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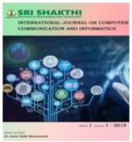

Configuration and Digital Simulation of STATCOM utilizing 48-Pulse VSC for Reactive Power Reparation and Potential Reliability

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Abstract: This paper analyzes the configuration of Static Synchronous Compensator-STATCOM utilizing 48 pulse voltage source converter for reactive force reparation and voltage adjustment in force framework transmission and dispersion systems alongside the advanced development of the STATCOM utilizing 48 pulse VSC, expecting framework subjected to unsettling disturbances of real and reactive power. The 48 Pulse voltage source converter is composed with the guide of four 3-level voltage source converters exchanging at the major recurrence to create a sinusoidal yield voltage with decreased symphonies substance. The outline and computerized recreation of STATCOM has been executed in the MATLAB/Simulink stage. It is strongly evident that the outcome of reactive power reparation and voltage stabilization have been substantially improved by the proposed STATCOM configuration with 48 pulse VSC.

Keywords: Voltage root converter, Reactive force reparation, Voltage adjustment, Harmonics Distortion.

1. Introduction

The utilization of power electronics based controllers in the electric power transmission assumes a significant job to make the system more solid, controllable and productive. Because of deregulation, natural enactments and cost of development, it has progressively become harder to install new distribution systems. Hence, it is wiser to effectively utilize the current transmission system. STATCOM has turned into a effective choice in utilizing the transmission system to the fullest limit while improving the power system controllability, productivity and the unwavering quality of the system.

The Static Synchronous Compensator device is a reactive power compensator unit connected in shunt with the utility supply. It produces or absorbs the required reactive power to the utility so that utility output is stabilized. The working of the STATCOM unit is equal to the a mechanical rotating synchronous compensator. Since STATCOM uses the static electronic power control, it eliminates the rotating mechanical elements, leading to the rapid management of the voltage and the phase angle of the utility. STATCOM gives the better stability and controllability to the utility output supply. The use of multilevel converters eliminates the need for harmonic filters in the case of a STATCOM. A voltage source converter-VSC based STATCOM uses for the required reactive power adjustment. This eliminates the need to use group of capacitor-bank units and shunt reactors in the system for the reactive power control. Hence, STATCOM is compact and small, leading to the silent operation and very less magnetic interference.

In this paper, the Static Synchronous Compensator-STATCOM employing 48-pulse voltage source converter-VSC is recommended for its ability to produce the smoother output with lesser harmonics [2]. The configuration and the simulation of STATCOM is executed in the simulink-Belvedere platform.

2. Static Synchronous Compensator (STATCOM)

A STATCOM is the responsive power source control unit. It gives the desired output power supply by injecting or absorbing the reactive power component using a voltage-source converter (VSC). An outline of single-line representation of the STATCOM unit is represented in Figure 1.

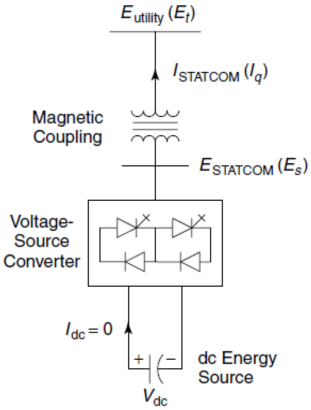


Figure 1. Single Line Outline for STATCOM

The figure 2 represents the equivalent circuit of the STATCOM. A Voltage Source Converter is used to create the sinusoidal alternating voltage with reduced harmonics from the given DC voltage by switching. If the phase angle between utility supply voltage (Et) and the STATCOM voltage Es is zero, active power flow becomes zero and the reactive power supply from STATCOM depends on (Et – Es). If utility supply voltage magnitude is larger, reactive power will stream from utility Et to the STATCOM Es. If the Es magnitude is larger, reactive power will stream from STATCOM Es to utility Et.

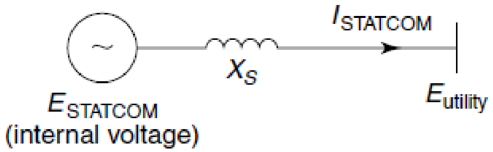


Figure 2. Equivalent circuit of STATCOM

A STATCOM is evident as a flexible voltage predecessor abaft a reactance expresses that group of capacitor-bank units and blow reactors are not uncovered for responsive power bearing and assimilation, along these lines giving a STATCOM a grouped engineering or little impression as healthy as low babble and low attractive effect. [3]

The exchanging of open power in the proposed system can be constrained by moving the ampleness of the 3-organize yield voltage, Es, of the converter, as spoke to in Figure 3. That is, if the ampleness of the yield voltage has extended over that of the utility, transport voltage, Et, at that point at present courses through the reactance within the converter-AC structure terminals and the converter makes capacitive-responsive power for the AC system. If the adequacy of the yield voltage is decreased underneath the utility, transport voltage, at that point the present streams in the converter-AC system and it acclimatizes inductive-open power. An occasion of STATCOM is said to be in a drifting state [4] when the yield voltage ascends to AC system voltage and the power exchange gets the opportunity to b ezero.

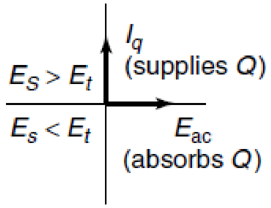


Figure 3. Power Exchange circuit

Changing the stage move between the converter-yield voltage and the AC system voltage can likewise control certified power-exchange in the converter-AC structure. So to speak, the converter can supply authentic vitality to the AC structure from its DC essentialness accumulating when the converter-yield voltage is made to lead the AC system voltage. In other words, it can absorb certifiable power from the AC system for the DC structure if its voltage waits behind the AC structure voltage. A STATCOM gives the ached for open power by exchanging the brief, responsive power among the times of the AC structure.

The component by which the converter inside crates or ingests the responsive force can be comprehended by considering the relationship between the yield and information forces of the converter. The converter switches associated the DC-information circuit specifically to the AC-yield circuits. Henceforth the net fast power at the AC yield terminals ought to reliably be equal to the net passing power of the DC-data terminals.

A PV connected static synchoronous compensator-STATCOM with fuzzy-logic rationale controller implemented integrator is utilized to compsensate the present current harmonics in the three-stage control conveyance systems. Based on the DC interface and the control techniques, the compensation ability as well as practicality of the device-compensation getting changes. The control systems is being utilized for the estimation gadgets and the expense of the control unit [5].

Its tough assignment to make a synchronization with the utility network, control quality and receptive power compsenasation. The ststaic synchoronous compsensator is effective gadget that can resolve control quality issues particularly in the distreibution utility grid matrix. A unit vector format control conspire is being used for producing gating sign of STATCOM. The Unit vector layout control calculation is used for pay of current harmonics content, receptive power, and voltage interference in power framework systems [6].

The model, three bus think about structures with STATCOM-Controller at transport B2 is showing up in Figure 4. The STATCOM-controller concept for FACTS application is outlined in Figure 4 [7-9].

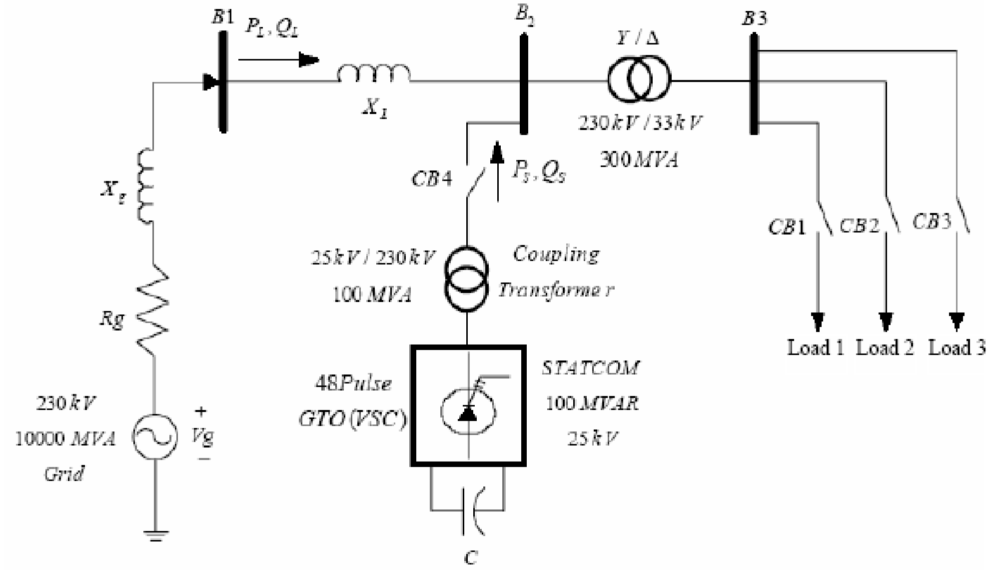


Figure 4. Test three-bus structures of the STATCOM-Controller at Bus B2

3. 48 pulse voltage VSC DESCRIPTION

3.1. Principle of converter

The 48-Pulse voltage-source converter controller has acquired from four 3-level inverters. The three level 48 Pulse VSC has done so as to acquire the sinusoidal voltage with low consonant substances yield. Figure 5. Demonstrates the four 3-level converters are associated in arrangement on the essential side to shape a proportionate 48 Pulse voltage source converter. It contains four 12 Pulse bridges associated in arrangement on the AC side, nourished by four transformers that can give 7.5° stage shift between voltages of contiguous transformers [10-11].

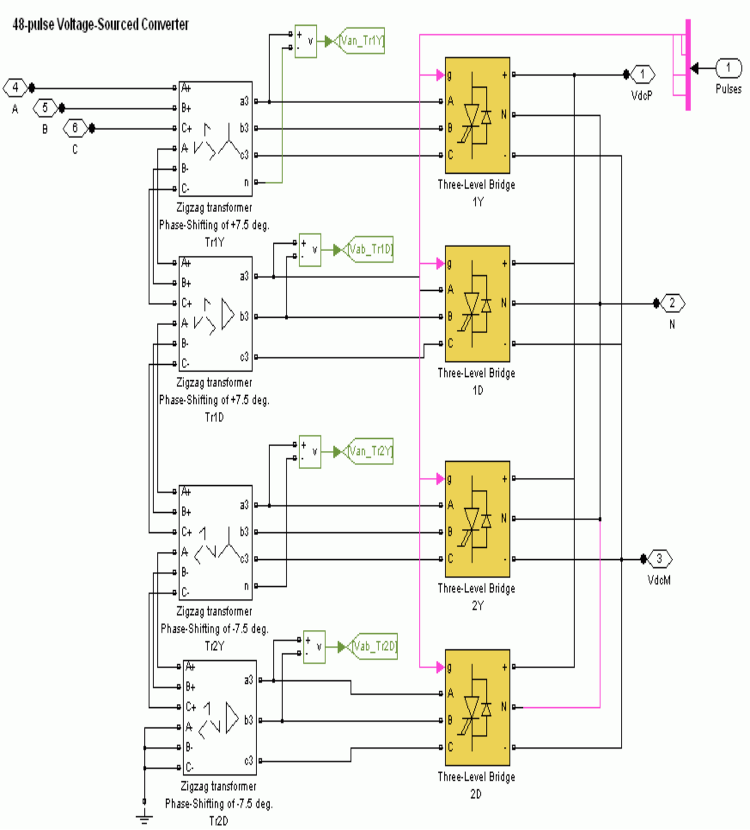
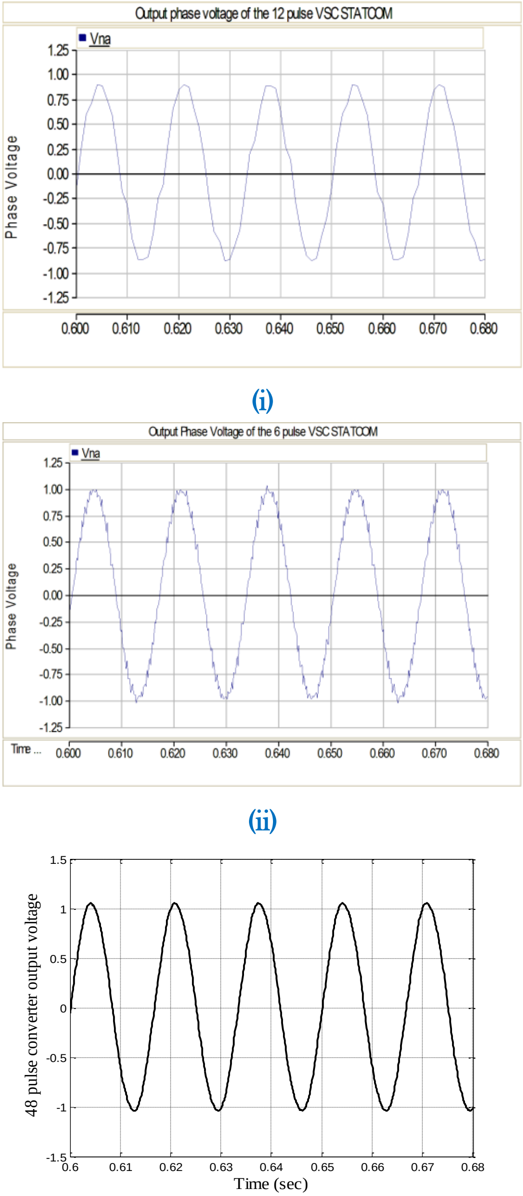


Figure 5. 48-pulse Voltage Source Converter STATCOM

The 6-Pulse, 12-Pulse and 48-Pulse converter-controller yield voltage are appearing in Figure 6. From the yield stage voltage wave types of 6 Pulse, 12 Pulse and 48 Pulse VSC it is clear that the harmonic distortion added to the framework diminishes when the level is expanded. It can be seen by the stripped eye that for 6 Pulse VSC the wave structure is having various numbers of spikes along the cycles and is again decreased in for 12 Pulse yet the waveform is again not smooth [12][13]. In any case, for 48 Pulse VSC wave structure is not having any stripped spikes and the waveform is just about smooth. The 48 Pulse converter can be utilized as a some portion of huge power applications without AC channels because of its elite and low harmonics rate on the AC side. The yield voltage has sounds $n=48r\pm1$, where r=10, 1,2,... .; i.e., 47th,49th,95th,97th,..., with sizes of 1/47th,1/49th,1/95th, 1/97th,..., independently, respect to the key; on the DC side, the lesser orbiting consonant current will be the 48th. The stage move structure on each 12-Pulse controller-converter is the going with the systems [13][14].



(i)

(ii)

Figure 6. Voltage source converter STATCOM **(i)** 6 Pulse VSC **(ii)** 12 Pulse VSC **(iii)** 48 Pulse VSC

1st, 12-pulse converter

PST: + 7.5° Important to take out the 24-pulse harmonics

+ 3.75° Important to take out the 48-pulse harmonics

Total + 11.25° turn rate of winding 1: tan (11.25°)

Driver: - 7.5° Important to take out the 24-pulse harmonics

- 3.75° Important to take out the 48-pulse harmonics

Total - 11.25°

The produced yield voltage created by this 12-pulse controller-converter is,

$$v_{ab12}(t) = 2[V_{ab}\, sin(\omega t + 30^\circ) + V_{ab11}\, sin(11\omega t + 195^\circ) + V_{ab13}\, sin(13\omega t + 255^\circ) + V_{ab23}\, sin(23\omega t + 60^\circ) + V_{ab25}\, sin(25\omega t + 120^\circ) + \ldots] \tag{1}$$

2nd, 12-pulse controller-converter

PST: - 7.5° Important to take out the 24-pulse harmonics

+ 3.75° Important to take out the 48-pulse harmonics

Total - 3.75° Winding turn rate 1: tan (3.75°)

Driver: + 7.5° Important to take out the 24-pulse harmonics

- 3.75° Important to take out the 48-pulse harmonics

Total + 3.75°

The resultant yield voltage created by this 12-pulse controller-converter is,

$$v_{ab12}(t)_2 = 2[V_{ab1}\, sin(\omega t + 30^\circ) + V_{ab11}\, sin(11\omega t + 15^\circ) + V_{ab13}\, sin(13\omega t + 75^\circ) + V_{ab23}\, sin(23\omega t + 60^\circ) + V_{ab25}\, sin(25\omega t + 120^\circ) + \ldots] \tag{2}$$

3rd, 12-pulse converter-converter

PST: + 7.5° Important to take out the 24-pulse harmonics

- 3.75° Important to take out the 48-pulse harmonics

Total + 3.75° Winding turn rate 1: tan (3.75°)

Driver: - 7.5° Important to take out the 24-pulse harmonics

+3.75° Important to take out the 48-pulse harmonics

Total -3.75°

The resultant yield voltage created by this 12-pulse converter is,

$$v_{ab12}(t)_3 = 2[V_{ab1}\,sin(\omega t + 30^\circ) + V_{ab11}\,sin(11\omega t + 285^\circ) + V_{ab13}\,sin(13\omega t + 345^\circ) + V_{ab23}\,sin(23\omega t + 240^\circ) + V_{ab25}\,sin(25\omega t + 300^\circ) + \ldots] \quad (3)$$

4th, 12-pulse converter

PST: -7.5°Important to take out the 24-pulse harmonics

-3.75° Important to take out the 48-pulse harmonics

Total -11.25° Winding turn rate 1: tan (11.25°)

Driver: +7.5° Important to take out the 24-pulse harmonics

+3.75° Important to take out the 48-pulse harmonics

Total +11.25°

The resultant yield voltage created by this 12-pulse converter is,

$$v_{ab12}(t)_4 = 2[V_{ab1}\,sin(\omega t + 30^\circ) + V_{ab11}\,sin(11\omega t + 105^\circ) + V_{ab13}\,sin(13\omega t + 165^\circ) + V_{ab23}\,sin(23\omega t + 240^\circ) + V_{ab25}\,sin(25\omega t + 300^\circ) + \ldots] \quad (4)$$

These four 12-pulse AC yield voltage, given by the conditions (1), (2), (3), (4), are incorporated with arrangement the discretionary transformers windings. The 48-pulset AC yield voltage is given by:

$$v_{ab48}(t) = v_{ab12}(t)_1 + v_{ab12}(t)_2 + v_{ab12}(t)_3 + v_{ab12}(t)_4 \quad (5)$$

$$v_{ab48}(t) = 8[V_{ab1}\,sin(\omega t + 30^\circ) + V_{ab47}\,sin(47\omega t + 150^\circ) + V_{ab49}\,sin(49\omega t + 210^\circ) + V_{ab95}\,sin(95\omega t + 330^\circ) + V_{ab97}\,sin(97\omega t + 30^\circ) + \ldots] \quad (6)$$

Therefore the general expression of the line-to-line voltage associated to a 48-pulse converter is given by the equation.

$$v_{ab48}(t) = 8\sum_{n=1}^{\infty} V_{abn}\,sin(n\omega t + 30^\circ n + 11.25^\circ t) \quad (7)$$

$$\forall_n = 48r\pm, r = 0,1,2,\ldots..$$

The line-to-neutral voltage is,

$$v_{ab48}(t) \quad = \frac{8}{\sqrt{3}}[V_{ab1}\, sin(\omega t) - V_{ab47}\, sin(47\omega t) - V_{ab49}\, sin(49\omega t) + V_{ab95}\, sin(95\omega t) + V_{ab97}\, sin(97\omega t) + \ldots\ldots.] \qquad (8)$$

4. Simulation Results

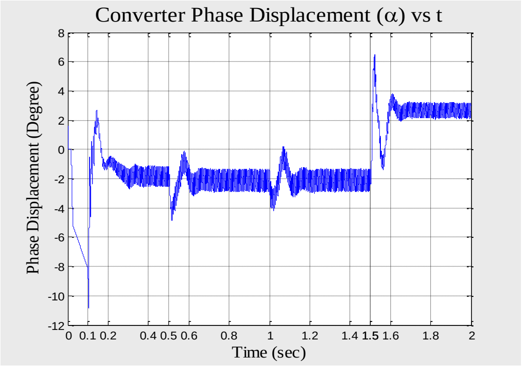
The displacement of phase of VSI and the terminal voltage of the STATCOM is clarified in Figure7 and Figure 8 independently. The Figure 7 demonstrates the stage relocation of converter regarding the time, which give the adjustment in stage at the converter when the STATCOM is associated alongside the different burdens as associated with Figure 4. The Figure 8 depictions about the terminal voltage with deference the time again in as the same condition specified previously.

It can be noticed that by including STATCOM at light load condition, the terminal voltage of STATCOM is expanded to p.u simply above 1.019 once more, it is settled after a period omission of under 0.006sec.

At the point when load 2 and burden 3 is added to framework the dunk in terminal voltage can be noted and the STATCOM comes to working after a little time deferral to take back the framework back to the ordinary balanced out quality. At time 1.5 Sec the both the heaps 2 and 3 are rejected off or expelled from the framework which brought about a surge in the framework by the sudden swell in the terminal voltage it is excessively redressed by the STATCOM after a little defer which gadget is set to work.

The capacitor potential, dynamic and reactive force when STATCOM associated with the thought of the capacitive and inductive mode under the level of burden 2, 3 are associated and rejected are appearing in Figure 9, Figure 10. From Figure 10, it can be seen that the infused voltage expanded by STATCOM association and amid the infusion of burden 1 and burden 2 the adjustment in voltage is remunerated by the STATCOM. Likewise, when both the hips are rejecting the capacitor voltage is diminished to keep the framework from going to surplus voltage which may bring about stumbling of the substations close by.

Figure 10 the dynamic and reactive force supply by the STATCOM, amid the expansion of STATCOM and the heaps the STATCOM is in a capacitive mode to keep up force variable and when the hips are rejected at time 1.5 Sec the gadget is moved to inductive mode to decrease the surge in voltage to go over the transmission line.



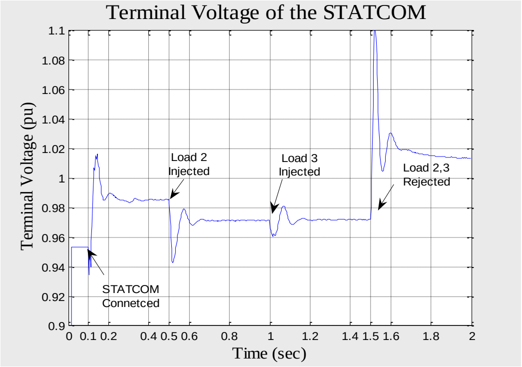
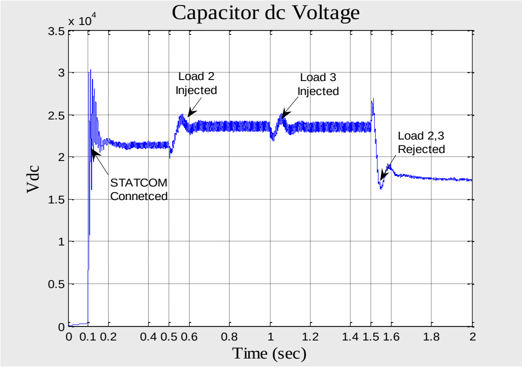


Figure 7. Phase displacement of converter **Figure 8.** Terminal voltage of the STATCOM



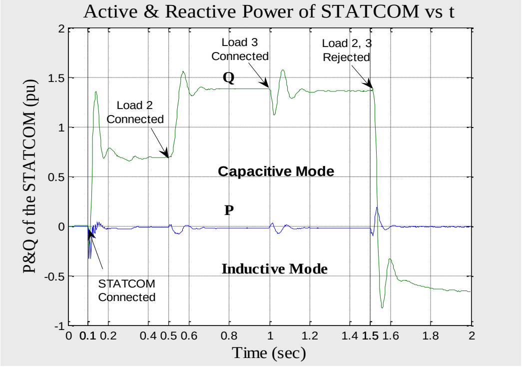
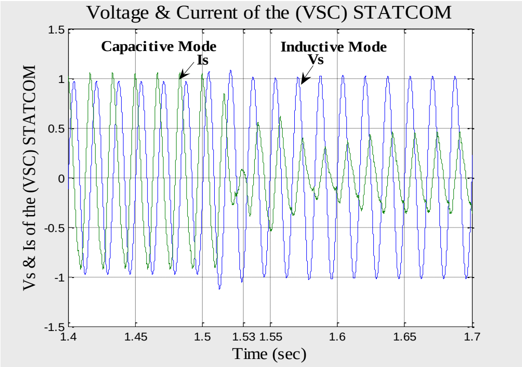


Figure 9. Capacitor DC voltage

Figure 10. Active element and Reactive element of STATCOM power



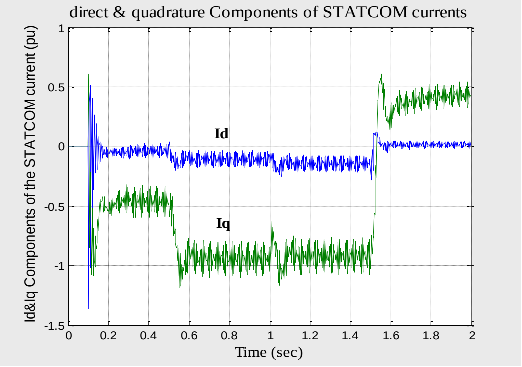


Figure 11. Voltage and current of VSC

Figure 12. I_d and I_q of STATCOM

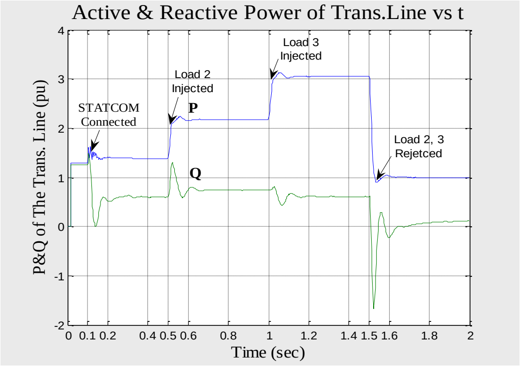


Figure 13. P and Q of Transmission line

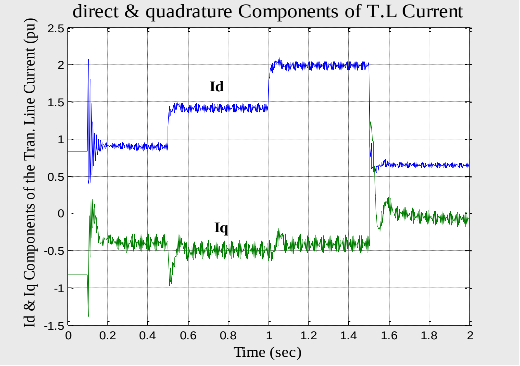


Figure 14. I_d and I_q of Transmission Line

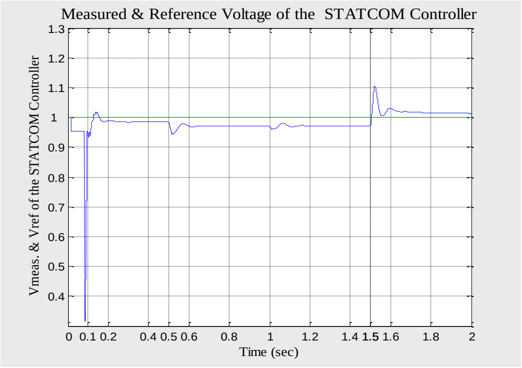


Figure 15. Measured voltage of controller

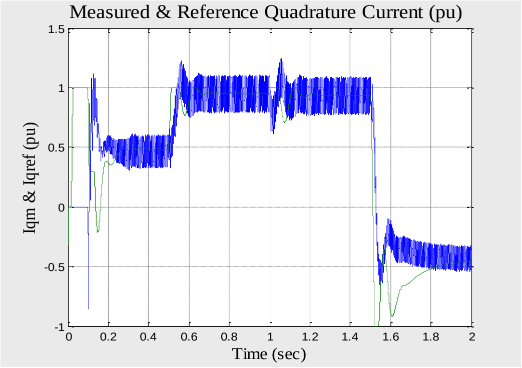


Figure 16. Measured i_q

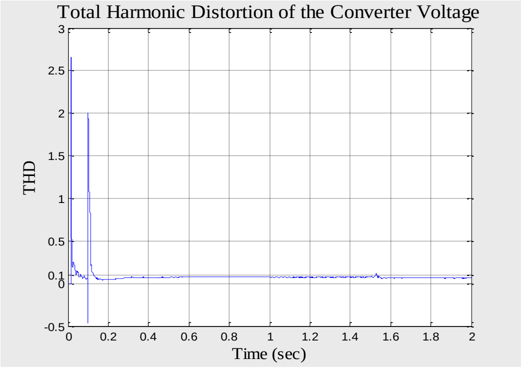


Figure 17. THD of the converter

The voltage and current of voltage source converters, direct and quadrature parts of STATCOM present, dynamic and receptive force of transmission line, direct and quadrature segments of transmission line current are appearing in Figure 11, 12, 13 and Figure 14 individually.

Figure 11 demonstrates the voltage and current of the VSC it can see that the is somewhat higher amid the time when the STATCOM is associated with the framework to the time till both burdens are associated, however, when the both the heaps are rejected, it is decreased for the initial two cycles the Vs is expanded and is lessened to typical as the STATCOM change to inductive mode. Figure 12 demonstrates the I_d and I_q variety concerning time at the diverse operation as said I_d is expanded by the expansion of STATCOM for the time when the hips are associated and decreases when burdens are rejected and if there should arise an occurrence of I_q its its vice verse.

The Figure 13 demonstrates the dynamic force and the reactive force change amid the different operations of burden expansion and dismissal. Figure 14 demonstrates the I_d and I_q variety regarding time in a transmission line, I_d is expanded at the expansion of STATCOM for the time when the hips are associated and diminishes when burdens are rejected. The reference and measured voltage, present as the contribution of voltage and current controller are appearing in Figure15 and Figure16 separately.

It can be viewed that the THD-Total Harmonic Distortion of the Converter's output voltage is less as appearing in Figure 17. The THD is very low or say that null after the addition of STATCOM to the system. The chosen parameters for power system for evaluation are tabulated in Table 1.

Table 1. Picked power system framework parameters

Three phase AC source		Active Power (PL2)	0.7 [Pu]
Rated voltage	230*1.03 [KV]	Reactive Power (QL2)	0.5 [Pu]
Frequency	60 [Hz]	**Load 3**	
Short circuit level	10000 [MVA]	Active Power (PL3)	0.6 [Pu]
Base voltage	230 [KV]	Reactive Power (QC3)	0.4 [Pu]
X/R	8	**STATCOM**	
Transmission line		Primary Voltage	138KV
Resistance	0.05 [Pu]	Secondary Voltage	15 KV
Reactance	0.2 [Pu]	Nominal Power	100 MVAR

Power transformer		Frequency	60Hz
Nominal Power	300 [MVA]	Equivalent Capacitance	750µF
Frequency	60 [Hz]	**Coupling Transformer**	
Primary winding voltage	230 [KV]	Nominal Power	100 [MVA]
Secondary winding voltage	33 [KV]	Frequency	60 [Hz]
Magnetization Resistance	500	Primary winding voltage	138 [KV]
Magnetization Reactance	500	Secondary winding voltage	230 [KV]
Three phase loads		**GTO Switches**	
Load 1		Snubber Resistance	1e5 [Ω]
Active Power (PL1)	1 [Pu]	Snubber Capacitance	Inf
Reactive Power (QL1)	0.8 [Pu]	Internal Resistance	1e-4 [Ω]
Load 2		No. of Bridge arm	3

5. Conclusion

This paper displayed an outline and computerized reproduction of STATCOM utilizing 48-pulse VSC alongside and the advanced recreation is finished. The entire system of the ±100 MVAR STATCOM-Controller have been circled and connected with the 230 KV AC network framework while to give the satisfactory responsive reparation and voltage control. Along these lines of methodology would improve the force exchange limit of the force framework systems. The entire control procedure has been made considering a decoupled current method using direct current and quadrature current of STATCOM-controller. The activity of STATCOM is affirmed in both capacitive and inductive mode operation in the precedent power exchange system, exposed to aggravations, for instance, changing to different sorts of weights. It is found that the STATCOM has infused receptive reparation and voltage direction in a superior manner.

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The authors declare that they have no conflict of interest.

Conflict of interest

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