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An Approach to Inverter-less STATCOM by Using Dual Virtual Quadrature Source Concept

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Abstract

The electric energy transmission and distribution characteristic by AC current is the real power with reactive power. The control on the reactive power of the AC power system has been achieved by the use of Flexible alternating transmission system devices like thyristor Controlled Reactors (TCR), static synchronous series compensator (SSSC), static compensator (STATCOM), and Unified Power Flow Controller (UPFC). The sources of VAR have the disadvantages of slow response, reduced voltage ampere reactance support in fault conditions and High coast of STATCOMs Because of the large DC/AC inverters and High levels of energy storage.

To overcome these drawbacks, an approach to create STATCOM functionality without inverters has been studied. This gives needed dynamic Voltage Ampere Reactance support by bidirectional IGBT semiconductor switches that are arranged in direct AC to AC structures along with voltage ampere reactance (VAR) compensation capacitors. The principle of operation for the Inverter Less-STATCOM is described by an AC chopper which is kept between the AC line and the Voltage Ampere Reactive (VAR) capacitor to provide the desired VAR required. This is explained with the help of C-buck and C-boost cell configuration in the paper.

1. Introduction

The STATCOMs generally provide well behaved harmonic compensation that is not susceptible to nearby capacitor banks and does not easily excite resonances. But the level of market penetration continues to be small due to cost. The high switching frequencies required and the substantial energy storage needed, result in high cost and poor reliability. Conventional sources which provide Voltage Ampere Reactance, such as capacitor banks and generators are too slow to give the desired impact. Static Compensator (SVC) is faster, responding in half to one cycle, but offers reduced voltage ampere reactor support under fault conditions. STATCOMs are faster, which allow dynamic control, but are much costly as they require large DC/AC inverters and significantly high levels of energy storage.

A full-scale Inverter Less-STATCOM from C-buck and/or C-boost cells can be implemented using a certain number of paralleled low voltage AC chopper modules configured in buck or boost mode as required. In this paper work, five series stacked C-buck cell are used for single phase to implement a full scale Inverter Less-STATCOM with each cell operating under ‘Voltage Quadrature Source’ modulation control strategy for reactive power compensation.

1.1 Dual virtual quadrature sources

To achieve both node voltage and branch current control, we need to control both the amplitude and the phase angle of the voltage. The methods for achieving such control involve phase-angle regulators, transformers with cross-coupled phases and tapped windings that are used to provide the desired amplitude and phase. This is expensive approach, and has some problematic faults modes that can not provide dynamic response. The ‘VQS’ concept have mathematic analysis as given in reference [24] is simulated in MATLAB.

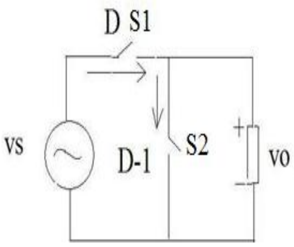

Fig. 1

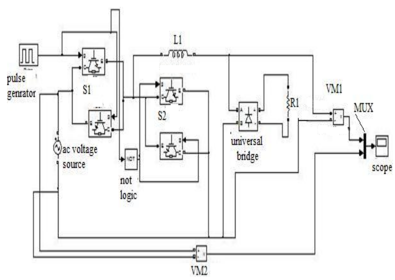

Fig. 2

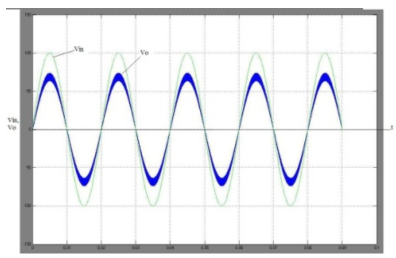

Fig. 3

The output voltage across the bridge and input voltage waveform are shown in figure (3) as figure (1) is simulated to verify voltage quadrature source concept [24] in simulink of MATLAB using the figure (2) block set. The Duty cycle used in the simulation is chosen constant D = 0.7 that gives the output voltage as $V_o = 0.7\times100 = 70V$. Thus we conclude that the magnitude of the output voltage of an AC chopper circuit can be varied by the duty cycle ‘D’. As when switch S_1 is on and S_2 is off the V_o achieves maximum value and the inductor current I_L increases, now when S_1 is off and S_2 is on the V_o decreases to zero and the inductor current I_L decreases.

1.2 buck and C-boost cell

AC converter can be used with capacitor to realize dynamically controllable 'Voltage Ampere Reactance' as an AC chopper is inserted between the AC line and the capacitor 'C', which is controlled with a constant duty cycle 'D' at a relatively high switching frequency 'f_{sw}'. Higher switching frequency components are filtered by 'L_f' and 'C_f'. The switches are operated by duty cycle 'D' and '(1-D)' as shown in figure (4). At a duty cycle 'D', the effective net capacitive impedance on the output is seen to be ($D.X_c$). The capacitive 'Voltage Ampere Reactance' drawn can be varied from zero to the maximum nominal value [22]. 'D' can be varied with even harmonic modulation (VQS) to realize harmonic distortion suppression functions [24]. Figure (4) shows that the capacitance can be increased by configuring the 'boost AC cell'. As 'D' is varied, the net capacitive impedance of the C-boost cell looks like '$C/ (1–D).X_c$', where 'C' can be varied between 0 and 'D'. The configuration of the C-buck and C-boost cell is described with their working which is verified by the simulation results.

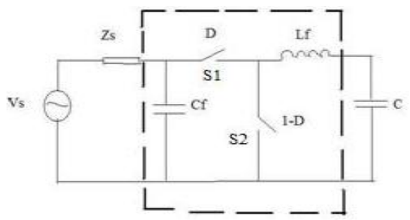

Fig. 4: (C-buck cell block 2)

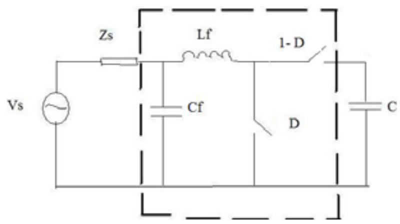

Fig. 5: (C-boost cell block 2)

The figure (4) and (5) shows buck and boost cell respectively. In both the C-buck and C-boost cell the voltage across the capacitor can be varied in a buck and boost mode. This can be understood with the help of simulation. The simulation of the C-buck cell configuration is given in figure (6) and the C-boost cell circuit configuration is given in figure (7).

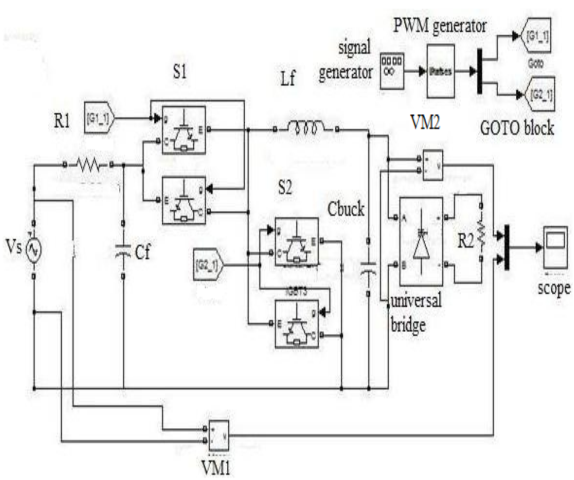

Fig. 6: Buck cell circuit

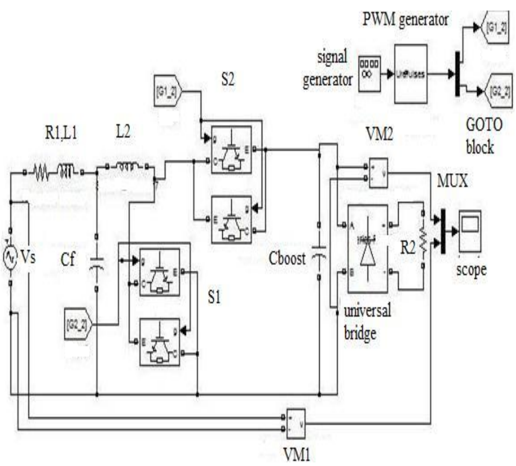

Fig. 7: Boost cell circuit

The switching pulses for switch S_1 and S_2 are generated by the 'PWM' bock shown in figure (6) & (7). These pulses are given to S_1 and S_2 switch by the 'GOTO' and 'FROM' blocks. Signal generator block gives the sinusoidal wave with 50 Hz frequency and compared with unipolar triangular wave having 50 KHz frequency. The 2-level sine wave PWM generator is used to generate pulses for S_1 and S_2 which having opposite polarity. The amplitude modulation index used in buck cell and boost cell is (0.2,0.4,0.6 & 0.8) and 0.22 respectively. The resulted waveforms are shown in the figure (8) & (9).

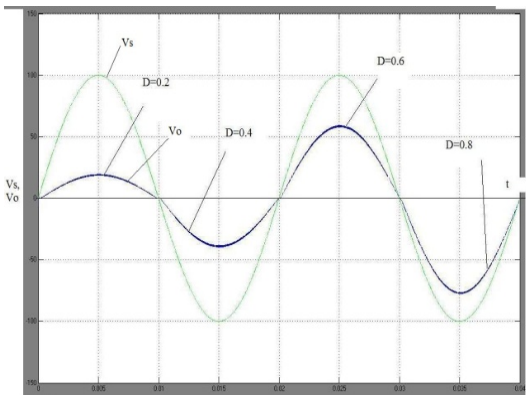

Fig. 8: Variation of magnitude according to duty cycle in C-buck cell)

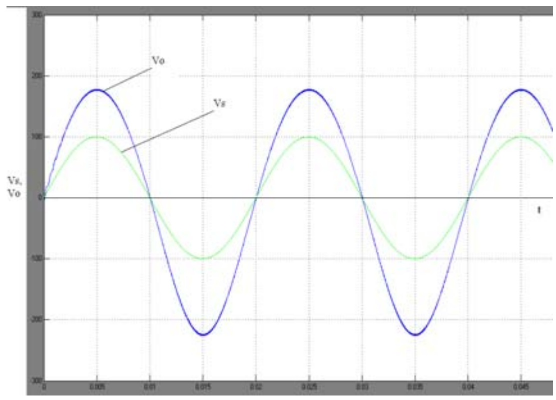

Fig. 9: Resulted waveform of C-boost cell

From the results, the behaviour of the C-buck cell is obtained as the output capacitive voltage is less than the input voltage and can be increased to the maximum value of the input voltage. Now this can be understood by taking the different values of the duty cycle in each half period of the input voltage as given in the figure (8). Here four values of the duty cycle are taken in each half period of the input voltage. The value of the different duty cycle is indicated in each half period such as D= (0.2, 0.4, 0.6, and 0.8). Now we can see that the output voltage is never exceeds the input voltage and the magnitude is varied according to increment in the duty cycle. The figure (9) shows the C-boost operation, where the value of the output capacitive voltage is higher than the input voltage and the equivalent capacitance at the input side is accordingly varied. The output voltage and the input voltage are indicated by the arrows in the figure (9). From the analysis of buck-boost cell we find that the buck output capacitance can be equal to 'D.C' and the boost output capacitance can be calculated as 'C/(1–D)'. Here 'D' has limit to ($0 \leq D \leq 1$). The figure (8) explained that how the magnitude of the output voltage of the buck cell can be varied by taking different values of the duty cycle.

2. System Consideration

Implementation of a full-scale IL-STATCOM of 17 KVA rating is done with C-buck cell configuration and simulated by using the ‘Voltage Quadrature Source’ even harmonic modulation technique. The three phase system with non linear load is simulated in MATLAB given in figure (10). Where the C-buck controller is connected between the two buses ‘B_1’ & ‘B_2’, these buses is used to measure the instantaneous value of current and voltage. The C-buck controller is a shunt compensator which is used to supply the reactive power to improve the voltage profile of the system. The C-buck controller has five C-buck cell per phase and each C-buck cell provide the dynamic ‘Voltage Ampere Reactance’ support to the line as the reactance of the C-buck cell can be varied dynamically with ‘VQS’ modulation technique [24]. The three phase breaker in figure (10) is used to connect C-buck controller after the 0.1 sec delay for analysis and to observe the effect of the C-buck cell controller on system voltage.

Parameters of C-buck cell controller:- C_f=5μF, L_f=1mH, R_1=10Ω, C_{buck}=5μF, Snubber resistance R=1KΩ Forward voltage V=1V, R_{on}=0.01, Bidirectional switches are S_1,S_2, Current and voltage measurement blocks= CM,VM.

Carrier frequency in PWM block =15KHz

C_f=5μF, L_f=1mH, R_1=10Ω, C_{buck}=5μF, Snubber resistance R=1KΩ Forward voltage V=1V, R_{on}=0.01, Bidirectional switches are S_1,S_2, Current and voltage measurement blocks= CM,VM.

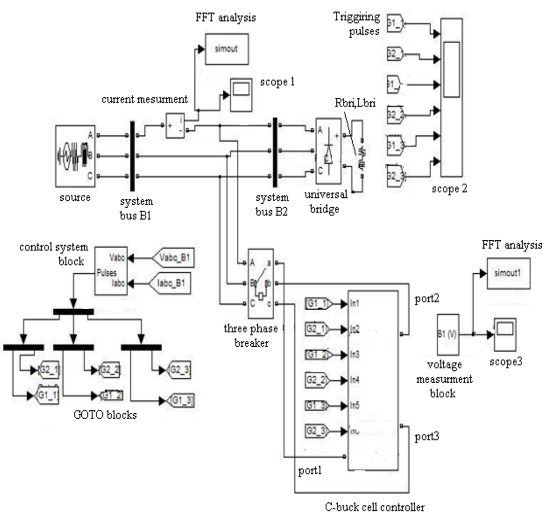

Fig. 10: Full IL-STATCOM circuit.

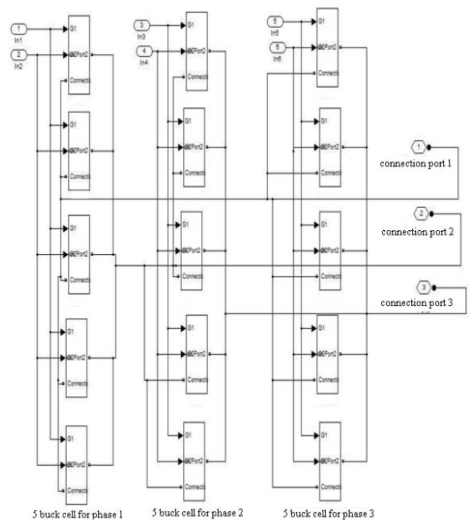

Fig. 11: 5-buck cell per phase.

C-buck cell parameters;- AC voltage source $V_{s(peak)}$=600V, Carrier frequency =15KHz, Source frequency f_s=50Hz, R_s=25 m Ω, L_s=1m H,R_l=50Ω, L_l=50mH

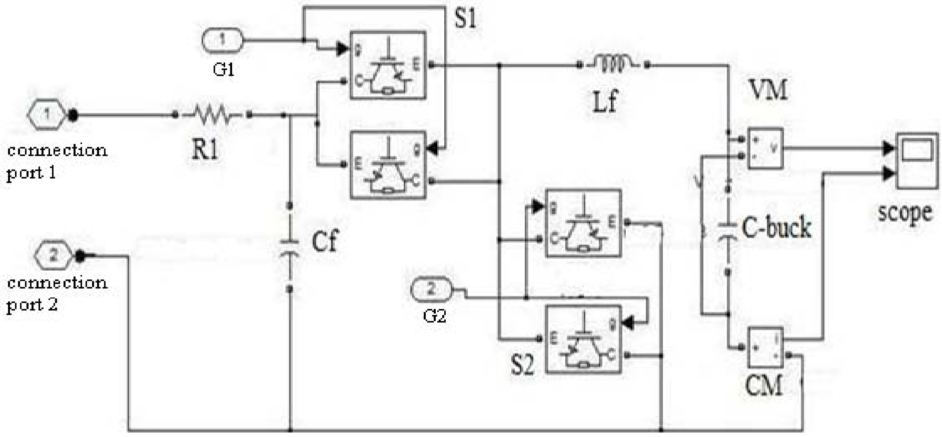

Fig. 12: C-Buck Cell.

3. Results

The carrier frequency used in discrete 'PWM' generator is 15 KHz, which is compared with instantaneously generated sinusoidal waveform to obtain variable duty cycle for C-buck cell controller. The generated three trigging pulses for three phase system are applied to the C-buck cell controller. The switching variation in C-buck cell voltage causes to generator injection current. This injection current is used to improve the voltage profile of the system and to remove the distortion of the line current and voltage due to the nonlinear load as shown in figure (13) and (14) respectively.

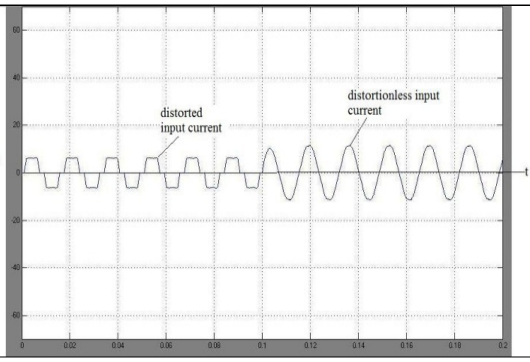

Fig. 13: Effect of C-buck controller on input current.

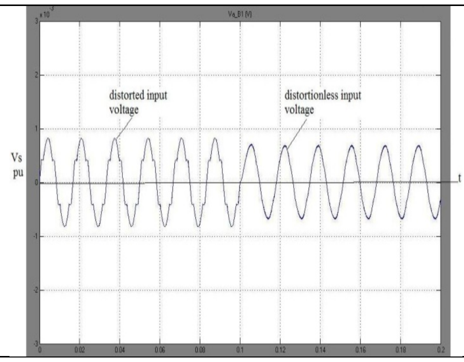

Fig. 14: Effect of C-buck controller on input voltage.

The distortion in the line voltage as well as in line current which can be measured by the Total harmonic distortion (THD) obtained by Fast Fourier transform (FFT) analysis for input current and input voltage respectively. That gives the 21.29% THD in line current and 11.47% THD in the line voltage. The FFT analysis is achieved by the 'SIMOUT' block in the MATLAB tools.

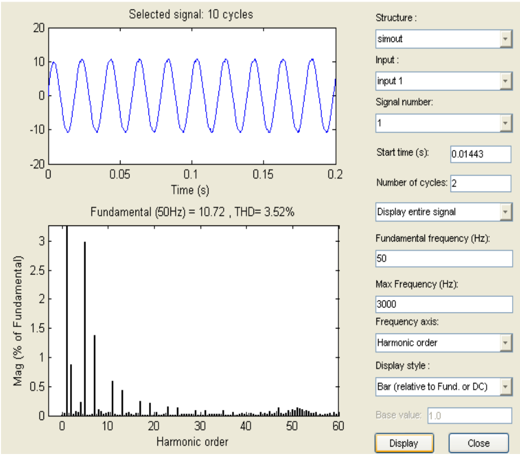

Fig. 15: FFT analysis of distortionless input current.

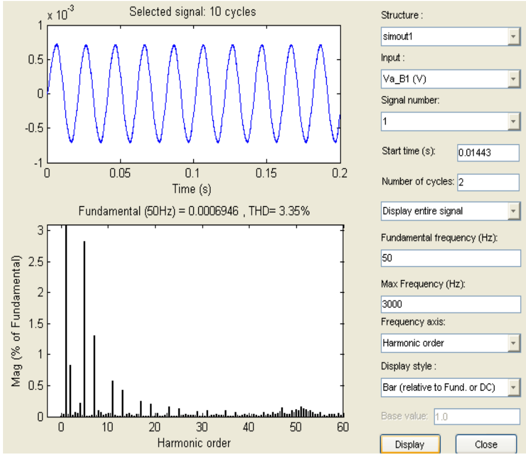

Fig. 16: FFT analysis of distortionless input voltage.

The THD in the input current and voltage is reduced by the C-buck controller by removing the significant distortion. The current THD is reduced to 3.52% and the voltage THD is reduced to 3.35% as shown in the figure (15) & (16) respectively. The fundamental frequency in all FFT analysis is taken to be 50 Hz. Using Labels within Figures.

4. Conclusion

The IL-STATCOM is implemented with the C-buck cells using 'VQS' modulation technique. The capacitors used in C-buck of IL-STATCOM are the compensating capacitor, which are used to provide the dynamic reactive power compensation and hence behaves as a reactive power compensating device like STATCOM without inverter. The IL-STATCOM consisting shunt VAR compensation capacitors coupled with IGBTs configured into direct AC converters (C-buck, C-boost cell) allows dynamic VAR control and harmonic isolation functions in the system by using VQS-PWM technique. The stacking of C-buck cells controller is used to obtain higher voltage levels and it shows good controllability to provide a good voltage balancing function. The IL-STATCOM presents higher-performance than SVCs, and lower cost than existing STATCOM designs by removing energy storing devices like inverter. The main attribute of IL-STATCOM is, removal of energy storing devices, which reduced the size and cost of the system where as in the conventional methods, the energy storing devices increases the size and cost of the system. In achieving regulation of the capacitor voltage, some of the FACTS devices causes the complexity in the system, but in the case of IL-STATCOM there is no requirement of regulation and therefore reduces complexity in the system.

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