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# CASCADED DC-AC CONVERTER WITH BIDIRECTIONAL POWER APPLICATIONS

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***Abstract :*** **Two stage-cascaded converters are widely used in dc– ac hybrid systems to achieve the bidirectional power transmission. The topology of dual active bridge cascaded with inverter (DABCI) is commonly used in this application. A coordinative control method for DABCI and it is able to reduce the dc-link voltage fluctuation between the DAB and inverter, then reduce the stress on the switching devices, as well as improve the system. In the proposed control method, the DAB and inverter are coordinated to control the dc-link voltage and the power, and this responsibility sharing control can effectively suppress the impact of the power variation on the dc-link voltage, without sacrificing stability. In this the space vector modulation is implemented in order to reduce the total harmonic distortion.**

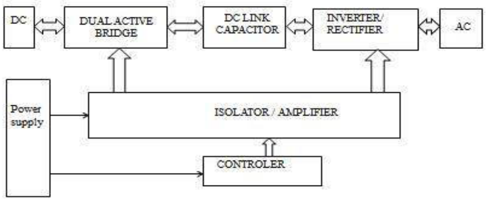
***Keywords :Bidirectional control, cascaded converters, coordinative control, dc-link voltage control.***

## 1.INTRODUCTION

WITH the increase of distributed generations (DG),more and more renewable energy-based generation units are integrated into the power systems, and they are in the form of ac or dc sources, such as the wind turbines, photovoltaic panels, bio fuel and biomass generations. Forming a local dc or ac active distribution network is an efficient way to integrate these DGs to support the local loads, as well as feed the utility grid [1]. The interconnection between the dc and ac active networks could become necessary, and a high effective interface converter would be the key issue to realize this connection. The interface converter between ac and dc systems normally fulfills the following requirements : 1) voltage buck-boost capability;2)bidirectional power control;3) galvanic isolation; and 4) high power density and high efficiency. Several bidirectional buck-boost or boost inverters have been presented offered a three phase single stage-distributed power inverter and it has the capability of voltage boost, with less switching devices, but cannot realize the galvanic isolation. [2] introduced a new topology of a boost inverter, which needs more switches, especially for three-phase applications. Z-source inverter can achieve boost dc–ac inversion and buck ac–dc rectification ,but its efficiency is not high, and it could be difficult for high power applications.A boost inverter for fuel cell applications, but it cannot be used in high power three-phase applications. The dual-active-bridge (DAB) has a number of significant advantages: the high-frequency transformer can realize galvanic isolation and high-power density; the symmetric topology can achieve bidirectional power flow; H-bridges with a transformer can easily operate in a zero voltage switching mode. So the DAB cascaded with inverter (DABCI) is attractive for the interface converter between ac and dc systems. Studies about the hybrid ac–dc systems are presented [3].For the cascaded converter, conventional control methods use one sub converter to control dc-link voltage, and the other controls the power output. When power flow is reversed, sub converters swap the control objectives with each other, but the function swapping increases the complexity and reduces the system redundancy. Different transient behaviors between the DAB and inverter cause transient power unbalance, either in bidirectional or unidirectional applications. The power unbalance results in the variation of dc-link voltage, and the potential over voltage increases the stress on the semiconductor devices and causes grid power quality problems. In this paper, an active power and dc-link voltage coordinative control method is proposed for the DABCI. The proposed control method shares dc-link voltage control and power control between the DAB and inverter. Without swapping control functions or sacrificing the stability, the proposed control can effectively improve the dynamic behavior of the DABCI with better dc-link voltage maintenance and power control. With better-controlled dc-link voltage, the stress on the switching devices is reduced, which is significant to prolong system devices life time.

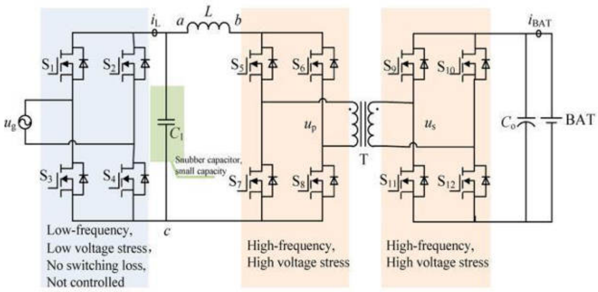
## II.SYSTEM DESCRIPTION

The block diagram of the proposed system is shown in Fig 1.




The DAB converter is a bidirectional DC-DC converter. It consists of two H-bridges and they are connected by a high or medium frequency transformer. The power flow can be controlled by the phase shift between the two bridges. Isolation is needed to provide safety for the equipment operating from the hybrid battery.

The circuit diagram of DAB is given,




The high-frequency transformer can realize galvanic isolation. High-power density. The symmetric topology can achieve bidirectional power flow. H-bridges with a transformer can easily operate in a zero voltage switching mode.

**Dual Active Bridge**

The average input current $I_1$ is (1), and DAB output power is (2),

$$I_1 = \frac{nV_2}{2\pi^2 f L_1}\phi(\pi - |\phi|) \quad (1)$$

where $n$ is the transformer turn ratio between the primary side and secondary side. $V_2$ is the output voltage, $f$ is the switching frequency, and $\varnothing$ is the phase shift between the two bridges

$$P = \frac{nV_1V_2}{2\pi^2 f L_1}\phi(\pi - |\phi|) \quad (2)$$

As in (2), when $\varnothing$ is $\pi 2$, $P$ will be the maximum value. The maximum power can be increased by reducing the switching frequency or the leakage inductance. Suppose $v_p$ and $v_s$ are, respectively, the transformer primary and secondary side voltages, $s_1$ $(t)$ and $s_2$ $(t)$ are the switching functions of the primary and secondary side, respectively, then the modeling of the DAB converter can be shown as

$$V_p = s_1(t)V_1(t) \quad (3)$$

$$v_s = s_2(t)V_2(t) \quad (4)$$

$$s_1(t) = \begin{cases} 1, & 0 < t = \frac{T}{2} \\ -1, & \frac{T}{2} < t = T \end{cases} \quad (5)$$

$$s_2(t) = \begin{cases} 1, & \frac{\varnothing T}{2\pi} < t = \frac{T}{2} + \frac{\varnothing T}{2\pi} \\ -1, & 0 < t = \frac{\varnothing T}{2\pi} \text{ or } \frac{T}{2} + \frac{\varnothing T}{2\pi} < t = \frac{T}{2} + \frac{\varnothing T}{2\pi} \end{cases} \quad (6)$$

State equation of DAB converter

$$\frac{di_{t(t)}}{dt} = \frac{-R_{1}i_{1(t)}}{L_1} + \frac{nS_1(t)V_1(t)}{L_1} - \frac{S_2(t)V_2(t)}{L_1} \quad (7)$$

$$\frac{dV_{2(t)}}{dt} = \frac{s_2(t)\frac{i_{t(t)}}{n}}{c_2} - \frac{i_{0(t)}}{c_2} \quad (8)$$

Fourier analysis

$$\frac{dx}{dt} = Ax + B\varnothing \quad (9)$$

$$y = Cx \quad (10)$$

$$x = \Delta V_2 \ \Delta i_{t1R} \ \Delta i_{t1I} \quad (11)$$

$$y = \Delta V_2 \quad (12)$$

$$A = \begin{bmatrix} \frac{1}{RC_2} & \frac{-4\sin(\varnothing)}{\pi C_2} & \frac{-4\cos(\varnothing)}{\pi C_2} \\ \frac{2\sin(\varnothing)}{\pi L_1} & -\frac{R_1}{L_1} & w_s \\ \frac{2\cos(\varnothing)}{\pi L_1} & -w_s & -\frac{R_1}{L_1} \end{bmatrix} \quad (13)$$

$$B = \begin{bmatrix} \frac{4}{C_2}\left(I_{0I}\sin(\varnothing) - I_{0R}\cos(\varnothing)\right) \\ \frac{2V_2}{L_1}\cos(\varnothing) \\ -\frac{2V_2}{L_1}\sin(\varnothing) \end{bmatrix} \quad (14)$$

$$C = [\ 1\ 0\ 0\ ] \quad (15)$$

$$\omega_s = 2\pi f \quad (16)$$

Transfer function of DAB converter

$$G = C(sI - A)^{-1}B \quad (17)$$

**Inverter Modeling**

Power references can be calculated using

$$P = \frac{3}{2}(U_d I_d + U_q I_q) \quad (18)$$

$$Q = -\frac{3}{2}(U_d I_q - U_q I_d) \quad (19)$$

where $Ud$ ,$Uq$ are the voltage on D and Q axis, respectively, and $Id$ ,$Iq$ are, respectively, the D and Q axis current

Current references

$$I_d^* = \frac{2P^*}{3U_d} \qquad \textbf{(20)}$$

$$I_q^* = \frac{2Q^*}{3U_d} \qquad \textbf{(21)}$$

Dc link voltage fluctuations

$$\Delta V_{dc} = \sqrt{{V_{dc}}^2 + \frac{2(E_{DAB} - E_{inverter})}{C}} - V_{dc0} \qquad \textbf{(22)}$$

$$\widetilde{I(s)} = \frac{1}{LCZ_{line}S^2 + (L + rCZ_{line})s + 1 + r} \frac{v_{dc}}{2K_{PWM}} \widetilde{I^*(s)} + \frac{1}{LCZ_{line}S^2 + (L + rCZ_{line})s + 1 + r} \frac{I^*(s)}{2K_{PWM}} \widetilde{V_{dc}}$$

**(23)**

Energy stored in dc link capacitor is $\frac{1}{2} CV^2{}_{dc}$

By neglecting higher order term, the small signal of $V_{dc}$ is linear with $V^2{}_{dc}$

$$V^{*2}{}_{dc} - (V^*{}_{dc} + \Delta V_{dc})^2 \simeq [V^*{}_{dc} - (V^*{}_{dc} + \Delta V_{dc})] 2V^*{}_{dc}$$

**(24)**

Active power and dc-link voltage coordinative control

$$V_{DC-link} = \int_{DAB}^{I} dt - \frac{1}{C_{DC-link}} \int_{INV}^{I} dt \qquad \textbf{(25)}$$

**APPLICATIONS**

DAB in a hybrid electric vehicle is a key component to manage power flow, Automotive applications, Battery chargers

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Electromagnetic induction produces an electromotive force which is exposed to time varying magnetic fields. Commonly transformers are used to increase or decrease the voltages of alternating current in electric power applications. A varying current in the transformers primary winding creates a varying magnetic flux in the transformer core and a varying magnetic field impinging on the transformer's secondary winding.

This varying magnetic field at the secondary winding induces a varying electromotive force (EMF) or voltage in the secondary winding due to electromagnetic induction.

**DC LINK CAPACITOR**

It exists between a rectifier and inverter. DC is switched to generate new ac power waveform. It connects the input and output stages. The DC link capacitor helps to keep the transients from radiating back to the input. It also prevents the switching network from oscillating or triggering inadvertently at an inappropriate moment and causing a short.

A rectifier is an electrical device that convertsalternatingcurrent(AC) which periodically reverses direction to direct current (DC) which flows in only one direction.

For three phase rectifier, no load average output voltage is

$$V_{dc} = V_{av} = \frac{3\sqrt{3}}{\pi} V_{peak} \qquad \textbf{(26)}$$

If thyristors are used in place of diodes, the output voltage is reduced by a factor $\cos(\propto)$

$$V_{dc} = V_{av} = \frac{3\sqrt{3}}{\pi} V_{peak} \cos(\propto) \qquad \textbf{(27)}$$

Line to line input voltage

$$V_{dc} = V_{av} = \frac{3}{\pi} V_{LL\ peak} \cos(\propto) \qquad \textbf{(28)}$$

The proposed control method is also effective for DABCI in unidirectional power transmission. The effectiveness of the propose control has been validated by both simulations and experiments.

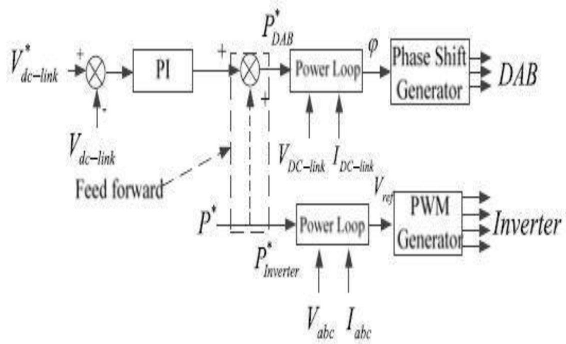



Fig. 2.Conventional power control of the DABCI.

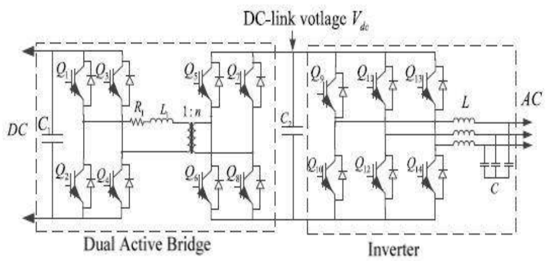
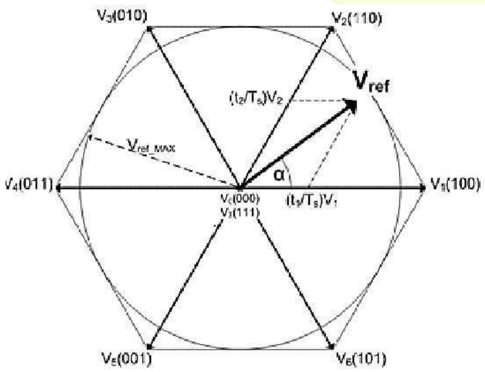



Fig. 3.Topology of interface converter DABCI.

**SPACE VECTOR MODULATION**

Space Vector Modulation (SVM) has become a standard for the switching power converters and important research effort has been dedicated to this topic. This seminar is intended to present the state of the art of Space Vector Modulation method, to emphasize the merits and demerits of different versions when applied to three-phase inverters and to make an in-depth presentation of the implementation possibilities. History and theory of the Space Vector concept are first introduced, followed up by a vectorial analysis of the three-phase voltage-source inverter (VSI). The meaning of PWM algorithms and the definition of the main performance indices follows. Basics of the Space Vector Modulation when applied to the three-phase voltage source inverters and link to Vector Control are mathematically developed.

Importance of the position of the active vectors within the sampling interval and choice of the switching sequence are discussed and it is shown how can improve performance. SVMs leading to continuous reference or discontinuous reference functions are detailed along with remarks related to their digital implementation. The DC voltage appears in the time intervals calculation and this can be used to develop an adaptive SVM to compensate the DC ripple effect on load. Frequency modulation on top of SVM model is also possible. All the presentation is enriched by many descriptive pictures including representation in the complex plane. Comparison between different choices are included and discussed. The outcome is a complete review of the Space Vector Modulation methods for three-phase inverters allowing the audience to be able to quickly understand and design their own SV application.




## COMPARISON OF SINE PWM AND SPACE VECTOR

### Sinusoidal PWM

Pulse width modulation is the process of modifying the width of the pulses in a pulse train, in direct proportions to a small control signal, the greater the control voltage, the wider the pulses become. By using a sinusoid of the desired frequency as the control voltage for a PWM circuit, it is possible to produce a high power waveform whose average voltage rises sinusoidal in a manner suitable for driving ac motors.

### Space Vector PWM

The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application. Because of the constraint that the input lines must never be shorted and the output current must always be continuous, a voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a non-zero output voltage and are known as non-zero switching states and the remaining two topologies produce a zero output voltage and are known as zero switching states.

The actual speed of the motor is compared with the speed reference. The error is given to a PI controller and limited. The resulting signal is called the torque reference current *. This is compared with the actual current, obtained from the motor after Clarke and Park's transformations of currents

, , the stator currents. The current is compared with a zero reference current. The errors are again amplified and limited and the outputs are given to the PWM block. The comparison between Sinusoidal PWM and Space Vector PWM clearly reveals that the torque and hence the speed fluctuations, the current waveforms are better for the Space Vector Modulation when implemented in a Vector Control circuit. A reference speed of 1500 is given as input. The speed fluctuations are more in sinusoidal PWM. This also reveals that the current waveforms are better for SVPWM.

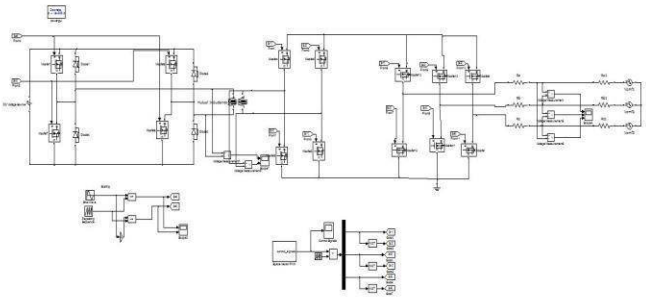
Total Harmonic Distortion (THD) is a complex and often confusing concept to grasp. However, when broken down into the basic definitions of harmonics and distortion, it becomes much easier to understand.

$$THD = \frac{\sqrt{(V_2{}^2 + V_3{}^2 + V_4{}^2 + \ldots\ldots V_n{}^2\,)}}{V_1} * 100\% \qquad (29)$$

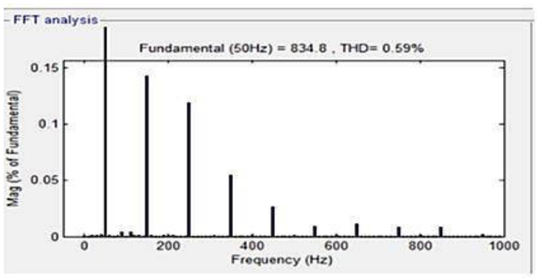
$$THDi = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1} \qquad (30)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{h=H} Ih^2} \qquad (31)$$

## SIMULATION CIRCUIT



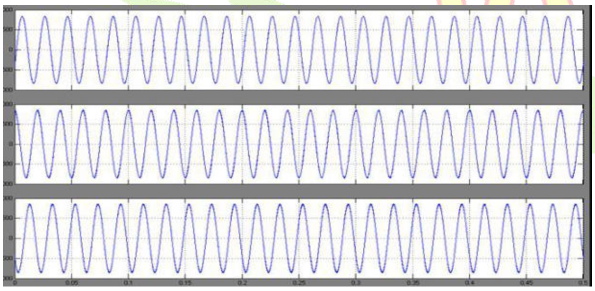
## TOTAL HARMONIC DISTORTION




## OUTPUT VOLTAGE

Output voltage for Phase a, Phase b and Phase c.

Voltage (volts)



Time (sec)

## CONCLUSION

This paper proposes a dc link voltage and active coordinative control method for a cascaded dc-ac interface converter. The coordinative control makes the inverter and DAB to share the tasks of maintaining dc-link voltage and controlling power output. The THD(Total Harmonic Distortion) of the system is reduced by implementing Space Vector Modulation. The efficiency of the system is increased.

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