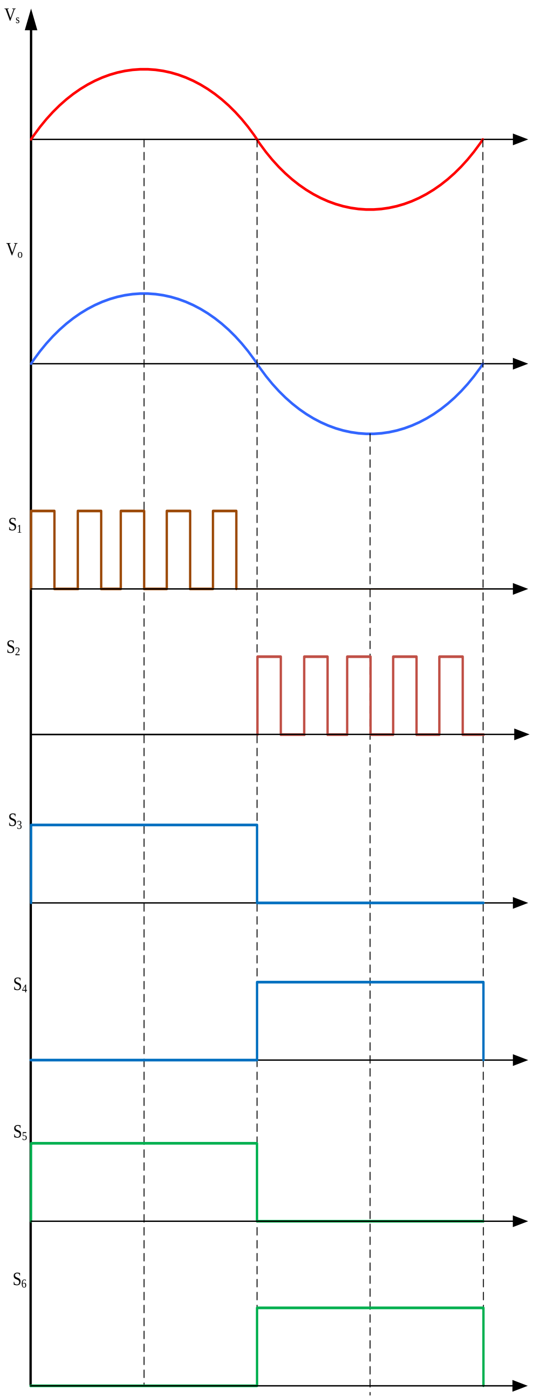
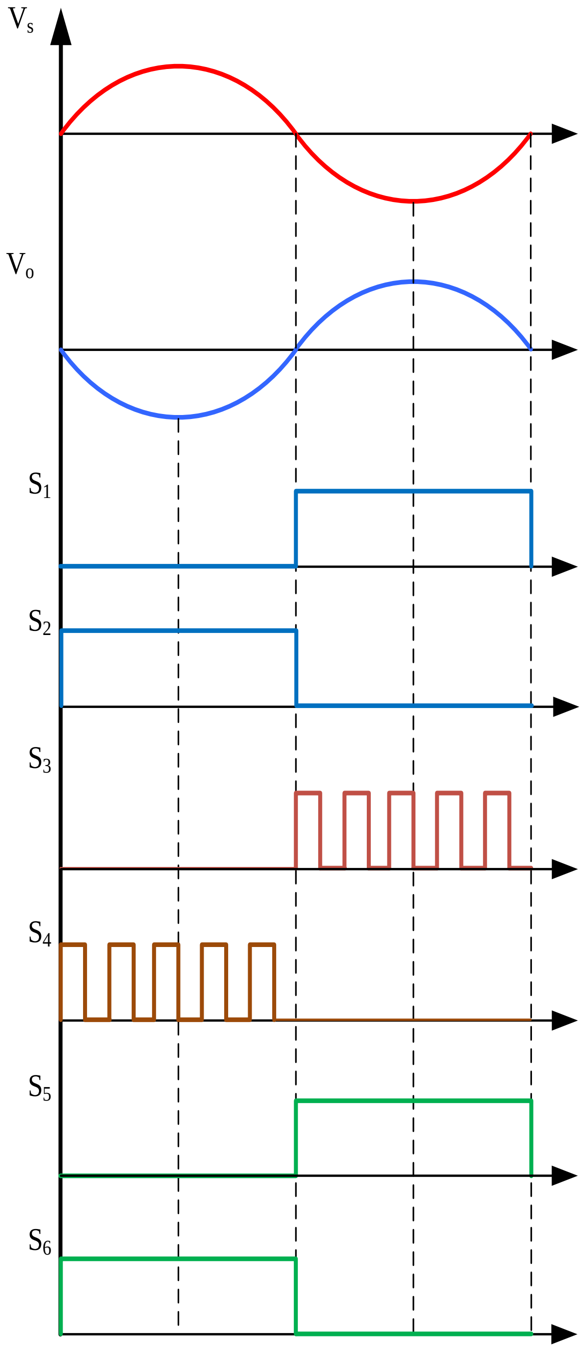


(i) *Non-inverting mode*



(ii) *Inverting mode*

Fig. 3. Switching Scheme for (i) *Non-inverting mode* (ii) *Inverting mode*

The behavior of switches M_1 to M_6. In modes 1 and 2, the current conduction path is illustrated in the Fig. 4(i), (ii), and (iii), (iv) when the input voltage is positive or negative, respectively is used to look into how in-phase output voltage regulation is attained using duty cycle control.

Mode I: Mode I is enabled when the positive input voltage is applied and the controlled switch M_1 is switched to PWM. As shown in Fig. 2(i), the current conducted by switches M_1, M_5, and diodes D_1, D_5 transfers power from input to output during PWM in the interval [0-mT]. To prevent the regulated switch S_3 is always turned on by the current interruption of the inductor. However, because the diode D_3 is reverse biased at input voltage level Vs, it cannot conduct. When the MOSFET (M_1) is off by PWM, it will become forward biased in the interval [mT-T]. During this time, the filtering inductor's stored power is transferred to the load through a highlighted channel made by switches M_3, M_5, and diodes D_3 and D_5, as shown in Fig. 2(ii) the turn on and off states controlled by switch M_3 of switch M_1.

Mode II: During interval [0-mT] of switch M_2, the load receives power from the source via the circuit shown in Fig. 2(iii) during the negative cycle of voltage. It is established by the semiconductor devices M_2, M_6, D_2, and D6 conducting. Because the diode D_4 is in reverse blocking mode, switch M_4 is turned off. It is only carried out after the PWM control switch M_2 transitions from 'on' to 'off' to disconnect the line from the load in the interval [mT-T]. Due to the conduction of semiconductor devices M_4, M_6, D_4, and D_6 a current conducting channel is produced, as shown in Fig. 2(iv), the filtering inductor's stored energy is released toward the output.

B. *Inverting mode of Operation*

For voltage swell compensation, the output voltage gain must be negative, therefore it is necessary to subtract the injected voltage to the input voltage to decrease the total voltage to the desired value.

Mode III: In the M_4 switch the PWM switching control, the inverting output voltage is achieved during the positive value of the line voltage. The switching devices M_4, M_6, D_4, and D_5 simplify the output connection with the source through the filtering inductor L_{in} during the PWM switching interval [0-mT], as shown in Fig. 2(v) to avoid this issue of the filtering inductor current interruption, the regulated switch M_2 remains in the on position.

As far as the source is detached from the circuit in the period [mT-T] of switching frequency, its diode D_2 which is connected in the series remains reverse biased. The energy which is stored in the input inductor which is used for filtering is conveyed to the ward's output during this time interval via path enabled by the conducting semiconductor devices M_2, M_6, D_2, and D_5, as shown in Fig. 2(iv). The forward and backward bias control of the M_2 is a controlled switch that can be turned on and off. Because its diode D_2 is connected in series, which is in control by controlled switch M_4's switching action.

Mode IV: The controlled switch M_3 high-frequency PWM operation realizes, the suggested topology's buck operation with a negative input voltage in inverting mode. As shown in Fig. 2(vii), In the PWM turn-on the duration [0-mT] M_3, M_5, D_3, and D_6 the input power is conveyed to the output via a current conducting path produced by the semiconductor devices turn-on operation. The controlled switch M1 remains off until the diode D1 becomes forward biased in the controlled switch M3 turn-off period [mT-T]. During this period, the inductor's stored energy is transferred output side through the path of current conduction formed by the devices M_1, M_5, D_1, and D_6, as indicated in the diagram Fig. 2(viii).

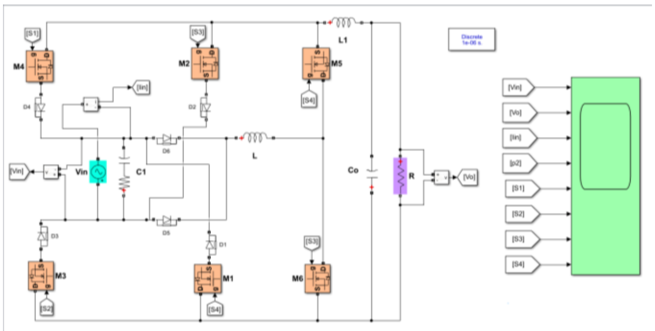


Fig. 4. Simulation diagram

PARAMETERS VALUES

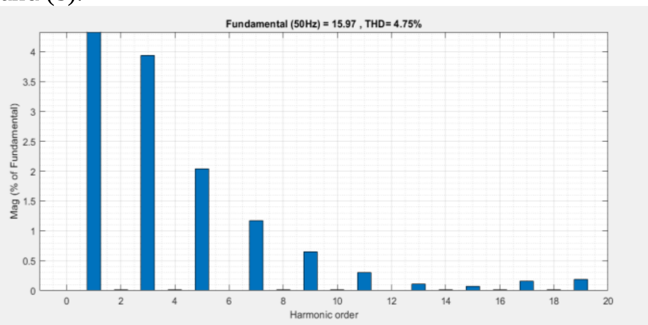
Parameter	*Values*
Switching frequency(f_s)	30kHz
Peak input voltage	36V
Input(output)frequency	50HZ
Load Resistance(R_L)	10 Ω
Output capacitor	4.7F
Output inductor	1mH
Diode (V_d)	0.8V
Diode (R_d)	0.007 Ω
MOSFET Resistance	0.09 Ω
Output filtering Inductor	1mH

III. RESULTS

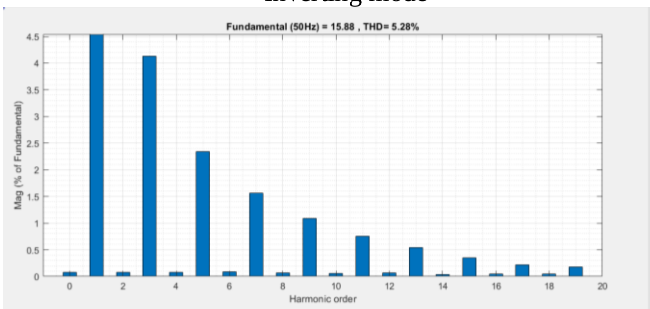
The presented converter strategies are performed in MATLAB/Simulink. At a 50 Hz input frequency, the maximum is 36V for input voltage. Through a 50 percent PWM duty cycle control, at f_{in} the V_o is controlled to an 18 V peak. To enhance the performance of the output voltage and output current, the L and C are changed to 1 mH and 4.7μF (o/p) and 1 μF (i/p), respectively. The table summarizes simulation parameters and practical outcomes utilized throughout the paper. The input and output voltage waveforms are shown in Fig. 6 (a) and (b). In non-inverting operation, the input and output voltage waveforms are in phase, while inverting action is out of phase. Because m is set to 0.5 duty cycle, the output voltage amplitude is half in both circumstances. In non-inverting mode the voltage is added to the line voltage, whereas the inverted voltage reduces the line voltage once it is added.

The voltages across the switches M_1, M_3, D_1, and D_3 during positive input voltage across M_2, M_4, D_2, and D_4 during negative input voltage. They're only allowed to use the input voltage. The switching devices operation M_2, M_4, D_2, D_4 for positive input voltage and M_1, M_3, D_1, D_3 for negative input voltage enables this operation. The CVS and VS switching voltages are created across the switching devices M_3, (D_3), M_4 (D_4), and M_1 (D_1), M_2 (D_2), respectively.

Thus, throughout inverting and non-inverting operations, the switching voltage never surpasses the input voltage. As a result, throughout inverting and non-inverting operations, the switching voltage never surpasses the input voltage during high frequency. The THD is reduced to 4.75% as shown in Fig. 5(a) and (b).

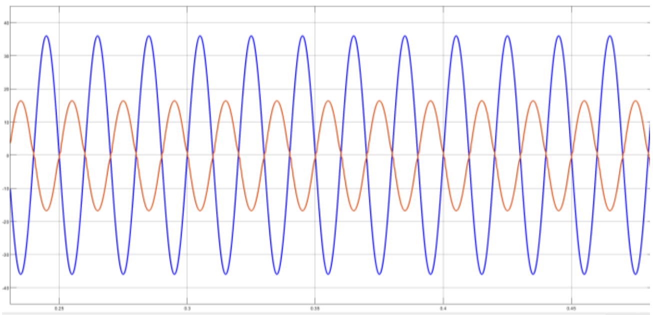


Inverting mode

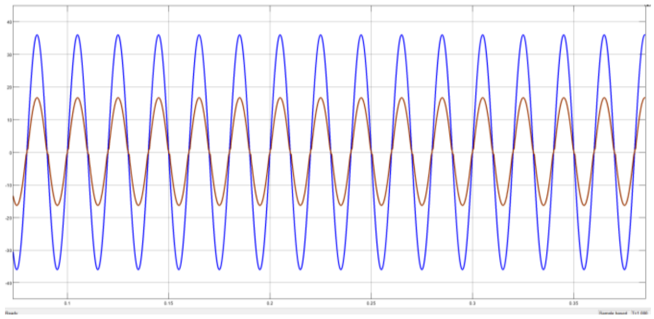


NON-INVERTING MODE

Fig. 5. THD of voltage in inverting and non-inverting mode



(a) Inverting mode



(b) Non-Inverting Mode

Fig. 6. Input and output voltages

IV. CONCLUSION

For grid voltage compensation, this study evolves a unique AC-AC converter strategy with dual polarity voltage gain. It controls switching voltages, currents and reduces them by 50 percent when compared to traditional converters with a voltage gain of 0.5. Low switching losses are ensured by lowering the switching voltage. At any point throughout its operation, a high and a low switching device can be used to achieve any of its operating modes. Conduction losses are greatly reduced by the use of MOSFETs and diodes which have low switching losses and current. Its operation in inverting and non-inverting are similar, make sure that both operations use the same switching method. It also assures that the output voltage has minimum ripples, resulting in improved power quality. Conversion efficiency improves when undesirable conversion losses are reduced. The simulated outcomes are used to verify the computed value.

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