DESIGN AND IMPLEMENTATION OF BIDIRECTIONAL THREE PHASE DC-AC CONVERTER WITH E-CHOPPER FOR HYBRID WIND-SOLAR GRID INTEGRATED SYSTEM

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Abstract

In this paper a three phase dc to ac converter with embedded chopper(e-chopper) is proposed for bidirectional interfacing applications, aimed at constant and stable irregular DC-bus, which can vary the battery voltage in wide range of applications. Compare to conventional dual stage conversion of DC to AC e-chopper requires less power for processing and consumes less power losses by using modest carrier built- pulse width modulation (CB-PWM) scheme through proposed zero structure addition. Implementation of proposed PWM scheme needs a small amount of power for processing of e-chopper, hence maximum control is managed through DC-AC conversion. So the overall transformation efficiency of DC-AC arrangement has been improved via e-chopper, by minimizing the power processing thus implies overall efficiency of the system. This paper analyzes the physical characteristics, ideologies and operation of the proposed Bidirectional inverter as well as its Pulse Width Modulation scheme in detail.

Keywords : Embedded chopper(e-chopper), carrier built -pulse width modulation (CB-PWM), Bidirectional DC-DC converter (BDC).

I. Introduction

Now a days bidirectional converter perform the major part in power systems usage. e. Grid integration of Renewable energy sources, uninterrupted power supply systems, electric vehicles, energy storage systems and micro grids etc., In general, the power conversion system of three phase dc-ac is categorized into three kinds, namely:
1) Buck (step-down) 2) Boost (step-up) and 3) Buck-Boost (bidirectional) topologies. Out of these, Buck converters are widely used to solve the industrial applications and having the salient features of finest construction, more effectiveness, springy variation and control approach [I, II, IV, V, VII, X]. Even though, due to the voltage fluctuations of output and input of Buck converters, amplitude of dc input is larger than the highest amplitude of the AC output. This result causes the voltage variations in step down converter, i.e. practical applications of Battery charging/settling for plug-in automobiles and drive storing requirements.

In general the electric load of battery is either lesser or more than the peak magnitude of ac line energy. Hence to overcome the extensive choice of dc energy deviations, a bidirectional dc to dc converter (BDC) needs, which is fed to an inverter.

![Block diagram of Conventional circuit (Bidirectional two stage DC-AC conversion system)](image)

So that, with this arrangement a two stage conversion of integrated chopper and inverter arrangement formed. But in this arrangement, control takes to be preserved two times; this considerably reduces the totaleffectiveness of the system[V]. Therefore recover the ability of such kind of systems by implementing multi-level dc-ac topologies, which can reduce the electrical energy stresses and converting damages of dynamic changes effectively[XII]. Even though the conversion stages cannot be reduced till now. Therefore the drawbacks of two-stage power conversion can be overcome by providing bilateral Z-source and quasi z source inverters; hence this arrangement obtains the reduced power conversion stages. But these proposed schemes also undergo from complex voltage/current concerns, thus results extra power losses of converting strategies and difficult control issues, this makes them challenging to increase extraordinary ability[I, II, IV].

1. Therefore drawbacks of two step power conversion system is minimized by using quasi one step architecture with e-chopper and dc-ac converter, which is applied to single phase system for small power rating applications[VIII, XII, XIII], as well as three phase systems of large power applications having the same principles as that of single phase system.
Proposed methodology for three phase system

![Block diagram of proposed circuit of DC-AC conversion with e-chopper](image)

Proposed methodology results quasisinglestepbidirectional 3øinverter, which is implemented with Bidirectional 3ø dc-ac conversion with e-chopper. However implementation of DP-TPC for three-phase system is mainly depends on the modulation strategy, which is more complicated in three phase systems when compare to single-phase systems i.e. the performance and characteristics of the system[III,VI,XI,XIII]. Several modulation topologies are applied for Bidirectional three phase dc-ac converters, i.e. 1). Space-vector Pulse width modulation (SVPWM), 2) Carrier built pulse width modulation (CB-PWM). Out of these two topologies CB-PWM is the best topology for bidirectional mode three phase dc-ac conversions, having salient features, like less computation resources, and simple implementation i.e. directly produces duty cycle for adjustments by comparison of carrier signals with modulating signals[III,VI].

Therefore, the issues of dual stage converter cannot be solved effectively till now. Here a novel bidirectional 3ø dc to ac conversion through e-chopper as well as simple CB-PWM approach is considered and assessed to overcome the disadvantages of conventional dual-step conversion. The primary benefits of proposed scheme results minimized power transformation losses, power rating of dc to dc conversion schemes. Hence power assessment and power lossese-chopper is reduced effectively, finally total efficiency of dc to ac conversion remains improved.
II. Implementation of Bidirectional 3φ DC-AC transformation through e-Chopper

Fig. 2. Bidirectional 3φ DC-AC transformation through e-Chopper

Fig. 2 represents the Bidirectional DC-AC conversion with e-chopper. The proposed converter has dual dc ports i.e. 1) minimum voltage ($V_{min}$) dc port as well as 2) maximum voltage ($V_{max}$) dc port. The circuit arrangement represents that ($V_{min}$) dc port stays directly linked to the battery, although the ($V_{max}$) dc port fed to the AC converter. The proposed circuit arrangement represents that ($V_{min}$) dc port as well as ($V_{max}$) dc port stays directly linked to the battery, although the ($V_{max}$) dc port fed to the AC converter. The proposed circuit arrangement represents that ($V_{min}$) dc port as well as ($V_{max}$) dc port stays directly linked to the battery, although the ($V_{max}$) dc port fed to the AC converter.

It allows a novel control flow path concerning the battery and ac grid assembled by e-chopper, offered through bidirectional switch i.e. connection of dual sequence isolated gate bipolar transistor (IGBTs) $S_{L1}$ as well as $S_{L2}$ ($x=R,Y,B$) for every switching limb. Therefore amount of power transfer from battery to ac grid managed without e-chopper also vice versa.

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Fig. 3 Power flow diagram of bidirectional 3Ø converter. (a) conventional dual-step architecture through cascaded dc to dc approach (b) suggested quasi single-step architecture via e-chopper approach.

Power system analysis of the bidirectional 3Ø DC-AC transformation through e-chopper is represented in Fig 3. Fig. 3(a) represents the two stage architecture via cascaded dc-dc approach, which permits the power flow from battery to ac grid as well as AC grid to battery. While fig. 3(b) represents the propose methodology of bidirectional 3Ø DC-AC conversion via e-chopper. Fractional power is handled through e-chopper only, hence power assessment and power victims of e-chopper is condensed. Finally we can observed that voltage $V_{\text{max}}$ is regulated by e-chopper and voltage $V_{\text{min}}$ is regulated by 3Ø inverter.

III. Proposed Carrier –built PWM approach

(a) Control methodology

Fig. 4 Block diagram of Control approach
Block diagram of bidirectional inverter through e-chopper for control mechanism is as shown in figure 4. The voltage $V_{\text{min}}$ is controlled by inverter. $V_{\text{max}}$ is the voltage which is controlled by e-chopper. It is strictly mentioned that, the battery current or voltage is regulated through current path $i_d$. Accordingly the current reference path $i_d^*$ can be created via battery mechanism loop. In AC-DC mode, energy storage device battery is straightly connected to $V_{\text{min}}$ port as well as power flows from $V_{\text{max}}$ port also transmitted to $V_{\text{min}}$ port via e-chopper. Therefore power from the $V_{\text{min}}$ port signifies the total power of both the $V_{\text{min}}$ and $V_{\text{max}}$ of the inverter ports. Hence, external voltage loop of $V_{\text{min}}$ defines the dynamic current location $i_d^*$ and controls the total dynamic power flows into the battery.

In this dc-ac conversion process the current regulation loop is employed in d-q coordinate via PI controller. Control loop of d-axis represented in fig.5 as well as open-loop transfer function is expressed as

$$G_{\text{i-open}}(s) = G_i(s) \cdot G_d(s) \cdot K_{\text{PWM}} \cdot \frac{1}{S_L} \cdot H_i$$ \hspace{1cm} (1)

Here $G_i(s)$ indicates current controller of PI, which is stated as

$$G_i(s) = K_p + \frac{K_i}{s}$$

Where $G_d(s) = e^{-5.5T_s}, K_{\text{PWM}}$ is the PWM unit as well as $H_i$ is the inductor current response. Parameters of PI controller can be easily obtained through designed cutoff frequency and phase margin.
Fig. 5. d-axis Current control loop

In e-chopper a signal task $Sgn$ is presented in control loop to define the power flow commands. Observation shows the regulation of the bidirectional dc-ac transformation through e-chopper is like the conventional solution through integrated chopper. Though, modulation approach of inverter is the important issue to define the power flow of the bidirectional dc-ac transformation using e-chopper is entirely dissimilar from the modulation approach of traditional three-phase inverter. Key effort of this paper proposed the CB-PWM approach for DC-AC conversion due to its ease for hands-on operation, and explored in fact in the following division.

(a) Modulation approach implementation

This section describes the implementation of proposed carried built-PWM approach for dc to ac conversion approach, which remains compared with conventional 3 level T-type transformation. The voltage $V_{\text{max}}$ of e-chopper is resolute by the voltage of battery, always it doesn’t satisfies one half of the $V_{\text{max}}$. Modulation aim of dc to ac conversion remains towards diminishes the power managed by e-chopper $P_{\text{High}}$, that means to increase the power openly transmitsto AC grid $P_{\text{Low}}$. (example in inverter mode).

Modulation of Asymmetrical Carrier Waveforms Conventional form of 3-level inverter is balancing the capacitors voltage is ended through normal CB-PWM approach. In this method of operation, dual carrier signals are evacuated symmetrically inefference to null alignment, thus consequences carriers’ peak-to-peak value. Yet frequently not intended in place of dc to ac conversion process, min voltage port $V_{\text{min}}$ is not persistent. Once CB-PWM approach is realistic of dc
to ac conversion, carrier’s peak-to-peak values are varied permitting to voltages of $V_{\text{min}}$ port as well as $V_{\text{max}}$ port.

![Carrier and Modulation waveforms](image)

**Fig. 6.** Carrier and Modulation waveforms

From fig. 6 we can observe that scales of dual carriers are in fraction to difference of dc voltages ($V_{\text{max}}-V_{\text{min}}$) and $V_{\text{min}}$ correspondingly then stabilized as follows.

$$V_{\text{Peak-Top}} = \frac{V_{\text{max}} - V_{\text{min}}}{V_{\text{max}}} - \frac{1}{2} = 2\left(\frac{V_{\text{max}} - V_{\text{min}}}{V_{\text{max}}}\right)$$  (2)

$$V_{\text{Peak-Bottom}} = \frac{V_{\text{min}}}{V_{\text{max}}} - \frac{1}{2} = \frac{V_{\text{min}}}{V_{\text{max}}}$$  (3)

Especially, when $V_{\text{min}} = V_{\text{max}}/2$, it satisfies the relationship of $V_{\text{peak-top}} = V_{\text{peak-bottom}}$.

Here amplitudes of dual carriers are equal to one another, thus related to the conventional 3 step converter through regular carriers.

Assumes that novel 3ø sinusoidal modulation signals are described as

$$V_R = n\cos \theta$$

$$V_Y = n\cos(\theta-120^\circ)$$  (4)

$$V_B = n\cos(\theta+120^\circ)$$

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Anywhere modulation directory = n, and phase position = θ.

In case of inverter mode $V_{\text{min}}$ supplies power to dc to ac conversion step if and only if the switches $S_{La1}$ and $S_{La2}$ represented in fig.2 are turned on, the phase leg R is connected to $V_{\text{min}}$, simultaneously $V_{\text{min}}$ charges or discharges via phase current $i_R$. This operation is similar for phase Y and phase B also. To enhance the maximum active power delivered by $V_{\text{min}}$, average value of $i_{\text{Low}}$ should be increases as much as possible, refer to fig.6 the duty cycle expression results, when the phase-leg is connected to $V_{\text{min}}$ is represented as follows.

$$d_x = \begin{cases} 
\frac{1 - V_x}{2 - 2\frac{V_{\text{min}}}{V_{\text{max}}}} & \text{if } V_x \geq 2 \frac{V_{\text{min}}}{V_{\text{max}}} - 1 \\
\frac{1 + V_x}{2\frac{V_{\text{min}}}{V_{\text{max}}}} & \text{if } V_x < 2 \frac{V_{\text{min}}}{V_{\text{max}}} - 1 
\end{cases}$$

Whereas current flows out of $V_{\text{min}}$ expressed as follows

$$I_{\text{Low}} = \sum_{x=R,Y,B} d_x i_x$$

Where $i_x (x=R,Y,B)$ is the current of the corresponding phase leg is related to $V_{\text{min}}$.

Hence to maximize the average value of $i_{\text{Low}}$, a straightforward technique is applied to block the negative phase current flows to $V_{\text{min}}$, that means switches coupled to Vmin are in off mode, while corresponding phase current is negative. To enhance such target, a null-sequence signal is introduced to the unique sinusoidal modulation waveforms. Then 3ø currents represented as follows.

$$\begin{align*}
\tilde{i}_R &= I_m \cos(\theta - \varphi) \\
\tilde{i}_Y &= I_m \cos(\theta - 120^\circ - \varphi) \\
\tilde{i}_B &= I_m \cos(\theta + 120^\circ - \varphi)
\end{align*}$$

While range of phase current = $I_m$ and power factor incidence = $\varphi$
Unity power factor instance is used for easy analysis, control dynamic angle $\theta=0$ is primarily considered on description besides the impact of control is deliberated later. Conferring the divergence of phase current, exploration is accomplished through six sectors (from S1 to S6), which is revealed in figure-7.

Of sector S1, when $30^\circ \leq \theta \leq 90^\circ$, it fulfills correlation of $i_R\geq0$, $i_Y\geq0$, $i_B\geq0$. In this situation the phase current $i_R$ and $i_Y$ flows out of the $V_{min}$ port, even though the phase current $i_B$ flows into $V_{min}$ port. The opposing current $i_B$ is blocked by using ideal null-ordered element to mark $d_c$ to remain nil. Hence, the inserted null-order element is simply resultant as $(-1-V_B)$, through null-order addition, hence opposing current of sector S1 is obstructed finally.
Fig. 8 (a) Null-order-component as well as original sinusoidal modulation signals

In S2 section, when \( \pi/2 < \theta \leq 5\pi/6 \), it satisfies the correlation of \( I_R \leq 0, I_Y > 0, I_B \leq 0 \). By applying suitable null-order element, create duty cycled as well as \( d_B \) to be nil to slab the undesirable current \( i_R \) besides \( i_B \) however which cannot be realized simultaneously.

Fig. 8 (b) Improved modulation signals through null-order –addition

Based on the correlation of 3Ø sinusoidal modulations signals, S2 sector is supplementary classified into two sub sections; they are S2/1 besides S2/2. In sub category S2/1, when \( 90^0 < \theta < 120^0 \), it is obtained that \( i_B \leq i_R < I_Y \). The injected null order signal is set as \(-1 - V_B\) to block the extreme negative current \( i_B \). Similarly in sub...
section S2/2, while \( \pi/3 < \theta \leq 2\pi/3 \), it is obtained that \( i_R \leq i_B < iy \). The injected null order signal is set as \((-1-V_R)\) to block the extreme negative current \( i_R \). Such type of analysis procedure applied to other sectors also. Lastly the null order \( V_o \) represented uniformly as follows.

\[
V_0 = -V_{\min} - 1
\]  

Where as \( V_R \), \( V_Y \) and \( V_B \) are the minimum values of \( V_{\min} \).

Improved modulations signals through null-order injection \( V_x(V_x = V_x + V_o) \) illustrated in fig.8(a) and 8(b) correspondingly. It is perceived that when null order signal added to sinusoidal modulation signals, then improved modulations signals clipped at -1, throughout 120 degrees intermission of major sequence. Thus it can be obtained that equivalent phase could not control in the course of intervals besides the destructive current flows to the \( V_{\min} \) port are censored off. Throughout the intermission of \( 0 \leq \theta \leq 2\pi/3 \), the modulation phase \( V_B \) is compressed at -1, later phase B could not change also destructive phase current \( i_B \) is prohibited formin voltage \( (V_{\min}) \) ports.

![Fig.9 Proposed CB-PWM approach representation by zero-sequence injection](image)

Fig.9 representsthe illustration of the suggested CB-PWM approach, anywhere the dual fundamental fragments of irregular carrier waveforms as well as improved modulations signals remain emphasized. Contributions of unique 3\( \theta \) sinusoidal modulations signals are reformatted through means of accumulating null order element with equation (8), which generates the
suggested modulations signals. Thus these pointers are matched with irregular carrier signals to produce control gating signals.

Mostly Digital controllers are used in practical applications like digital signal processing (DSP), the irregular carrier is not simply fulfilled through PWM component. Alternatively, the carrier retains constant, though the modulations signals are evenly reformed to confirm the equal switching signal to every alteration.

\[ V_{x1}^l = \frac{V_x^l + 1 - 2V_{\text{min}}}{2 - 2V_{\text{min}}/V_{\text{max}}} \]  
\[ V_{x2}^l = \frac{V_x^l + 1}{2V_{\text{min}}/V_{\text{max}}} \]

Here suggested CB-PWM approach using constant carrier signal is shown in figure.10, it perceived that two modulations signals \( V_{x1}^l \) as well as \( V_{x2}^l \) meet through constant carrier.
hence produce the gating signals to each alteration. It is clear that process for utilization of the recommended CB-PWM approach is too easy, which concludes the operational scheme fit for hands-on uses.

IV. Simulation Results

Fig. 11 DC Link Voltage Output

Fig. 12 Voltage and Current of Wind output
Fig. 13 Voltage and Current of Inverter output

Fig. 14 Output of Voltage and Current

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Output waveforms of Hybrid solar and wind system is represented in figure.11 to figure.14. The input source is obtained from solar boost converter and wind PMSG are having variable supply is converted initially into DC voltage from Wind through three phase uncontrolled bridge Rectifier. The output of variable DC voltage and Bridge Rectifier output voltage is converted to fixed DC through boost converter in both the two primary sources, those boost converters are controlled by PI controller aswell as converter voltage is nearly constant through less amount of ripple content. These constant DC is a straightconnection and formed a DC bus. DC power is supplied to e-chopper. In the other side, the bidirectional converter operates in boost mode aswell as buck mode. Again the input energy is further converted from DC-AC and to the required level which is supplied to th Resistive load.

V. Conclusion

In this paper novel bidirectional $3\phi$ inverter through e-chopper and its CB-PWM implemented, we observed that suggested dc-ac conversion through CB-PWM approach has salient features from theoretical approach, i.e. voltage of battery varies in wide range through help of e-chopper. Implementation of suggested CB-PWM approach gives the most active power for processing, through $3\phi$ dc-ac converter minimum power ratio needs for processing of e-chopper. Hence power requirement as well as power losses and cost of e-chopper also minimized.

In this, suggested CB-PWM approach of e-chopper minimizes the average switching frequency; consequently minimized power losses are obtained. Because quasi single-step conversion of power is obtained through suggested dc to ac conversion, hence transformation efficiency of whole dc to ac power system is enriched. Finally whole attractive features noticed that, suggested dc to ac conversion through CB-PWM approach is attractive for several maximum efficiency of bidirectional $3\phi$ dc to ac conversion applications, i.e. energy storage arrangements, micro grids as well as electric vehicles etc.

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