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VIRTUAL IMPEDANCE AND FFT BASED ACTIVE HARMONIC SUPPRESSION FOR DC-DC CONVERTERS

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ABSTRACT

This project contributes to the steady-state design of the bidirectional dual active bridge (DAB) dc–dc converter by proposing a new model that produces voltages at two directions. An analysis of zero-voltage switching (ZVS) boundaries for boost mode, while considering the effect of snubber capacitors on the DAB converter is also presented. The proposed model can be used to to get a fixed voltage at any desired operating point. The new model can serve as an important teaching cum-research tool for DAB hardware design (devices and passive components selection), soft-switching-operating range estimation, and performance prediction at the design stage. The operation of the DAB dc–dc converter has been verified through extensive simulations. The major task in such design is to reduce the current harmonics present in the power delivered to the DC loads. In the existing system, it claims up to 200% of THD, whereas in the proposed system it is as less as 3.71% of THD. This method does not require any online replacement of lumped components during the operation of the circuit. Moreover, extended phase shift in the gate pulses generation gives a better reduction in the current harmonics.

INTRODUCTION

A harmonic of a wave is a component frequency of the signal that is an integer multiple of the fundamental frequency, i.e. if the fundamental frequency is f, the harmonics have frequencies 2f, 3f, 4f., etc. The harmonics have the property that they are all periodic at the fundamental frequency, therefore the sum of harmonics is also periodic at that frequency. Harmonic frequencies are equally spaced by the width of the fundamental frequency and can be found by repeatedly adding that frequency. For example, if the fundamental frequency (first harmonic) is 25 Hz, the frequencies of the next harmonics are: 50 Hz (2nd harmonic), 75 Hz (3rd harmonic), 100 Hz (4th harmonic) etc. IT is well known that voltage or current harmonics generated by power converters can cause various problems to other equipment connected to the common ac lines

However, the grid background harmonics are not considered in the traditional SHE PWM. In a current source rectifier (CSR) system, due to the use of an input LC filter, the grid background voltage harmonics (such as fifth or seventh harmonic) could be amplified by the filter, which results in a high distortion of the line current, although the grid voltage harmonics are low.

HARMONICS MEASUREMENTS

Harmonics provides a mathematical analysis of distortions to a current or voltage waveform. Based on Fourier series, harmonics can describe any periodic wave as summation of simple sinusoidal waves which are integer multiples of the fundamental frequency. Harmonics are steady-state distortions to current and voltage waves and repeat every cycle. They are different from transient distortions to power systems such as spikes, dips and impulse

$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$

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A pure sinusoidal voltage is a conceptual quantity produced by an ideal AC generator built with finely distributed stator and field windings that operate in a uniform magnetic field. Since neither the winding distribution nor the magnetic field are uniform in a working AC machine, voltage waveform distortions are created, and the voltage-time relationship deviates from the pure sine function. The distortion at the point of generation is very small (about 1% to 2%), but nonetheless it exists. Because this is a deviation from a pure sine wave, the deviation is in the form of a periodic function, and by definition, the voltage distortion contains harmonics.

EXISITING SYSTEM

The inverted voltage is coupled to the secondary of the topology via an SMPS transformer made of ferrite core. This transformer offers a very low impedance to the high frequency in the order of 200 KHz. This high frequency basically introduces harmonics in the output current as well due to the stray capacitances and stray inductances of the power switch. Hence the existing model is very inefficient in terms of harmonic removal.

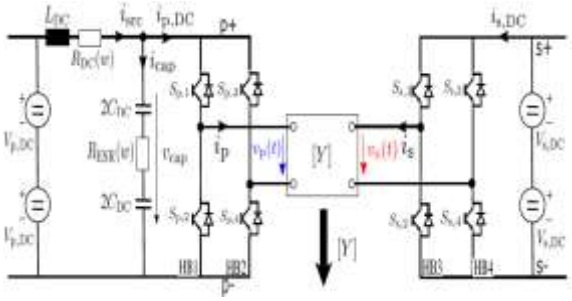

Fig: 1 Proposed virtual impedance Topology

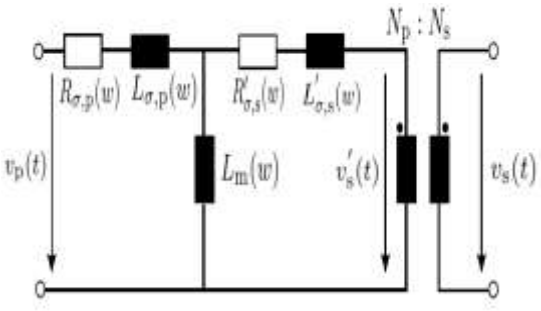

Fig: 2Equivalent circuit of SMPS transformer

Table: Parameters used in existing system

Parameter		Value
Primary bridge _		
..DC bus inductance (parasitic)	L_{DC}	200 nH
..DC bus capacitance	C_{DC}	TBD
..Bulk source capacitance	C_{src}	4.4 mF
AC link coupled inductor	L	103 μH
	R	0.4 Ω
Primary DC bus voltage	$2V_{p,DC}$	50 V
DC-DC bus voltage ratio	d	0.8
Switching frequency	f_{sw}	20 kHz

In addition to say, the operating current is in the order of less than 2A, which is practically very less value of load. In practical cases the current would be in the order of 5A and above.

MATLAB SIMULATION

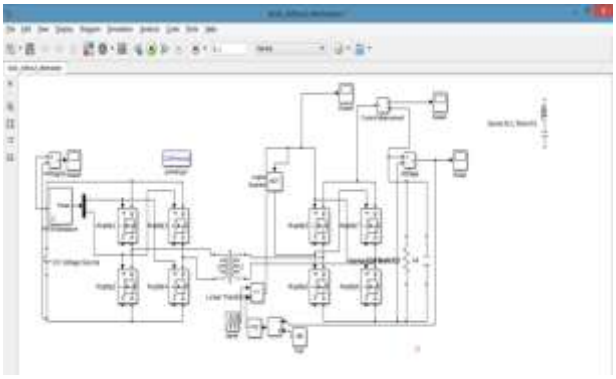

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Fig: 3 Simulink model of DC to DC converter

The Simulink model implemented in matlab 7.13 is shown in the above figure. This consists of H bridge at both inverter section and rectifier section. The PWM pulses are applied separately to the rectifier and inverter. However, the rectifier section is additionally controlled by a PI controller to maintain a stable output DC voltage. Inverter and Rectifier are coupled through a high frequency coupling transformer. The switches in H bridge are operated on diagonal wise. When one diagonal switches is ON, the switches in other diagonal are OFF. The switched waveform obtained at final stage is filtered using a DC capacitor.

Current with harmonics

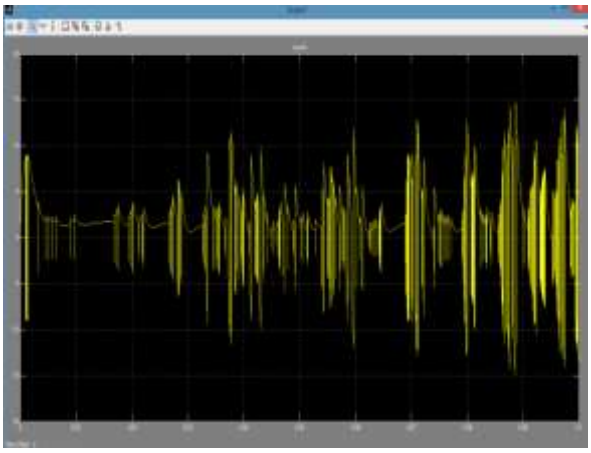

Fig:4 DC Current waveform with harmonics

The output reveals that the current harmonics are more and the pulsating DC current itself has higher harmonics and vibrating in the range of +10 to -10 A. Though the peak to peak value is in the order of 20A the average DC value of the current is the order of 1.5 A as seen in the above simulation output. The task is to increase this magnitude as well as without harmonics.

Voltage with harmonics

Fig:5 DC voltage waveform in existing system

The output reveals that the voltage harmonics are existing and moreover the output is also not stable. It is seen that the output DC voltage in the order of 210 V, which is not stable and pure DC line.

THD in existing topology

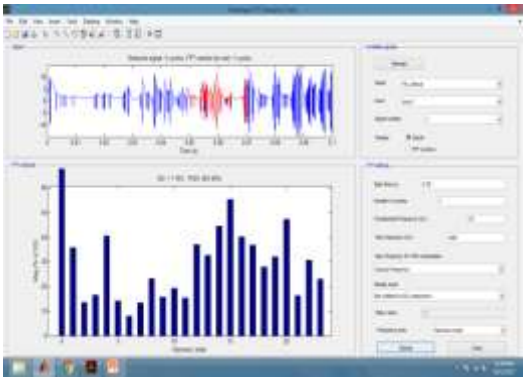

Fig: 6 Current harmonics and its FFT in existing system

FFT analysis is done in matlab by using the power GUI tool box. The fundamental is set as 50Hz, and the harmonics are measured up to 24 harmonic orders. A total THD of around 261 % is obtained in the existing system. Maximum frequency is set to

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1200 Hz, beyond which the harmonics have no impact, because of negligible amplitude at higher harmonics.

PROPOSED SYSTEM

The virtual impedance concept has been increasingly used in power converters or active damping of the converter filter circuit converter output power flow control system harmonics compensation etc. In different applications, virtual resistance, virtual inductance, virtual capacitance, or combination of them has been used. Generally, the virtual impedance is realized through the control of a power converter, and it does not involve the physical loss as in real impedance.

Combining the virtual impedance concept with the recently proposed SHC PWM scheme, an improved SHC scheme can be developed, and is called virtual impedance SHC (VI-SHC) scheme. In the proposed VI-SHC scheme, the extracted harmonic in the line current is used to realize a virtual impedance at the harmonic frequency.Virtual impedance variation is detected and through that the presence of harmonics is detected in current only.

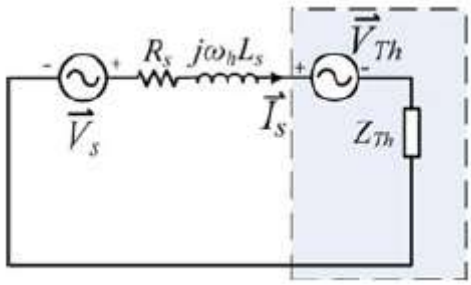

Fig: 7 Concept of virtual impedance

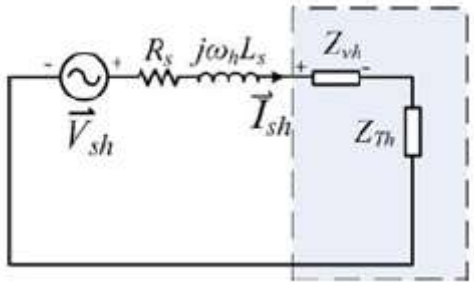

Fig: 8 Equivalent circuit of virtual impedance

1) The proposed VI-SHC scheme compensates the system background harmonics using the line current measurement instead of the source voltage in the SHC scheme. Therefore the VI-SHC PWM is more practical in the real applications, since the voltage distortion is usually very subtle for accurate measurement.

2) As the PWM output in a CSR system is directly related to the line current, the VI-SHC method is essentially a closed-loop compensation scheme by feeding back the line current harmonics. Therefore, it does not require the detailed and precise system parameters for the derivation of the system transfer functions.

Table: 1

Parameter	Value
Rated power	100W
Rated voltage	230V
Fundamental frequency	50 Hz
DC link voltage	200 V
PWM switching frequency	10KHz
DC current	~2A

Both virtual impedance and FFT based analysis is done and both are compared. This is a new method to detect and eliminate both voltage and current harmonics.

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PROPOSED SCHEMATIC DIAGRAM

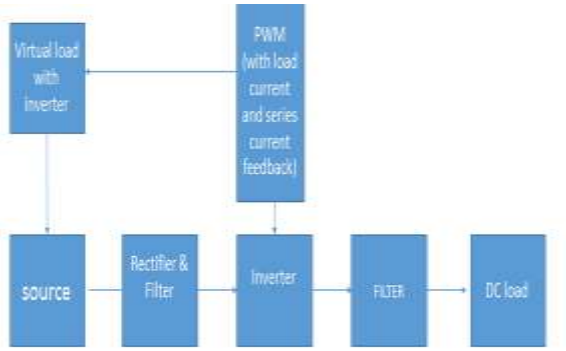

Fig: 9 Block diagram of harmonics elimination method

The proposed current harmonics elimination method is realized using the block diagram shown above. The source DC voltage is first inverted via H bridge consisting of 4 switches. They are operated on diagonal wise and switched ON and OFF vice versa. The inverted voltage is now applied to high frequency ferrite core based transformer to couple this power from primary to secondary. This AC coupled at secondary is now rectified using the H bridge consisting of same 4 switches. Rectified voltage is finally applied to a filter capacitor made of electrolytic capacitor type. The load voltage and current is sensed and feedback is applied to the control circuit which generates the PWM.

$$Ish = \frac{Vsh}{Rs + j\omega hLs + Zth + Zvh}$$

TPS control includes multiple operating modes with respect to the buck/boost and various operating conditions such as heavy-load and light-load cases. Three phase shifts are adopted in the TPS control and the corresponding phase shift ratio are symbolized as D1, D2 and D3. D1 is the phase shift ratio between the diagonal control signals of the same bridge, for instance, between the gate signals of Q11 and Q14; D3 is the phase shift between the primary control signal and the corresponding secondary gate signals, for instance, between the gate signals of Q11 and Q21; D3 is the phase shift between the gate signals of Q11 and Q24. In the forward mode, the transformer primary voltage VT1 is leading to the transformer secondary voltage VT2 so that the power flows from V1 to V2. Considering the volt-second balance of the inductor current iL in one switching period, the current value at switching intervals 1 φ, 2 φ , 3 φ and π for different operating modes of TPS control can be obtained.

$$I_b = V_1/(4L_s f_s), P_b = dV_1^2/(4L_s f_s)$$

Where f_s is the switching frequency, d is the voltage conversion ratio. The variables of d, V1, fs and Ls affect only the magnitude of P_o. The phase-shift group determines operating modes and the amount of output power.

Proposed Hardware block diagram

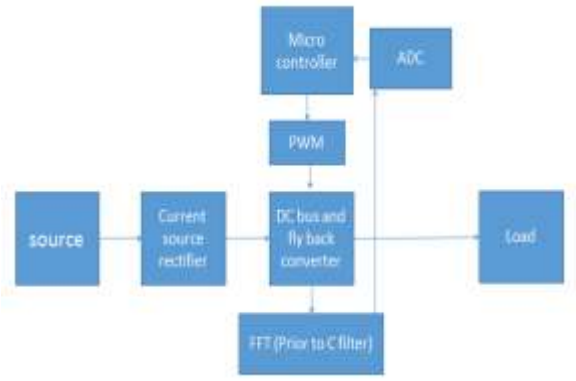

Fig: 10 Block diagram of hardware

The proposed current harmonics elimination method is realized using the block diagram shown above. The source DC voltage is first inverted via H bridge consisting of 4 switches. They are operated on diagonal wise and switched ON and OFF vice versa. The inverted voltage is now applied to high frequency ferrite core based transformer to couple this power from primary to secondary. This AC

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coupled at secondary is now rectified using the H bridge consisting of same 4 switches. Rectified voltage is finally applied to a filter capacitor made of electrolytic capacitor type. The load voltage and current is sensed and feedback is applied to the control circuit which generates the PWM.

Matlab Simulink model

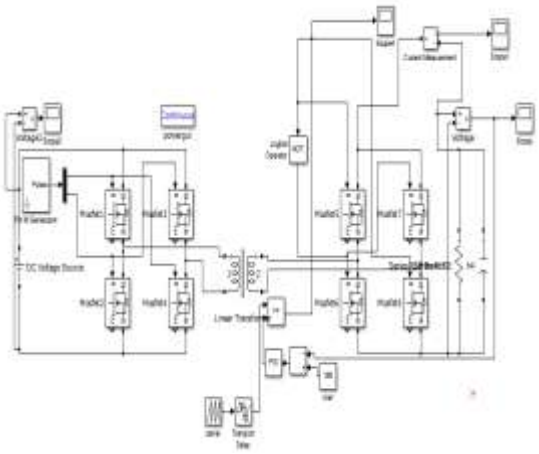

Fig: 11Simulation in matlab

Voltage after harmonics elimination

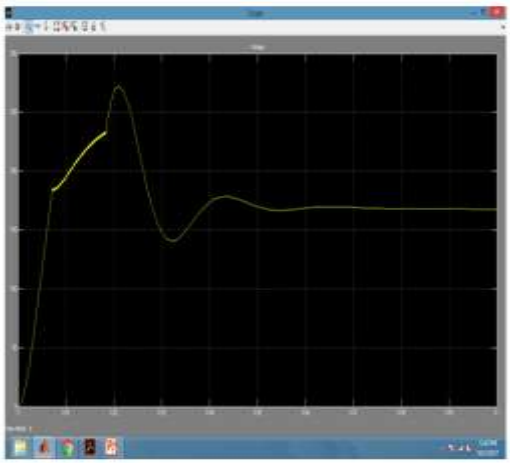

Fig: 12 DC voltage after harmonics elimination

The output reveals that the voltage harmonics are absent and moreover the output is also stable. It is seen that the output DC voltage in the order of 170V, which is stable and pure DC line.

Current after harmonic elimination

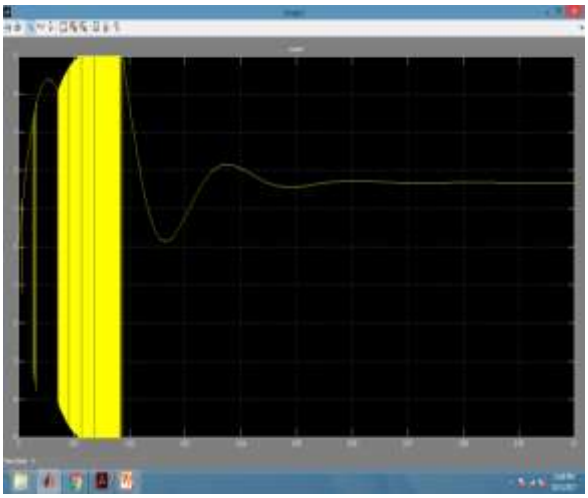

Fig: 13 DC current after harmonics elimination

The output reveals that the current harmonics are more only during the initial conditions and later it settles down to around 1.8 amperes in positive magnitude.

THD after harmonic elimination

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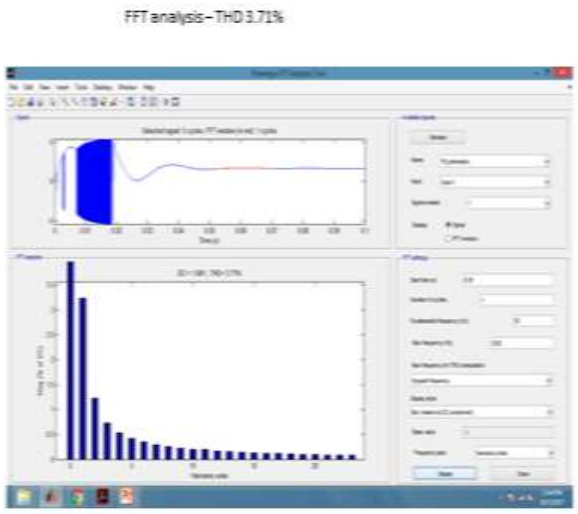

Fig: 14 DC current harmonics through FFT analysis

This shows the THD calculated via matlab up to 24th order as a bar representation by having 50Hz as fundamental (X axis shows the frequency and Y amplitude shows the % magnitude of harmonic current).FFT analysis is done in matlab by using the power GUI tool box. The fundamental is set as 50Hz, and the harmonics are measured up to 24 harmonic orders. A total THD of around 3.71 % is obtained in the proposed system. Maximum frequency is set to 1200 HZ, beyond which the harmonics have no impact, because of negligible amplitude at higher harmonics. Though the THD is not absolute 0%, the best possible least value of THD has been obtained.

HARDWARE REALIZATION

CIRCUIT DIAGRAM

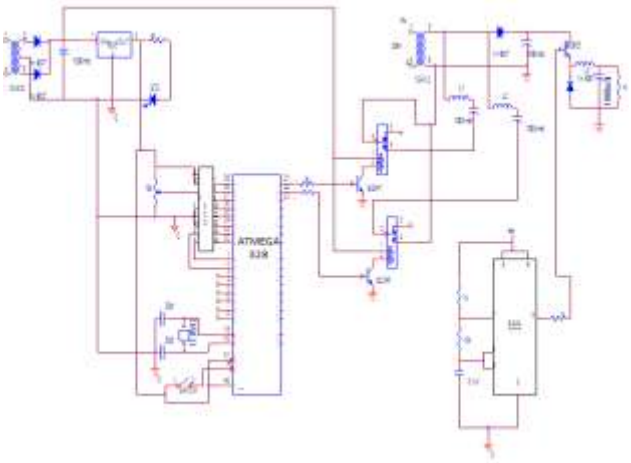

Fig: 15 circuit diagram

Fig: 16 Snapshot of hardware

Previously, a measurement was taken across the whole of the flyback waveform which led to error, but it was realized that measurements at the so-called knee point (when the secondary current is zero, see fig. 3) allow for a much more accurate measurement of what is happening on the secondary side. This topology is now replacing ringing choke converters (rccs) in applications such as mobile phone chargers.

Such filtered DC 5V output after the regulator 7805 is applied to all low voltage devices

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such as LCD, micro controller etc. The buck converter mode is chosen in our hardware implementation to convert from the source AC.

The input source voltage 230Ac is first stepped down to 12V AC. The same is then rectified to produce a DC voltage of peak value around 16V DC. This is considered as the DC voltage input for buck converter. The buck converter is designed with 2N3055 power transistor. The buck voltage will be around 8V. At this conditions, the current lags behind the voltage and this produces harmonics in the input side which will pollute the other AC circuits. Now an impedance is added at the input side, in order to eliminate this harmonics, an LC parallel virtual load is connected. The loads are switched by the relays and controlled by the micro controller atmega 328. The micro controller codings are written in assembly level language and burnt into the programmer via a , Arduino IDE and a flash programmer hardware. The waveforms are viewed in the oscilloscope, both harmonics and without harmonics. This circuit saves enormous energy dissipation in the form of harmonics.

CONCLUSION

This project has presented a new steady-state model for the DAB converter. The square-wave operating mode of DAB is the best mode for high-power transfer. The proposed model produced key design equations for the square-wave mode of the DAB dc–dc converter. Hardware to be implemented using BJT 2N3055. The system gives fine output at both the directions, and able to drive a DC load with 10W power capacity. The harmonics generated in the proposed topology is as less as 3.71% as seen the Simulink outputs. Power loss in the form of harmonics is reduced enormously in the proposed system. Hardware implementation could successfully eliminate the harmonics present in the DC output at the load side.

SIMULATION PERFORMANCE COMPARISON

Parameter	Current state of art	Proposed work
THD (%)	> 200%	3.71 %
Power flow directions	Forward only	Both forward and reverse
Reduction method	Using additional components put in circuit	By varying the virtual impedance of the SMPS transformer
Frequency (kHz)	200	10
Maximum current rating (A)	1.6 A	Around 2 A
Harmonic Order	24	>24 is possible
Stability analysis	Not done	Stable at 0.06 s

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