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Improvement of Voltage Profile by 84-Pulse VSC Configuration Using Multi-Level Converter Using STATCOM

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Abstract: ***In this work, the Static Synchronous Compensator (StatCom) is one of the most useful FACTS devices, since it can synthesize the reactive power from small storing elements. By regulation of the StatCom's output voltage magnitude, the reactive power exchange between the device and the transmission system may be controlled to improve the power system voltage profile .Since the StatCom may cause interference on the system's fundamental sine wave at frequencies that are multiples of the fundamental one, special care should be taken to ensure not to pollute the system to prevent further harmonic issues. In general, there are three feasible strategies to assemble a VSC: (i) the multi-pulse; (ii) the multi-level; (iii) and the pulse width modulation. Strong efforts have been made in order to reach minimum harmonic distortion in the VSC's output voltage. This paper analyzes the structure of an 84-pulse voltage source converter (VSC), assembled by combining one twelve-pulse VSC, in conjunction with an asymmetric single phase seven-level converter plus an injection transformer.. With this arrangement, the VSC output's total harmonic distortion in voltages is reduced, allowing it to be used in special applications The results found that the proposed strategy allows savings in the number of employed switches.***

Keywords: Statcom, Multi Pulse Converter, Voltage Source Converter Injection Transformer, Fast Fourier transform (FFT)

1. Introduction

In recent years, Voltage Stability and Control (VSC) are increasingly becoming a limiting factor in the power systems planning and operation, mainly in longitudinal ones. However, a variety of factors constrain the construction of new transmission lines. This has been reflected in the necessity of maximizing the use of existing transmission facilities. On steady state, bus voltages must be controlled within a short interval. A suitable voltage and reactive power control allows to get important benefits in the power systems operation such as the reduction of voltage gradients, the efficient transmission capacity's utilization and the increase of stability margins.. The Static Synchronous Compensator (STATCOM) is one of the most useful FACTS devices, since it can synthesize the reactive power from small storing elements. When it is operated within the linear region, it is seen by the system as a synchronous voltage source. By regulation of the Statcom's output voltage magnitude, the reactive power exchange between the device and the transmission system may be controlled to improve the power system voltage profile. Since the StatCom may cause interference on the system's fundamental sine wave at frequencies that are multiples of the fundamental one, especial care should be taken to ensure not to pollute the system to prevent further harmonic issues. In general, there are three feasible strategies to assemble a VSC:
(i) The multi-pulse;
(ii) The multi-level;
(iii) The hysteresis controller
The sub sequent chapter describe a strategy to generate the 84-pulse VSC, assembled with the combination of one 12-pulse converter with a seven-level converter, as well as one reinjection transformer to attain the required performance The main objective of the work is to maintain power flow in transmission lines, and to eliminate the harmonics such as voltage sag, swell, flicker and as well as the current harmonics and to maintain power factor also.

1.1STATCOM

In 1999 the first SVC with Voltage Source Converter called STATCOM (STATIC COMPENSATOR) went into operation. The STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost and lower operating and maintenance costs. A STATCOM is built with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs.

The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point. This means, that even during most severe contingencies, the STATCOM keeps its full capability. In the distributed energy sector the usage of Voltage Source Converters for grid interconnection is common practice today. The next step in STATCOM development is the combination with energy storages on the DC-side. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.STATCOMs are based on Voltage Sourced Converter (VSC) topology and utilize either Gate-Turn-off Thyristors (GTO) or Isolated Gate Bipolar Transistors (IGBT) devices. The STATCOM is a very fast acting, electronic equivalent of a synchronous condenser. If the STATCOM voltage, Vs, (which is proportional to the dc bus voltage Vc) is larger than bus voltage, Es, then leading or capacitive VARS are produced. If Vs is smaller than Es then lagging or inductive VARS are produced. Diagrammatic representation of the same in available in the below diagram

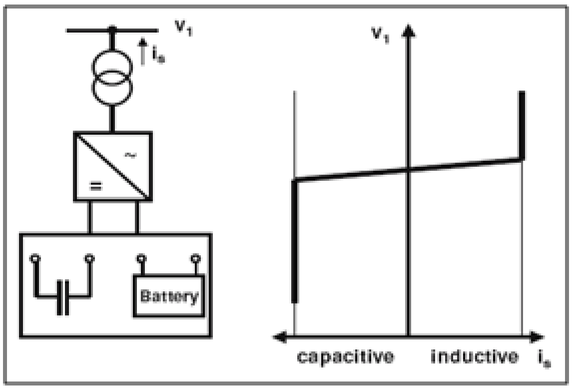

Figure 1.1: STATCOM structure and voltage / current characteristic

1.2 Structure of STATCOM

Basically, STATCOM is comprised of three main parts (as seen from Figure below): a voltage source converter (VSC), a step-up coupling transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors. The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters.

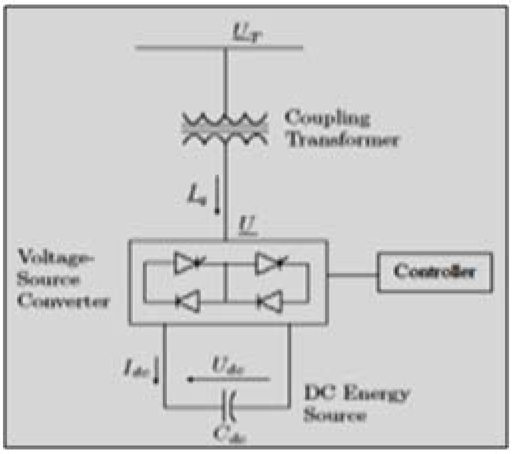

Figure 1.2: Structure of STATCOM

1.3 Control of STATCOM

The controller of a STATCOM operates the converter in a particular way that the phase angle between the converter voltage and the transmission line voltage is dynamically adjusted and synchronized so that the STATCOM generates or absorbs desired VAR at the point of coupling connection.

1.3.1 Two Modes of Operation

There are two modes of operation for a STATCOM, inductive mode and the capacitive mode. The STATCOM regards an inductive reactance connected at its terminal when the converter voltage is higher than the transmission line voltage. Hence, from the system's point of view, it regards the STATCOM as a capacitive reactance and the STATCOM is considered to be operating in a capacitive mode. Similarly, when the system voltage is higher than the converter voltage, the system regards an inductive reactance connected at its terminal. Hence, the STATCOM regards the system as a capacitive reactance and the STATCOM is considered to be operating in an inductive mode

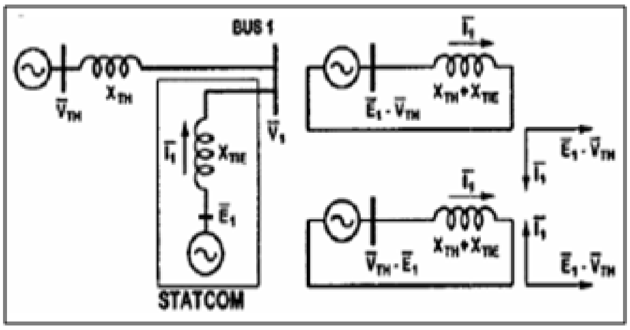

Figure 1.3:.1STATCOM operating in inductive or capacitive modes

This dual mode capability enables the STATCOM to provide inductive compensation as well as capacitive compensation to a system. Inductive compensation of the STATCOM makes it unique. This inductive compensation is to provide inductive reactance when overcompensation due to capacitors banks occurs. This happens during the night, when a typical inductive load is about 20% of the full load, and the capacitor banks along the transmission line provide with excessive capacitive reactance due to the lower load. Basically the control system for a STATCOM consists of a current control and a voltage control.

1.3.2 Current Controlled STATCOM

Figure 2.3..2 shows the reactive current control block diagram of the STATCOM. An instantaneous three-phase set of line voltages, v_l, at BUS 1 is used to calculate the reference angle, θ, which is phase-locked to the phase a of the line voltage, v_{la} . An instantaneous three-phase set of measured converter currents, i_l, is decomposed into its real or direct component, I_{1d}, and reactive or quadrature component, I_{1q}, respectively.

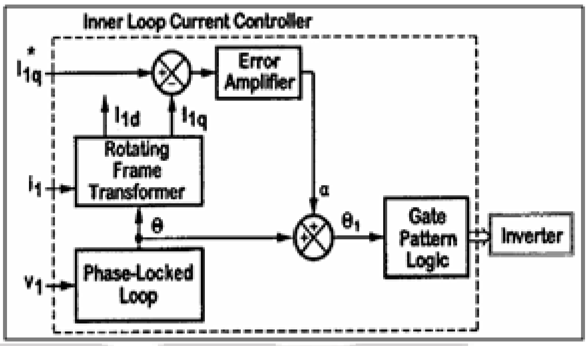

Figure 1.3.2: Current controlled block diagram of STATCOM

The quadrature component is compared with the desired reference value, I_{1q}^* and the error is passed through an error amplifier which produces a relative angle, α, of the converter voltage with respect to the transmission line voltage. The phase angle, θ_1, of the converter voltage is calculated by adding the relative angle, α, of the converter voltage and the phase – lock-loop angle, θ. The reference quadrature component, I_{1q}^*, of the converter current is defined to be either positive if the STATCOM is emulating an inductive reactance or negative if it is emulating a capacitive reactance. The DC capacitor voltage, v_{DC}, is dynamically adjusted in relation with the converter voltage. The control scheme described above shows the implementation of the inner current control loop which regulates the reactive current flow through the STATCOM regardless of the line voltage.

1.3.3 Voltage Controlled STATCOM

In regulating the line voltage, an outer voltage control loop must be implemented. The outer voltage control loop would automatically determine the reference reactive current for the inner current control loop which, in turn, will regulate the line voltage.

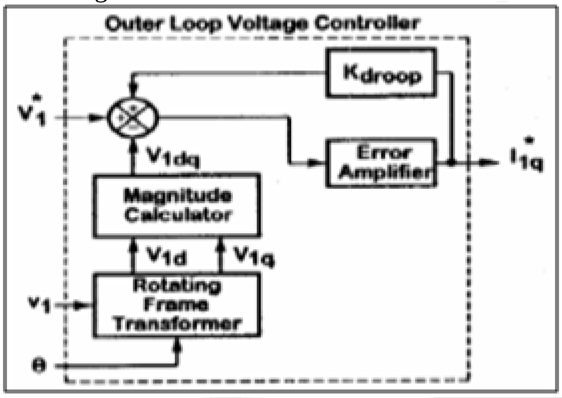

Figure 1.3.3: Voltage controlled block diagram of STATCOM

Figure 1.3.3 shows a voltage control block diagram of the STATCOM. An instantaneous three-phase set of measured line voltages, v_1, at BUS 1 is decomposed into its real or direct component, V_{1d}, and reactive or quadrature component, V_{1q}, is compared with the desired reference value, V_1^*, (adjusted by the droop factor, K_{droop}) and the error is passed through an error amplifier which produces the reference current, I_{1q}^*, for the inner current control loop. The droop factor, K_{droop}, is defined as the allowable voltage error at the rated reactive current flow through the STATCOM.

2. Modelling of VSC Based STATCOM

2. 1 Basic Operating Principles Of STATCOM

The STATCOM is connected to the power system at a PCC (point of common coupling), through a step-up coupling transformer, where the voltage-quality problem is a concern. The PCC is also known as the terminal for which the terminal voltage is U_T. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals (firing angle) to drive the main semiconductor switches of the power converter accordingly to either increase the voltage or to decrease it accordingly. A STATCOM is a controlled reactive-power source. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external reactors or capacitor banks. Using the controller, the VSC and the coupling transformer, the STATCOM operation is illustrated in Figure 3.1below

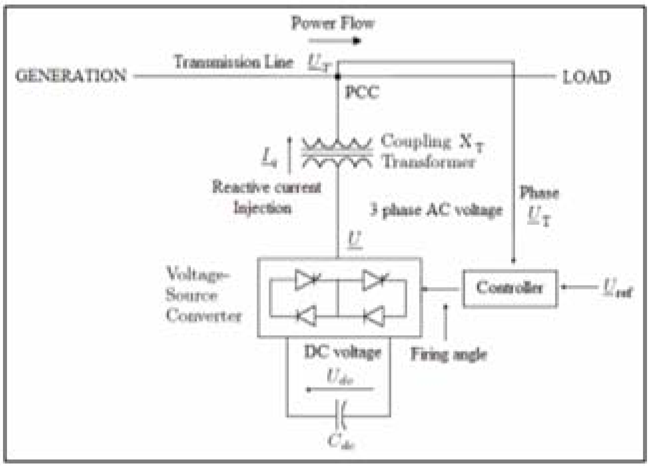

Figure 2.1: STATCOM operation in a power system

2.2 Voltage Source Converters (VSC):

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

The voltage source-converter or inverter (VSC or VSI) is the building block of a STATCOM and other FACTS devices. A very simple inverter produces a square voltage waveform as it switches the direct voltage source on and off. The basic objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage. Three basic techniques are used for reducing harmonics in the converter output voltage. Harmonic neutralization using magnetic coupling (multi-pulse converter configurations. Harmonic reduction using multi-level converter configurations and the pulse-width modulation (PWM).

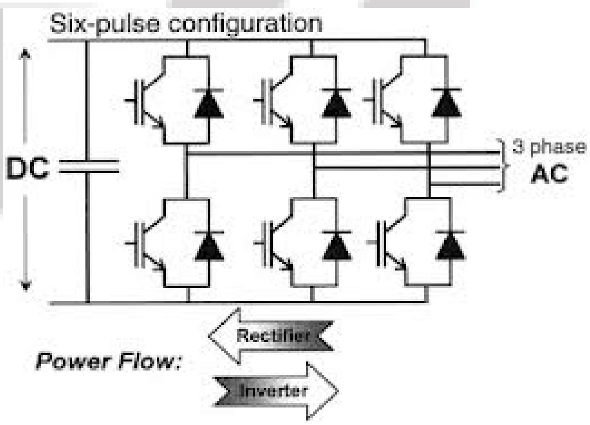

Figure 2.2: Voltage Source Converter

2.3Multi-Pulse Converter Configuration

Multi-pulse operation is achieved, by connecting identical three-phase bridges, Fig. 1.2, to transformers which have outputs that are phase-displaced with respect to one another. Star and delta-connected windings have a relative 30o phase shift and a 6-pulse converter bridge connected to each transformer will give an overall 12-pulse operation eliminating 5th and 7th harmonics. This principle can be extended to 24- and48-pulse operation summing at the primary windings the transformed outputs of several 6-pulse converters(4 for 24-pulse and 8 for 48-pulse operation). The harmonic cancellation is carried out into the transformer secondary winding

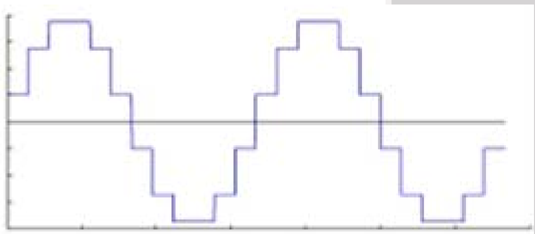

Figure 2.3: Multi-pulse staircase voltage waveform

2.4 Multi-Level Converter Configuration

The multi-level inverters synthesize a staircase voltage wave, Fig.3.3, from several levels of DC voltage sources, obtained from capacitor voltage source. As the number of levels increases, the synthesized staircase wave approaches the sinusoidal wave resulting in reduced harmonic distortion. Fig.3.4 shows a single-phase five level voltage source-inverter, this converter is more complex and requires the DC voltage source to be split or centre-tapped in order to provide a zero voltage reference

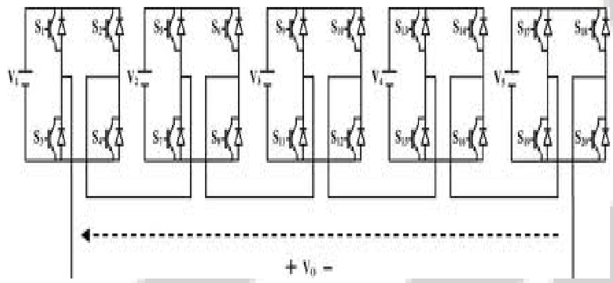

Figure 2.4: Five-level voltage source inverter

The fundamental magnitude and the harmonic spectrum are controlled varying the switching angles, α. The fundamental voltage component can also be changed by keeping α constant and changing VDC. Alternative forms of multi-level converters is the chain circuit in which several converter bridges, each with its own source capacitor, are connected in series.

2.5Pulse Width Modulation (PWM)

In multi-pulse and multi-level converters, there is only one turn-on, turn-off per device per cycle. An- other approach is to have multiple pulses per half-cycle, and then vary the width of the pulses to vary the amplitude of the AC voltage. The pulse width modulation (PWM) technique is commonly employed to generate high quality output waveforms by relatively low power converter used in variable frequency AC motor drives and distribution applications . With this technique, the output of each converter pole is switched several times during a fundamental cycle between the positive and negative terminals of the DC PWM requires a considerable increase in the number switch operations (high switching frequency);thereby it generally increases the switching losses of the converter . However, the always increasing switching frequency of modern solid-state power switches could made possible the use of PWM in high power applications

3. Three-Phase Voltage Source Inverters

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, var compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators). The standard three-phase VSI topology is shown in Fig 4.1. and the eight valid switch states are given in Table 1. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states (1 to 6 in Table 1) produce nonzero ac output voltages.. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.

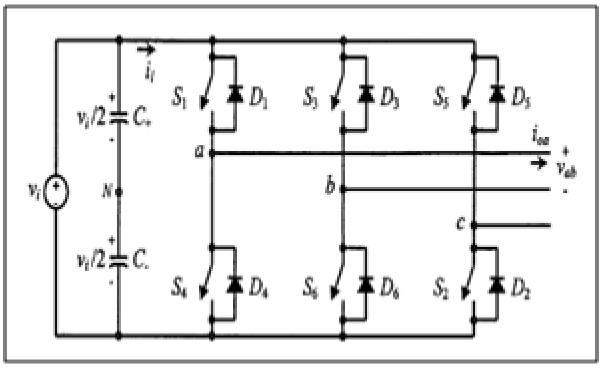

Figure 3.1: Three-Phase Voltage Source Inverters

Table 3.2: Switching states

State	State	v_{ab}	v_b	v_a	Space Vector
$_1$, $_2$, and $_6$ are on and $_4$, $_5$, and $_3$ are off	1	v	0	$-v$	$V_1 = 1 + j0.5$
$_2$, $_3$, and $_1$ are on and $_5$, $_6$, and $_4$ are off	2	0	v	$-v$	$V_2 = j1.155$
$_3$, $_4$, and $_2$ are on and $_6$, $_1$, and $_5$ are off	3	$-v$	v	0	$V_3 = -1 + j0.5$
$_4$, $_5$, and $_3$ are on and $_1$, $_2$, and $_6$ are off	4	$-v$	0	v	$V_4 = -1 - j0.5$
$_5$, $_6$, and $_4$ are on and $_2$, $_3$, and $_1$ are off	5	0	$-v$	v	$V_5 = -j1.155$
$_6$, $_1$, and $_5$ are on and $_3$, $_4$, and $_2$ are off	6	v	$-v$	0	$V_6 = 1 - j0.5$
$_1$, $_3$, and $_5$ are on and $_4$, $_6$, and $_2$ are off	7	0	0	0	$V_7 = 0$
$_4$, $_6$, and $_2$ are on and $_1$, $_3$, and $_5$ are off	8	0	0	0	$V_8 = 0$

3.2 12-Pulse Converter

The basic design for practically all HVDC converters is the 12-pulse double bridge converter which is shown in Figure below. The converter consists of two 6-pulse bridge converters connected in series on the DC side. One of them is connected to the AC side by a YY-transformer, the other by a YΔ transformer. The AC currents from each 6-pulse converter will then be phase shifted 30°. This will reduce the harmonic content in the total current drawn from the grid, and leave only the characteristic harmonics of order 12 m±1, m=1,2,3..., or the 11th, 13th, 23th, 25th etc. harmonic. The non-characteristic

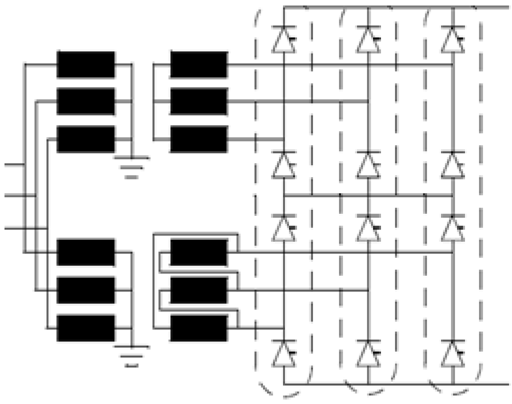

Figure 3: 12 pulse converter

harmonics will still be present, but considerably reduced. Thus the need for filtering is substantially reduced, compared to 6-pulse converters. The 12-pulse converter is usually built up of 12 thyristor valves. Each valve consists of the necessary number of thyristors in series to withstand the required blocking voltage with sufficient margin. Normally there is only one string of thyristors in each valve, no parallel connection. Four valves are built together in series to form a quadruple valve and three quadruple valves,

4. Simulation of Transmission Line without STATCOM Circuit

4.1 Simulation Diagram of Transmission Line without STATCOM

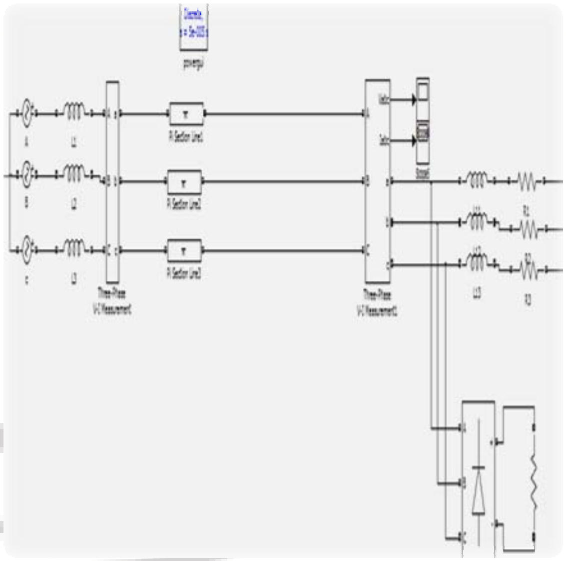

Figure 4.1: Simulation Diagram Of Transmission Line without STATCOM

4.2 Simulation Results For Without STATCOM

These results shows the harmonic content in the system and figures represents the source and load voltages and currents and we can obserd the harmonics currents in it The below figure shows the simulation results for the above simulink diagram. This figure illustrates the voltage and current waveforms for the circuit shown below

4.2.1Voltage Vs time

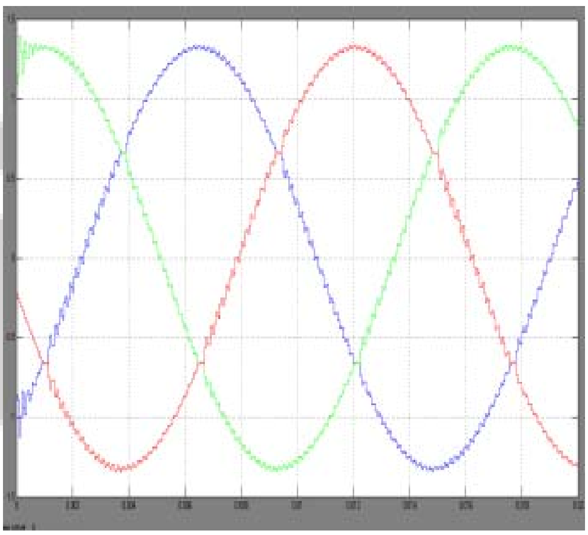

Figure 4.2.1: voltage Wave form for without statcom

4.2.2Current Vs Time

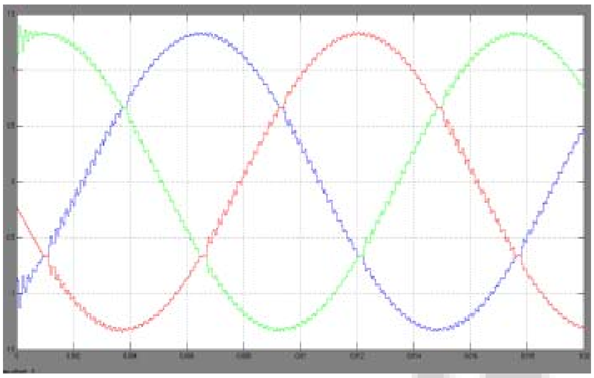

Figure 4.2.2: Current Wave form for without statcom

4.3 FFT Analysis for Above Waveform

A fast Fourier transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) and its inverse. Fourier analysis converts time (or space) to frequency and vice versa; an FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. As a result, fast Fourier transforms are widely used for many applications in engineering, science, and mathematics. The basic ideas were popularized in 1965, but some FFTs had been previously known as early as 1805. Fast Fourier transforms have been described as "the most important numerical algorithm[s] of our lifetime" By using the above simulation results the FFT analysis is taken as below

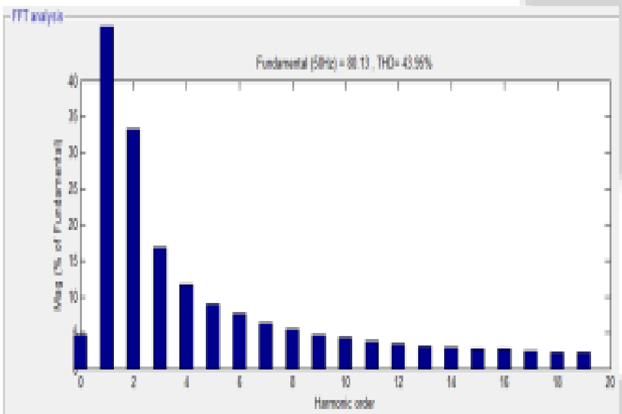

Figure 4.3: FFT analysis for without statcom

4.3.1 Calculation of Total Harmonic Distortion

$$\% \text{ THD} = \sqrt{\frac{V_2^2 + V_3^2 + V_4^2 + \cdots}{V_1^2}} * 100$$

From the above FFT analysis diagram the voltage magnitudes from 2nd order to 20th order of harmonics are given below.

Table 4.3.1: The voltage magnitudes from 2nd order to 20th order of harmonics

V1=100V	V2=33V	V3=18V
V4=13V	V5=10V	V6=9V
V7=8V	V8=7V	V9=9V
V10=5V	V11=4V	V12=3V
V13=2V	V14=1V	V15=1V
V16=1V	V17=0.9V	V18=0.8V

On substituting the above values in the equation given above we get the THD value of 44.4%

5. Simulink Model of 84-Pulse STATCOM

5.1 84-Pulse VSC Topology

Numerous methods have been investigated to increase the number of pulses in the multi-pulse converters' output. The simplest one is by increasing the number of six-pulse converters and the corresponding transformers (4 six -pulses converter results in 24-pulse, 8 six-pulse converter results in 48-pulses operation, and so forth). The harmonic cancellation is carried out by the transformer secondary windings' arrangement. The weakness of this method is the large size and high cost due to the increased number of bridges and transformers. In order to overcome such difficulty, an auxiliary circuit in the DC link side has been proposed for reinjection. Such topology results through modifying the DC input on the conventional double bridge twelve-pulses shunt converters through a multi-level auxiliary circuit with an injection transformer

In this paper, an asymmetric 7- level array for the auxiliary circuit is used as a reinjection scheme,. The conventional double bridge twelve-pulse operation is assembled by connecting two identical three-phase bridges to three-phase transformers in a parallel VSC configuration. Each branch in the six-pulse converter must have a displacement of 120° among them. The upper switch is conducting while the lower one is open and vice versa (180° voltage source operation). A 30° displacement in then firing sequence of both converters should be considered. Transformer's turn ratios are 1:1 and 1: 3 on the YY and YΔ transformers, respectively. By injecting additional DC pulses via the three-phase bridges' neutral point, an effect of pulse spreading is attained.

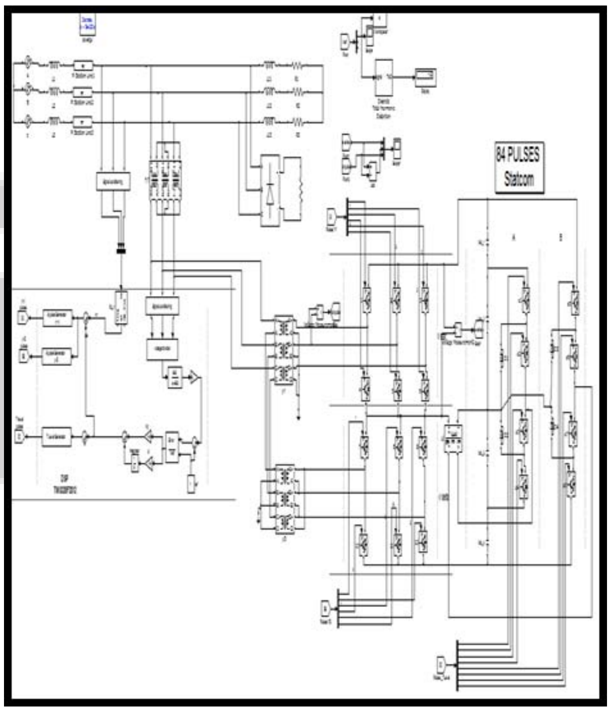

Figure 5.1: 84 pulse statcom structure

The auxiliary circuit is common to the three phases, reducing the number of extra components. A-B illustrates the auxiliary seven-level inverter utilized as a reinjection circuit

5.2 Mixing 7-Level 6-Pulse Signal

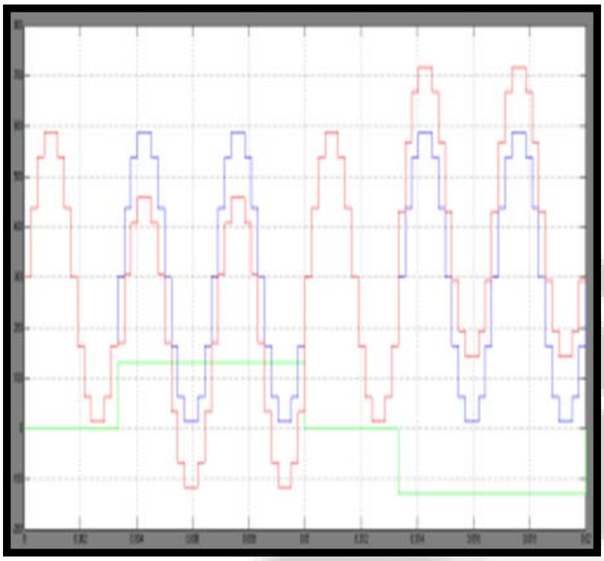

Figure 5.2: Wave form for mixing of 7 level 6 pulse signal

5.3 Pulse Line-To-Neutral Voltage Waveform

Taking the voltage reference 84-pulse line to neutral waveform in one cycle.

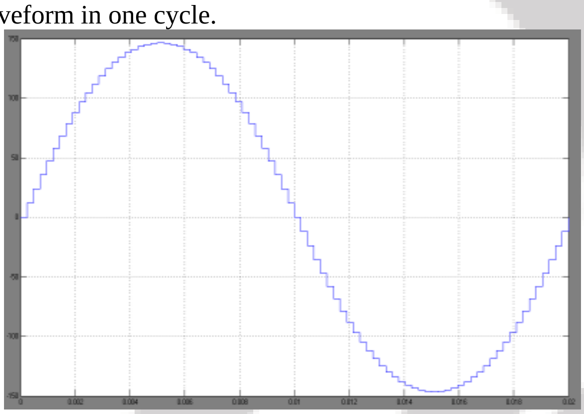

Figure 5.3: Wave form for 84-pulse line to neutral voltage

5.4 FFT Analysis of Above Waveform

The results with StatCom indicates that the harmonics content has been decreased and the graphs plotted are reference voltage and seven level and six pulse outputs voltages, and THD is considered as 2.

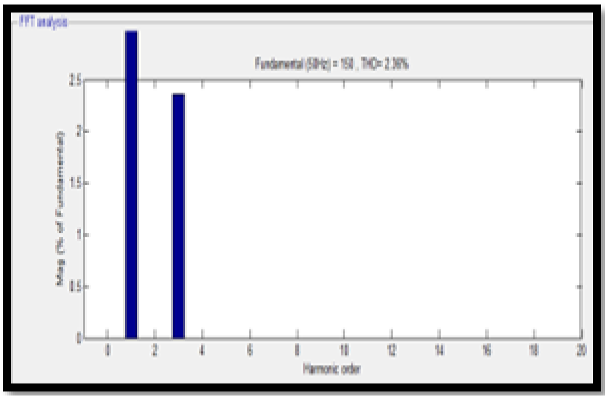

Figure 5.4: FFT analysis for 84-pulse STATCOM with PWM technique

5.5 Calculation of Total Harmonic Distortion

Using FFT Analysis the total harmonic distortion is calculated by using below formula

$$\% \text{ THD} = \sqrt{\frac{V_2^2+V_3^2+V_4^2+\cdots}{V_1^2}} * 100$$

From the above FFT analysis diagram the voltage magnitudes from 2nd order to 20th order of harmonics are given below.

V1=100V V2=2.3

On substituting the above values in the equation given above we get the THD value of 2.3%

5.6 Total Harmonic Distortion Output Reprecentaion

Since we are going for the current harmonic compensation hysteresis controller is the best for the current control system. In this system also we plot the graphs between time and voltages, he we consider the seven level o/p and six pulse o/p and voltage reference voltage and we can observed that by using hysteresis controller there is a decrease in the harmonic content and the THD is at 1.45%

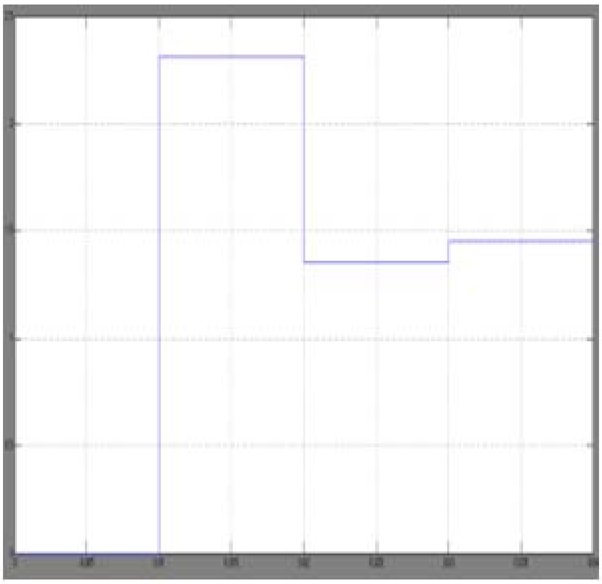

Figure 5.5: Diagram for % THD value in display

6. Conclusion

This paper describes the strategy to obtain an 84-pulse VSC three-phase voltage with the associated low THD, by combining one twelve-pulse converter plus a seven-level converter.THD is decreased to 5.5. The exhibited low THD permits the system to be used in FACTS devices. The three-phase digital PLL used to detect the phase of the fundamental voltage synchronizes the firing signals. in all switches within a sample cycle.

References

[1] Song, Y. H., and Johns, A. T.: 'Flexible AC transmission systems FACTS,' (IEE Power and Energy Series 30, 1999)
[2] Acha, E., Fuerte-Esquivel, C. R., Ambriz, H., Angeles, C.: 'FACTS. Modelling and Simulation in Power Networks.' (John Wiley and Sons, LTD, 2004.)
[3] Wang, H. F.: "Applications of damping torque analysis to StatCom control", Electrical Power and Energy Systems, Vol. 22, 2000, pp. 197-204.
[4] CIGRE, "Static Synchronous Compensator", CIGRE working group 14.19, September 1998.
[5] Hingorani, N. G., and Gyugyi, L.: 'Understanding FACTS,' (IEEE Press 2000).
[6] El-Moursi, M. S., and Sharaf, A. M.: "Novel Controllers for the 48-Pulse VSC StatCom and SSSC for Voltage Regulation and Reactive Power Compensation", IEEE Transactions on Power Systems, Vol. 20, No. 4, November 2005, pp. 1985-1997
[7] Davalos-Marin, R.: 'Detailed Analysis of a multi-pulse StatCom', Cinvestav – Internal Report. May 2003, available at http://www.dispositivosfacts.com.mx/dir_tesis_doc.html

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