An Analysis of Inverter-Less STATCOM using AC Chopper

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Abstract— This paper presents an approach of implementing Inverter-Less STATCOM by AC chopper in which AC chopper is placed between the AC line and compensating capacitor for desired VAR control. For this we place C-buck and C-boost cell configurations instead of inverter. Dynamic VAR support is necessary to grid for balancing the faults on the system. The conventional sources of VARs which are capacitor bank and generator are too slow to provide desired impact. STATCOMs have fast response for dynamic control but they are much costly as they consist of large DC/AC inverters and significant high levels of energy storage. Inverter-Less STATCOM provide dynamic control of VAR and there is no need of storage energy. The principle of operation, design and methods of the IL-STATCOM has been discussed in detail with simulation and experimental results to validate the same.

Key words: dynamic control, STATCOM, C-buck and C-boost converter, inverter-less STATCOM

I. INTRODUCTION

There is a growing need for dynamic control of the power system. The primary driving factors are the growth in penetration of renewable resources and growth in the consumption of power. The power system is operated with conservative safety margins. Dynamics seen on the network today do not impact the network significantly enough to cause interruption in supply of power to the consumer. This will however not be the case in the near future because of the decreasing safety margins with which the system is operated.

Resources used to control operation of the power system can be classified as static and dynamic. The classification is based on the steady state and dynamic control capabilities and response times. Along with the need for dynamic control, increased controllability of the power network is also desirable. This is required to ensure maximum utilization of the existing infrastructure. Dynamic controllability of the network is achievable using commercially available solutions. These solutions are however cost intensive and have poor reliability, as they are typically single-point solutions, failure of which will result in large sections of the network being affected. [1-2]

Capacitor banks and generators are the conventional sources of VARs responses too slowly to have the desired dynamic control. Static VAR compensator (SVC) is widely used but it consist several drawbacks such as the response time for the SVC is still at least ½ to 1 cycle, making it slow for fault ride-through. Further, during fault conditions, the system voltage is frequently depressed and SVC VAR sourcing capability is dramatically reduced, at precisely the time when maximum VAR support is needed.

The STATCOM uses a high power inverter to synthesize a current that is in quadrature with the voltage. Through appropriate pulse width modulation inverter control, the STATCOM can appear like a desired value of an inductive or capacitive load to the utility grid. Further, the current produced by the STATCOM can be rapidly varied through microprocessor control to produce the dynamic capabilities required for fault ride-through. This has made it an attractive tool for utilities to consider using when grid faults occur. As a result, several vendors now offer STATCOM devices commercially But it is costly due to use of high level DC-AC inverter and high level of energy storage is needed [3].

This paper proposed the concept of an Inverter-Less STATCOM (IL-STATCOM or Smart VAR) that realizes a wide range of dynamic capacitive VAR control without using a dc/ac inverter stage. Gate turn-off semiconductor switches are configured in direct ac/ac structures along with VAR compensation capacitors, to realize the desired functionality. Under nominal voltage the IL-STATCOM can deliver fully controllable capacitive VARs from zero to a maximum design value. By adding a suitably rated inductor, the VARs can be varied over a lagging to leading value as desired. Under system fault conditions, the effective capacitance connected to the grid can be increased under control, to be able to maintain a maximum value of leading reactive current. The response of the IL-STATCOM is rapid, matching the inverter based STATCOMs, and the levels of VARs that can be supplied are comparable.[4].

II. C-BUCK AND C-BOOST CELLS

C- buck cell and C-bost cell are the configration in which voltage across the capacitor of capacitance C can be instantaniously varied. The C-buck cell is configured in the buck mode as it provieds the reduced voltage across C with respect to the input voltage. The C-buck cell configuration is shown in fig.1.

In the C-buck cell configuration an AC chopper circuit is inserted between the input voltage and the C-buck capacitor as shown by the dotted lines in fig.1(a). Now as in AC chopper the output voltage is varied according to equation

$$V_o = DV_{in}$$

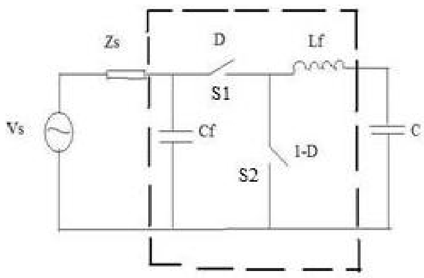

Fig. 1: IL-STATCOM- buck cell

Therefore the output voltage is accordingly changed with the variation in the duty cycle and hence the variable capacitance is observed as C_{eq}=D.C where D is the duty cycle. Thus the capacitance is varied from 0 to C.

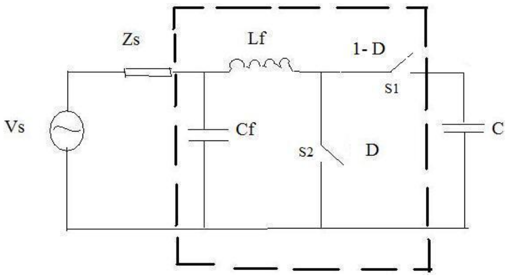

Fig. 2: IL-STATCOM boost cell

Fig.2shows the'C-buck' cell configured to operate backwards, i.e. as a 'C-boost' cell. It is operated in boost mode as the output voltage can be varied to higher magnitude with respect to input voltage. The equivalent capacitance observed is C / (1 – D). Now the C-boost capacitance can be varied more than the value of C as D is limited to 0 < D < 1.

III. SYSTEM CONSIDERATION

A full-scale IL-STATCOM from C-buck and C-boost cells can be implemented using one of several different approaches. The IL-STATCOM can be implemented using a certain number of paralleled low voltage ac chopper modules configured in buck or boost mode as required, with the whole group connected to the high voltage line. One possibility for achieving higher power levels is through the use of series stacked cells, possibly looking at transformer-less versions for even lower cost and losses. Two distinct approaches are possible. The first involves a simple stacking of individual C-buck and/or C-boost cells, with a small rated transformer providing a voltage balancing circuit. If we assume operation of say five stacked C-buck cells operating as shown in Fig.3, the cells can be controlled so as to dynamically share voltage.

However, when the duty cycle D is zero, with the IL-STATCOM providing minimum VARs to the line, it is critical that the voltages across the semiconductors be balanced. This function is provided by the filter capacitors C_f in each module, but may need to be augmented by the small rated transformer block that is an integral part of the series-stacked C-buck module. Fig.3 shows the basic design of a stacked C-buck cell, including how the transformer can be integrated into the basic module.

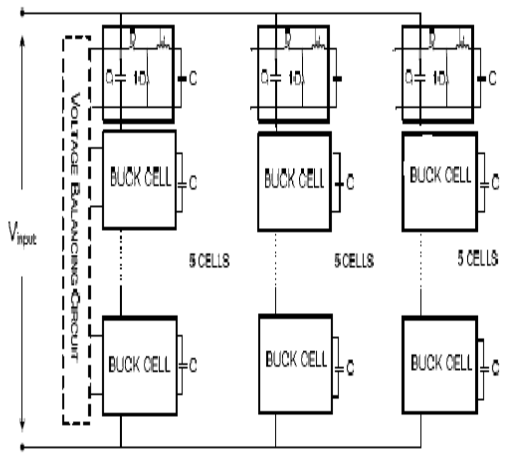

Fig. 3: Single-phase implementation of IL-STATCOM with Buck Cells

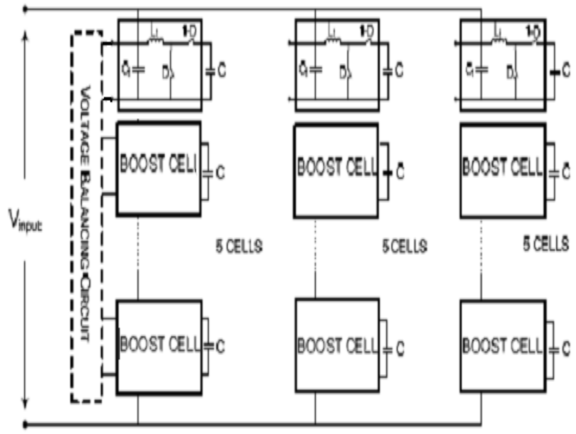

Fig. 4: Single-phase implementation of IL-STATCOM with Boost Cells

A similar stacking arrangement and operating principle is proposed for the stacked C-boost cells as shown in Fig.4 Taken together, it is possible to realize a transformer-less IL-STATCOM suitable for medium voltage applications.

IV. IMPLEMENTATION OF INVERTER-LESS STATCOM

A. *Inverter-less STATCOM using C-buck cell controller*

Implementation of a full-scale IL-STATCOM is done with C-buck cell configuration and simulated by using the VQS even harmonic modulation technique. The three phase system with non linear load is simulated in MATLAB given in fig.4 where the C-buck controller is connected between the two buses B_1 & B_2 as shown in figure. These buses are 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 VAR support to the line as the reactance of the C-buck cell can be varied dynamically with VQS modulation technique

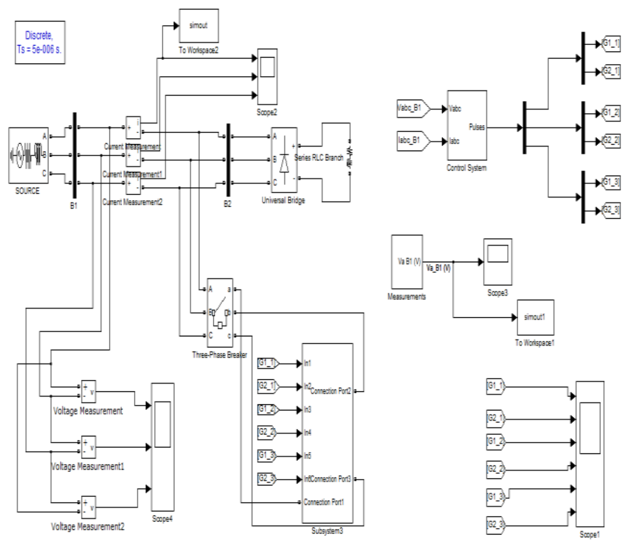

Fig. 5: Inverter-less STATCOM simulation circuit

The subsystem-3 in the fig.5 incorporates 15 subsystems which are showing five C-buck cell per phase as given in fig.6.

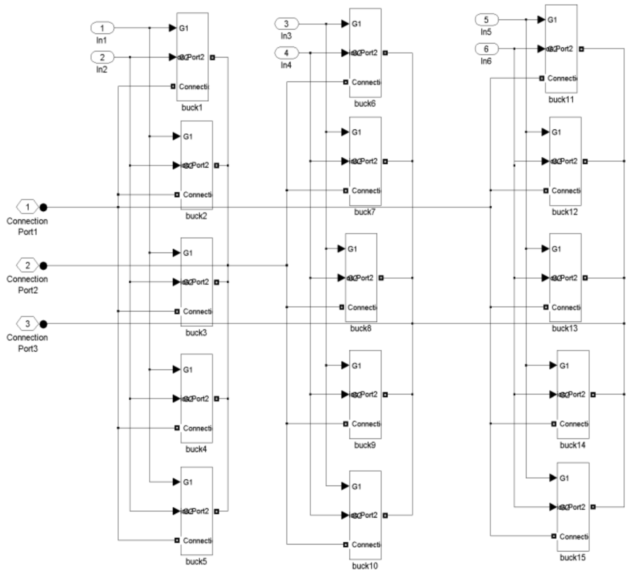

Fig. 6: C-Buck controller consisting 5-buck cell per phase

There are 15 subsystems shown in fig.6 and each subsystem is the C-buck cell as given below:

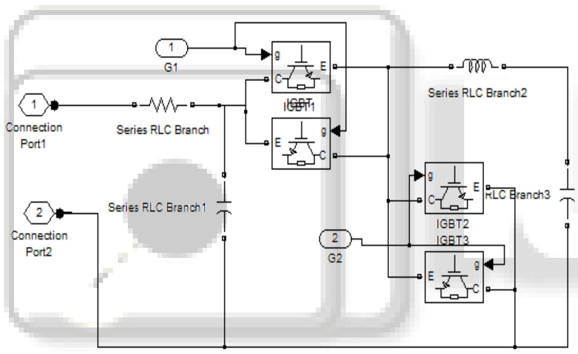

Fig.7: C-Buck Cell

Fig.8 and fig.9 shows the distortion-less input voltage and current using the C-buck controller.

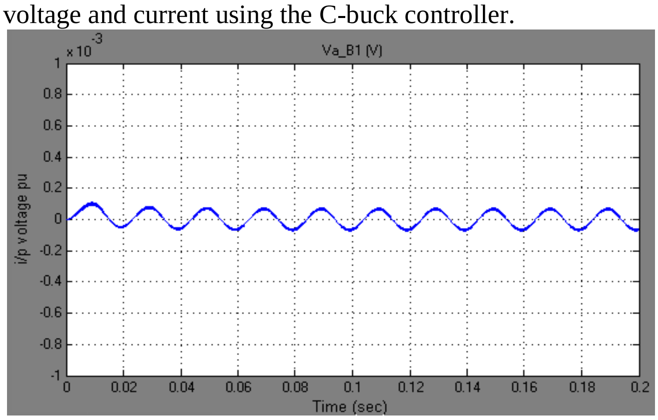

Fig. 8: Distortion-lees input voltage using C-buck controller

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 analysis (FFT) as shown in the fig.10 and fig.11 for input voltage and input current respectively. This shows the 0.40% THD in line current and 7.47% THD in the line voltage. This FFT analysis is achieved by the SIMOUT block in the MATLAB tools.

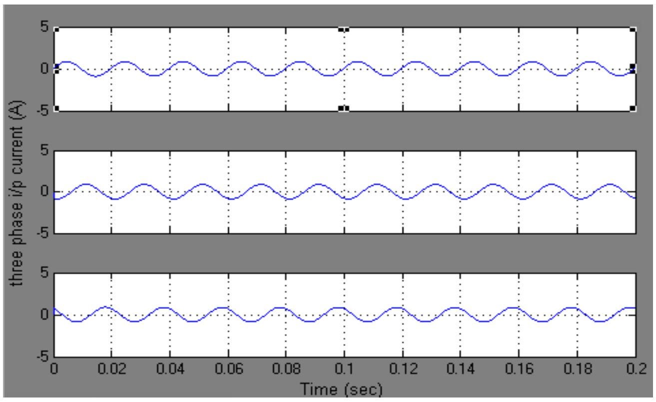

Fig. 9: Distortion-lees three-phase input current using C-buck controller

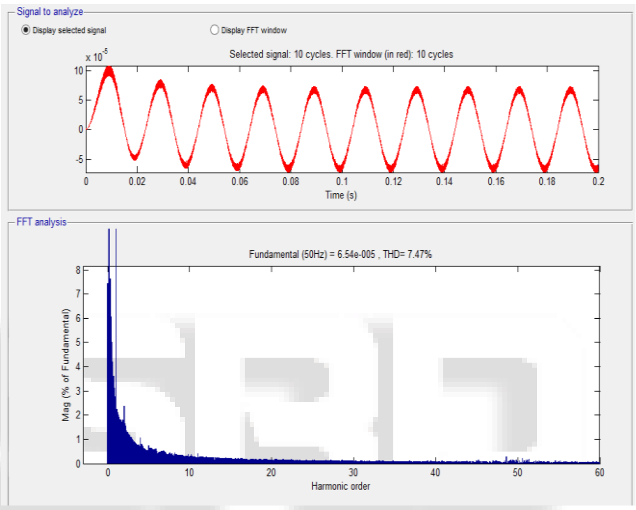

Fig. 10: FFT analysis of distortion-less input voltage using C-buck controller

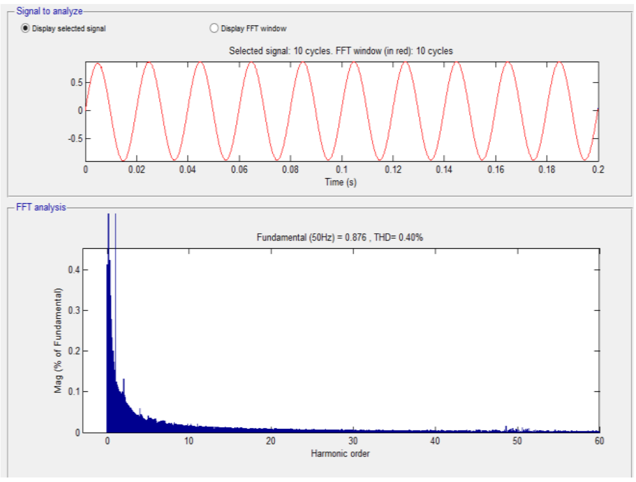

Fig. 11: FFT analysis of distortion-less input current using C-buck controller

B. Inverter-less STATCOM using C-boost cell controller

Inverter-less STATCOM can be implemented using boost cell also. The subsystem-3 in the fig.5 incorporates 15 subsystems which are showing five C-boost cell per phase as given in fig.13.

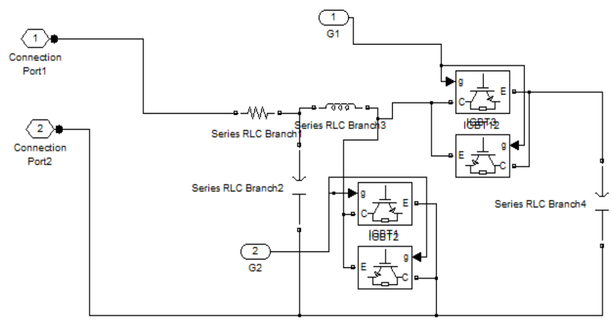

Fig. 12: C-Boost Cell

There are 15 subsystems shown in fig.13 and each subsystem is the C-boost cell as given in fig.12:

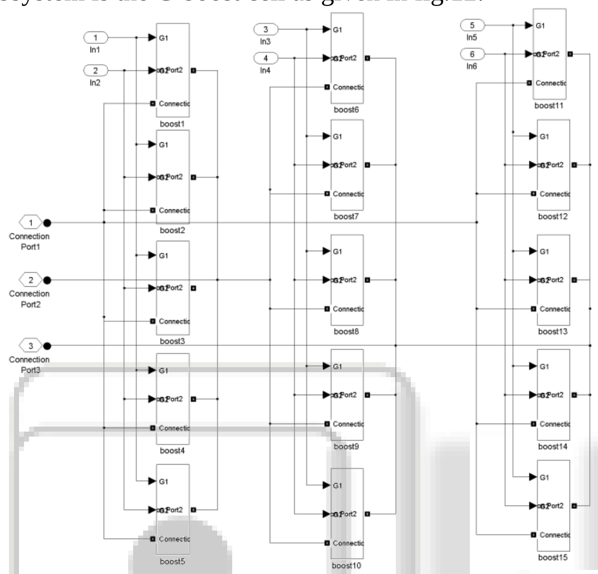

Fig. 13: C-Boost controller consisting 5-boost cell per phase

Fig.14 shows the graph of distortion-lees input voltage using C-boost controller

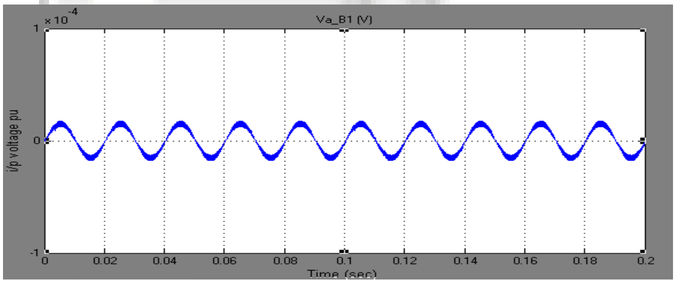

Fig. 14: Distortion-lees input voltage using C-boost controller

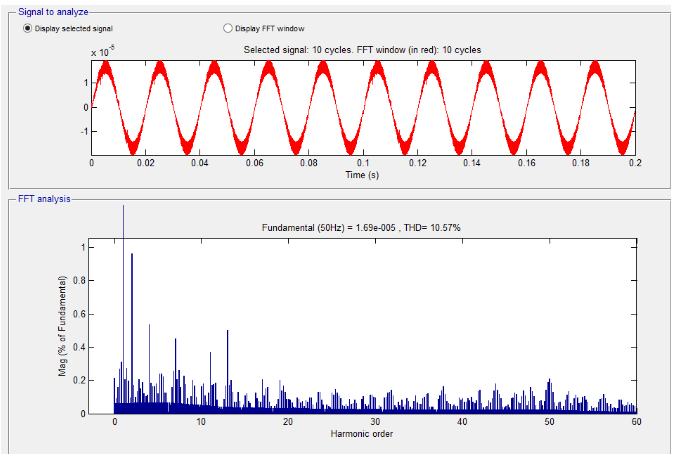

Fig. 15: FFT analysis of distortion-less input voltage using C-boost controller

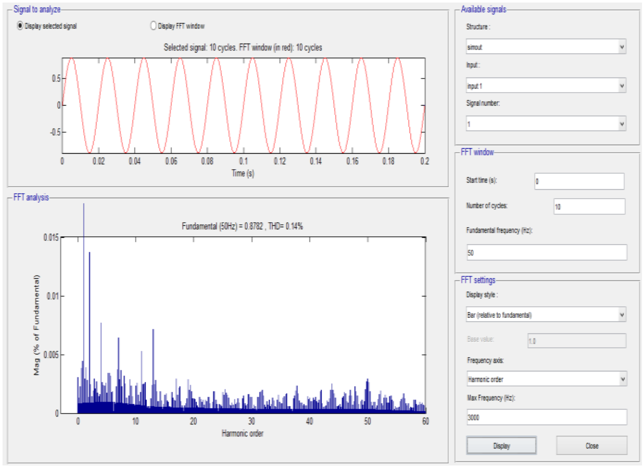

Fig. 16: FFT analysis of distortion-less input current using C-boost controller

Fig.15 and Fig.16 show the total harmonic distortion for input voltage and input current respectively. This shows the 0.14% THD in line current and 10.57% THD in the line voltage.

When C-buck or C-boost controller is disconnected through circuit breaker then distorted voltage and current is resulted. This gives the comparative analysis of with and without controller in the circuit.

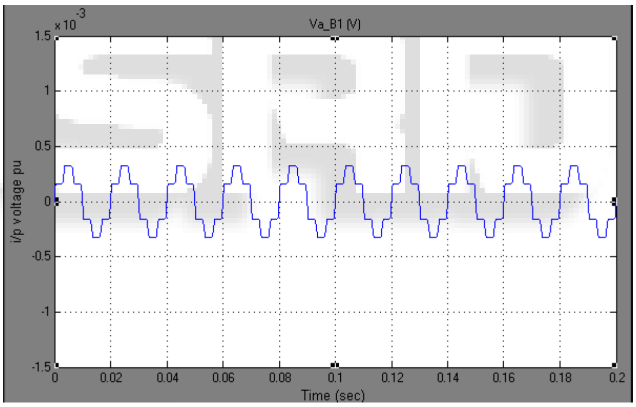

Fig. 17: Distorted input voltage

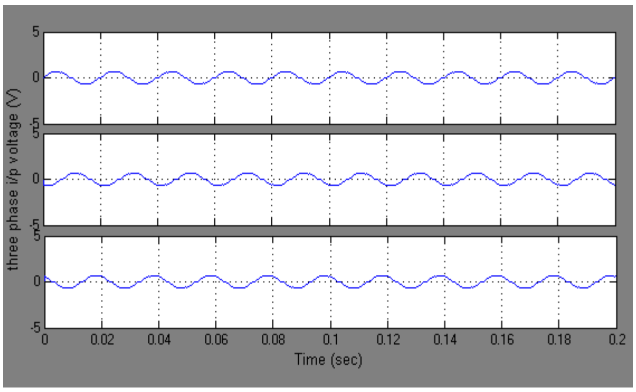

Fig.18 Three phase distorted input current

Fig.17 and fig.18 shows the graph of distorted input line voltage and current respectively.

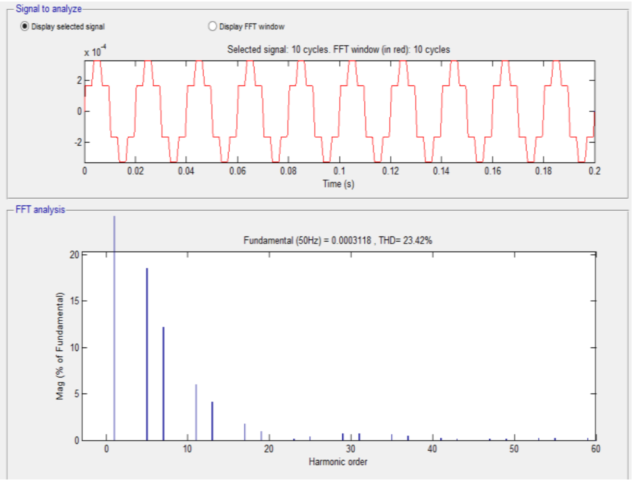

Fig. 19: FFT analysis of distorted input voltage

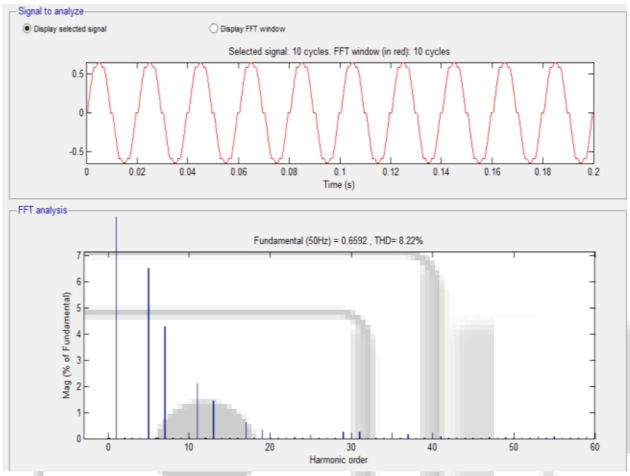

Fig.20 FFT analysis of distorted input current

Fig.19 and Fig.20 show the total harmonic distortion for distorted input voltage and current respectively. This shows the 8.22% THD in line current and 23.42% THD in the line voltage.

V. CONCLUSION

A novel approach to implementing Inverter-Less STATCOMs, or IL-STATCOMs, using shunt VAR compensation capacitors coupled with readily available IGBTs configured into direct ac converters has been presented in this paper. The use of VQS PWM techniques allows dynamic VAR control and harmonic isolation functions [6]. The proposed approach can be easily scaled using a variety of approaches to implement IL-STATCOMs suitable for high power and high voltage operation. Two approaches has been presented in this paper for implementing Inverter-Less STATCOM by using series stacked C-buck cell configuration and C-boost cell configuration, both methods provide distortion-less input voltages and currents and reduced harmonic distortion. By using the C-buck cell along-with C-boost cell i.e. C-buck cell in one phase and C-boost cell in two other phases also provide third type of Inverter-Less STATCOM.

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