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Stability Analysis of Distributed Generation System Connected to 48-Pulse VSC Based STATCOM Using MATLAB

Shubham Dewangan
M. Tech. Student, Department of Electrical and Electronics Engineering
Disha Institute of Management and Technology, Satya Vihar, Raipur, India
Uma Shankar Patel
Assistant Professor, Department of Electrical and Electronics Engineering
Disha Institute of Management and Technology, Satya Vihar, Raipur, India

Abstract:
In this paper The STATCOM (Synchronous Static Compensator) based on voltage source converter (VSC) is used to supply dynamic VARs required during power system faults for voltage support. However, magnetic saturation of transformers used in VSC topology result in over-current and trips of the STATCOM during system faults, when dynamic VARs and voltage support are required the most. In this paper, we propose and develop an "emergency PWM" strategy to prevent over-currents in VSC and transformer magnetic saturation for line-to-line system faults. A + 100 MVAR STATCOM with a 48-pulse VSC based on 3-level Neutral Point Clamped (NPC) topology and four series connected transformers with realistic saturation (B-H) characteristics are considered. Simulation results are presented for a 48-pulse VSC based + 100 MVAR STATCOM connected to a 2-bus power system to validate the "emergency PWM" strategy to prevent VSC over-current and transformer saturation and supply reactive power under line-to-line system faults. A practical issue of impact of slightly different saturation (B-H) characteristics of the four series transformers, on VSC performance is shown by simulation results for line-to-line fault in SIMULINK based MATLAB environment.

Keywords: *STATCOM, Distributed generation system, 48-pulse STATCOM, VSC.*

1. Introdction

The STATCOM (Synchronous Static Compensator) based on voltage source converter (VSC) is used for voltage regulation in transmission and distribution systems [1-5]. Strict requirements of STATCOM loss and total system loss penalty preclude the use of PWM (Pulse-Width Modulation) for VSC based STATCOM applications. Under system faults, the system bus voltage involves positive sequence and negative sequences. The conventional PLL (Phase Locked Loop) is based on positive sequence of bus voltage; therefore, it cannot respond to dynamic changes in negative sequence of bus voltage due to system faults and disturbances. These constraints result in over-currents and trips of the STATCOM during system faults, when its reactive power support functionality is most required. For "angle controlled" STATCOM, there are two methods to improve the performance of the power system. One option is implementing multiple controllers based on separate conventional PLLs, which track positive and negative sequence accurately. In [5], the authors present a FRF-PLL (Fixed Reference Frame PLL) to provide an estimation of both the positive and negative sequences of the bus voltage. The other option is implementing a single controller based on a single PLL, which is able to provide the information of both positive and negative sequences. An enhanced PLL (EPLL) is proposed in [6]. The EPLL provides an on-line estimate of the fundamental component of the input signal while following its variations in amplitude, phase and frequency. In this paper, the "Instantaneous PLL" is employed in the system. Simulation results in PSCAD and RTDS verification are presented for a 48-pulse VSC based +100 MVAR STATCOM connected to a 2-bus power system, and a single-line to ground (SLG) fault is considered. These results show that IPLL exactly works as the conventional PLL under normal conditions. The comparison results with different distance based SLG faults validate that IPLL is able to track the real phase of the voltage under system faults and disturbances. As a result, over-currents (and trips) in the VSC during faults is prevented, and the STATCOM is ensured to supply required reactive power. It can be shown that the practical operation range of the STATCOM can be further improved through high frequency notching in case of system faults or bus voltage disturbances which is called "Emergency PWM" or EPWM. The implementation of this controller is also covered in this paper.

A double generator system and a transmission line where an ideal shunt compensator is connected to the middle of the line. The generators have an equivalent reactance of XG1 and XG2 while the transmission line has an equivalent reactance of XdL. The voltages at Point of Common Coupling (PCC) of the generators are given asV1∠δ1 and V2∠δ2. The shunt compensator connected in the middle of the line is a voltage source that is continuously controlled to VSC∠δSC.

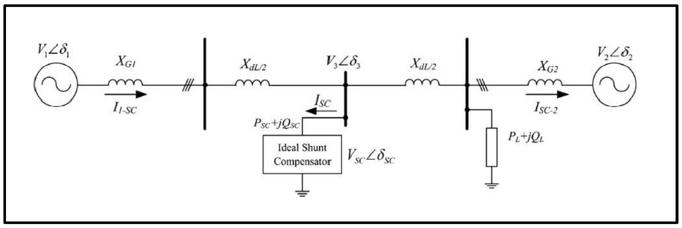

Figure 1:Connection of an ideal shunt compensator to transmission line

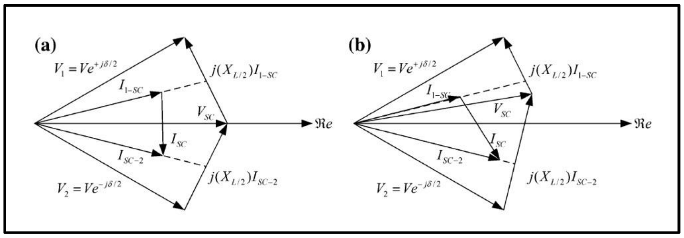

Figure 2: Phasor diagram of shunt compensation. (a) Reactive power compensation, and (b) reactive and active power compensation.

The phase differences show that I1−SC current flows from first generator to the line while ISC−2 flows from line to the second generator. The ISC phasor is the derived current flowing through the shunt capacitor where it is orthogonal to the Vsc as seen in Fig. 2(a). This means the compensator does not exchange active power (P) with the line. In this case, the compensator has only reactive power on its connections. Hence, the power transferred from V_1 to V_2 can be calculated as

$$P_1 = \frac{2V^2}{X_L}\sin(\delta/2) - - - -(1)$$

Where the P_1 is the active power supplied by V1 while V is the vector sum of V1 and V2 sources. In case of any compensator was not included in the system, the transferred power would be expressed as given in the following,

$$P_1 = \frac{V^2}{X_L}\sin(\delta) - - - -(2)$$

Where the compensator increases the power control ability of the transmission line since 2sin(δ/2) yields higher value than sin(δ) in the range of [0, 2π]. In case of the phase angles of V1 and V2 are different from δ/2, this situation causes the power flowing through sources has active and reactive power components as shown in Fig. 1.2b. In this situation, the shunt compensator owing to its power electronics based structure can be operated to adjust one of active or reactive power. Besides, the device structure also varies according to requirement of active or reactive power compensation since they are different in terms of energy storage elements. The connection type and switching device of compensators involve several different operating characteristics. The thyristor based topologies are classified into two main groups of self-commutated and force-commutated.

2. Statcom System Description

Figure 3 shows the voltage source converter topology and the 48-pulse output voltage waveform construction for STATCOM application. The VSC consists of four (Inv 1 – Inv4) 3-level Neutral Point Clamped (NPC) converters which are connected in series by four (T1-T4) transformer coupling. The primary side of the transformer is connected in series as shown in Figure 3. The gating of VSCs is phase shifted so as to yield a 48-pulse output voltage waveform with series transformer coupling on the primary side.

2.1. 48-Pulse Converter

The most important benefit of the multi-pulse converters is the harmonic eliminating owing to the 6n ± 1 ratio. The 48-pulse converter based STATCOM is the most important VSC type to reduce lower ordered harmonics since harmonic orders appears at 47th, 49th, 95th, and 97th orders that are managed by 48n ± 1 ratio of eight 6-pulse VSCs. Furthermore, this facility of 48-puse converter allows using in high power FACTS without requiring any ac filter. The topology includes 6-pulse VSCs as introduced in previous devices where the phase shifts and transformer connections are depicted similarly. The transformer connections are realized with zigzag type on primary side and Y/Δ types on secondary sides where the outputs of phase shifting sides are connected in series in order to eliminate lower order harmonics. The operation of 48-pulse STATCOM is depended on appropriate phase shift angles applied to VSCs and arranged between transformer connections.

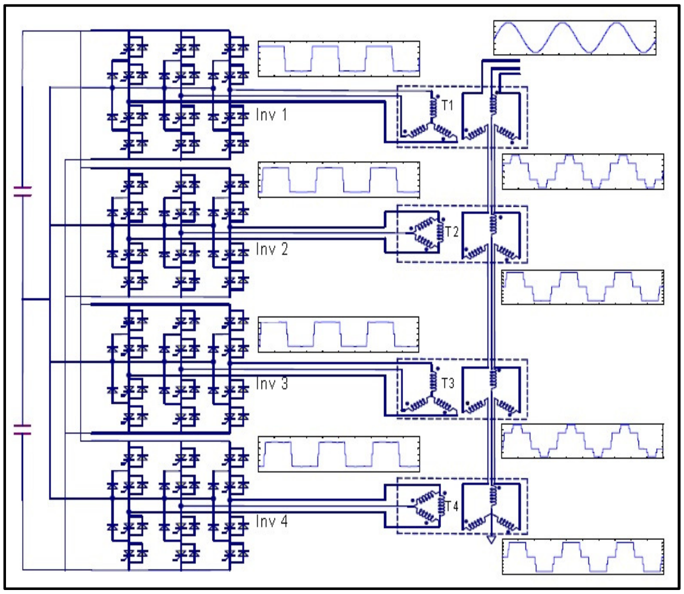

Figure 3: The 48-pulse voltage source converter circuit operating as STATCOM

Transformer connection	VSC switching angle (°)	Transformer phase shift angle (°)
Y-Z	+11.25	-11.25
Δ-Z	-18.75	-11.25
Y-Z	-3.75	+3.75
Δ-Z	-33.75	+3.75
Y-Z	+3.75	-3.75
Δ-Z	-26.25	-3.75
Y-Z	-11.25	+11.25
Δ-Z	-41.25	+11.25

Table 1: Phase shift angles for a 48-pulse VSC

The proper shifting angles are shown in Table 1 where switching signals of each VSC are generated by considering these orders. The transformer connection types and phase shift angles are also done according to this order and therefore high quality sinusoidal output voltage is generated to compensate the utility grid.

Transformer connection	Vsc switching angle (°)	Transformer phase shift angle (°)
Y-Z	+7.5	-7.5
Δ-Z	-22.5	-7.5
Y-Z	-7.5	+7.5
Δ-Z	-37.5	+7.5

Table 2: Phase shift angles for a 48-pulse STATCOM including 12-pulse VSCs

Another 48-pulse topology is constituted with 12-pulse VSCs that is similar to the connection diagram and phase-shift angles as shown in Fig. 1.10. The 48-pulse converter requires 12-pulse transformers with phase shifting windings to match with 12-pulse VSCs. In this situation, the phase shift angles of transformers are at $-7.5°$ and $7.5°$ for Y and Δ connections respectively as shown in Table 2. The switching angles α is calculated as shown below where the k is harmonic component to be eliminated

$$\alpha = 180\left(1 - \frac{1}{k}\right) - - - - (3)$$

The switching angle of VSC is intended to eliminate desired harmonic contents depending to its frequency spectrum and the instantaneous phase voltage of the STATCOM is expressed by Fourier series expansion as

$$V_{an}(t) = \sum_{k=1}^{\infty} \sin k\omega t - - - - (4)$$

$$V_{an_k} = \frac{2V_{dc}}{k\pi} \cos k \left(\frac{\pi - \alpha}{2}\right) - - - - (5)$$

Once the Van(t) is calculate, Vbn(t) and Vcn(t) can be easily calculated in a similar way where they are phase shifted by 120° and 240° respectively. The four VSCs of the 48-pulse STATCOM generate phase shifted AC output voltages to compensate the utility grid voltage where the output line voltage is given by,

$$V_{ab48}(t) = V_{ab}(t)_1 + V_{ab}(t)_2 + V_{ab}(t)_3 + V_{ab}(t)_4 - -(6)$$

Voltages Vbn48(t) and Vcn48(t) can also be easily calculated in a similar way to phase voltages since they are phase shifted by 120° and 240° respectively.

3. Matlab Block Diagram

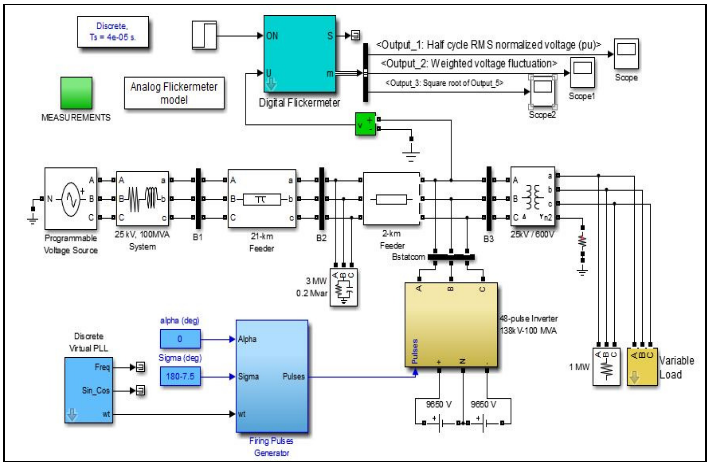

Figure 4: 48-pulse STATCOM connected to system

4. Statcom Dynamic Performance with the Proposed Strategies

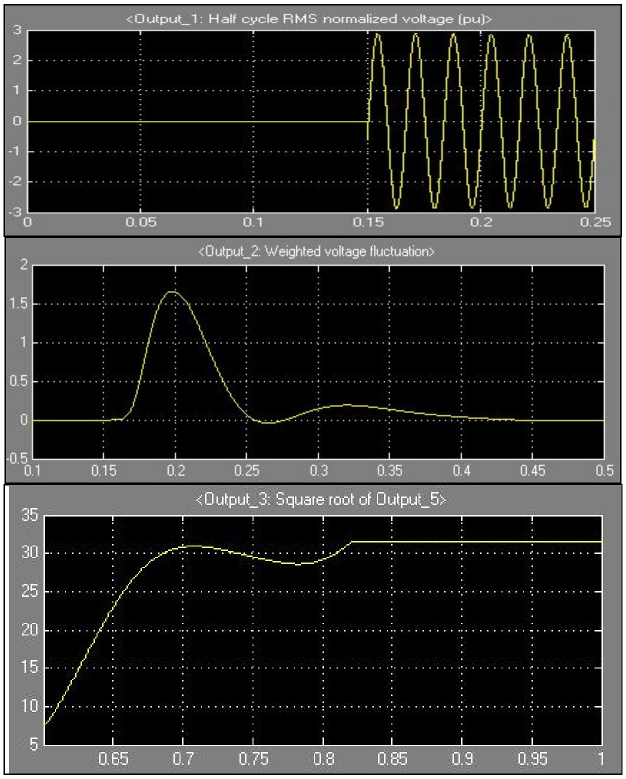

Figure 5: rms normalized voltage, weighted voltage fluctuation, square root of output at bus 3

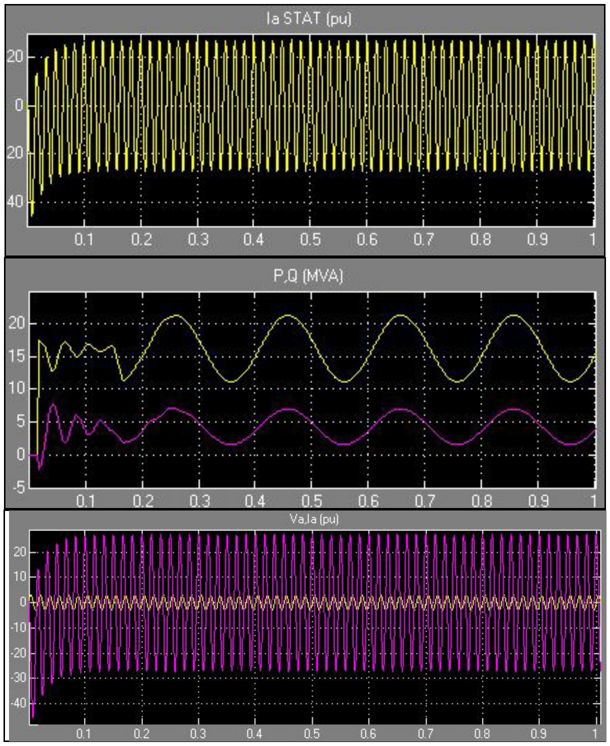

Figure 6: Output current, real and reactive power, current-voltage waveform of STATCOM

5. Conclusion

In this paper, the stability of a distributed generation system connected with a 48-pulse VSC based STATCOM is studied. As shown in figure 5 this compensate the effect of voltage fluctuation in a very short period of time and provide stability to the system. And figure 6 shows that at the STATCOM active and reactive power varies with the variation in load to compensate its effect and get stable after a short time period. The output current increases as per the requirement and come to its final value in less time. Although the angle control based STATCOM has a superior performance in terms of waveform quality and switching losses, it loses the required performance and may be shut down under system faults. The IPLL based controller limits the current and keeps the STATCOM system within safe operating area under and after faults while using regular and not over-rated transformers. The MATLAB results showed the applicability of the proposed methods.

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