Journal of Electrical Engineering and Automation (ISSN: 2582-3051)
www.irojournals.com/iroeea/

GRID INTEGRATION OF VOLTAGE SOURCE CONVERTER USING POWER SYNCHRONIZATION CONTROL

Madhubhala D[1], Dr. Sujatha Balaraman[2], Ponrekha M[3]

[1]Post Graduate,[2]Scholar, Professor,[3]Research Scholar, Electrical & Electronics Engineering, Government College of Technology, Coimbatore, India

Email: madhukmdeee@gmail.com[1], sujathaeee@gct.ac.in[2], mponrekha@gmail.com[3]

Abstract

Renewable Energy Sources (RES) are integrated with electric power systems around the world at an accelerated pace. Due to their intermittent nature, integrating RES into the power grid is a challenging task. Because of their good controllability and superior performance in weak AC grids, the three phase Voltage Source Converters (VSCs) are generally used for this purpose. The grid connected converter has to correctly detect the grid voltage signal during voltage distortion and unbalance condition. In this research work, a control method using power synchronization for grid integration of VSC is developed and simulated. In this control technique, the electricity fed to AC grid from VSC is controlled using the internal synchronization mechanism as like in conventional synchronous machine. Utilizing this type of control, the instability of VSC affected by a standard Phase Locked Loop during weak grid condition can be avoided. Moreover, a VSC terminal could support a weak AC system with strong voltage, just similar to an ordinary synchronous machine organizer. Simulations are done in Matlab/Simulink to validate the system performance of grid attached VSC with the Power Synchronization Control.

Keywords: Voltage Source Converter, Control Techniques, Power Synchronization Control (PSC), weak grid.

1. Introduction

Renewable energies such as wind, solar, etc. can be integrated into the system via Voltage Source Converter (VSC). Since the control through the vector current is a dominant scheme, there are certain limitations when the VSC is connected with a weak grid. Virtually,

DOI: https://doi.org/10.36548/jeea.2023.1.005
Received: 01.03.2023, received in revised form: 01.04.2023, accepted: 16.04.2023, published: 26.04.2023

in all grid connected VSCs, a Phase Locked Loop (PLL) is used to achieve an exact synchronization with the grid. Article [7] analysed the power transmission limit and the stability of VSC based on which it was found that the Power Synchronization Control (PSC) decreases with the increase of SCR. i.e., the SCR of the power transmission lines impedance is nearby 1.

In this work, power synchronization is used as a substitute with an ordinary PLL. The power-synchronization loop directly controls active power output. PSC is related to power angle control. The main concept of power synchronization is active power control of VSCs connected to the grid. Most utility-scale renewable generation systems are required to operate under weak grid conditions for effective transmission of renewable power to the load centres located in remote.

2. VOLTAGE SOURCE CONVERTER

2.1 Overview of VSC

The demand for electricity has been increasing rapidly in the last few decades. To meet this high requirement of electricity, more and more attention is being paid to power generation from renewable resources such as solar, wind, etc. in place of conventional power generation. Several topologies of power electronic converters are being used in grid-connected converter applications. The VSC has been used extra powerfully in three phase grid connected applications.

The control techniques for VSCs driven by motor drive applications do not seem to be suitable for grid-connected modes in the case of grid-connected VSCs. Particularly in weak grid state of affairs, the Point of Common Coupling (PCC) where the VSC is being integrated to the grid stays at the end of the distribution system. Figure 1 indicates the block diagram of VSC with PSC.

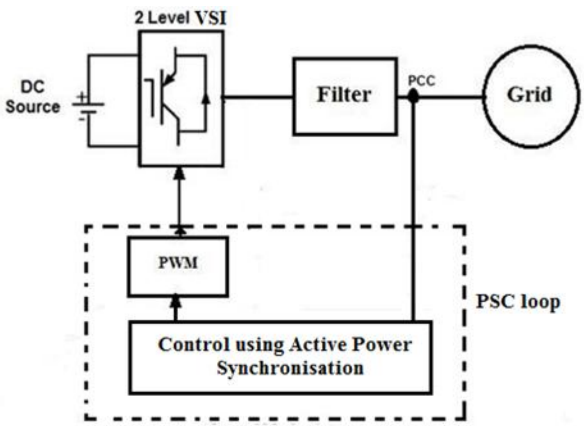

Figure 1. Block diagram of VSC with PSC

2.2 Mathematical Model of VSC

The following equation shows the connection between the inverter and the grid.

$$e_{abc}(t) - v_{abc}(t) = L\frac{di_{abc}(t)}{dt} + Ri_{abc}(t) \qquad (1)$$

Where,

$$[T] = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix}$$

[T] denotes transformation-matrix, and the rotating angle is denoted using θ. At this instant, the dynamic equation is changed straight to synchronous dq frame.

$$v_d(t) = e_d(t) - L\frac{di_d(t)}{dt} - Ri_d(t) + L\omega i_q(t) \qquad (2)$$

$$v_q(t) = e_q(t) - L\frac{di_q(t)}{dt} - Ri_q(t) + L\omega i_d(t) \qquad (3)$$

P(t) & *Q(t)* indicate the instantaneous real power and apparent power respectively.

$$P(t) = \frac{3}{2}\left[e_d(t)i_d(t) + e_q(t)i_q(t)\right] \qquad (4)$$

$$Q(t) = \frac{3}{2}[e_q(t)i_d(t) - e_d(t)i_q(t)] \quad (5)$$

A common feature of power converters (either rectifiers or inverters) based on power electronics technology is that, they are coupled in parallel or series with the grid either directly or by way of transformers and reactors, to depend on the supply voltage to coincide with the grid.

2.3 Requirements of VSC grid integration

The grid connection with the numerous distributed power generators, may result in instability of these systems and of the grid. Therefore more stringent standards have been issued with respect to grid-connected VSCs for distributed power generation.

Therefore, the VSC has to operate in transient voltage fluctuations coming from the PCC in the power grid instead of being disconnected from the grid to protect the converters.

2.4 The Grid Synchronization

The main role of grid synchronisation is to prevail the phase and frequency information of the grid voltages, and the conversion of state variables into frame of rotational reference and the other way round [8]. To get the better of the issues in instability caused by the effect of high impedance in grid, which is an end result of an action in weak grid under PLL, the model of grid synchronization is extended to increase its steadiness for increased power transfer from VSC in conditions of weak grid.

2.5 Effects of weak grid on VSC performance

The SCR is small which makes the grid vulnerable. Even a small variation that causes instability in the signal power will result in activating the renewable generator system.

3. CONTROL TECHNIQUES OF VSC

3.1 Vector Current Control

Originally, VSCs have improved current control of vector in variable speed drives, where the AC motor is coupled to the VSC. Usually, this technique is considered to be an important step in AC motor control. To achieve better performance, it is most important to maximize the current bandwidth of the VSC [4].

3.2 Power Angle Control

The concept of power angle control relies on the following equations.

$$P = \frac{V_1 V_2 \sin\theta}{X} \qquad (6)$$

$$Q = \frac{V1^2 - V_1 V_2 \sin\theta}{X} \qquad (7)$$

Here, the P & Q represent the real and apparent powers in an AC network with voltage magnitudes V1 and V2 respectively.

3.3 Power Synchronization Control

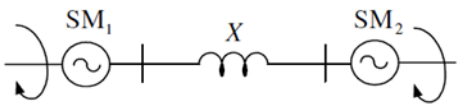

Figure 2. Mechanism of synchronization between SMs in an AC Network

From this part, Power Synchronization Control is explained [3]. The great goal of this control method is to defeat the problem of vector current control with weak AC networks.

4. POWER SYNCHRONIZATION CONTROL

4.1 Synchronous Machines Mechanism

Mechanism of synchronous machine synchronization is revealed in Figure 2. The system having two interrelated SM_1 and SM_2 acts as generator and motor correspondingly [5]. As shown by the phasor Figure in 3(a), E_1 and E_2 are described by line identical of the inner emfs of the two phasors respectively. The energy transferred from M_1 to M_2 is given by,

$$P = \frac{E_1 E_2 \sin\theta}{X} \qquad (8)$$

Meanwhile the emf of the machine is securely connected with its position of rotor. The mechanical angle in SM_1 certainly causes in phase of SM_1 emf, as specified through the phasor E'_1 which is shown in Figure 4(b).

$$J_2 \frac{d\omega_{m2}}{dt} = T_{m2} - T_{e2} \qquad (9)$$

Where, J_2 –Total shaft inertia

Ω_{m2} - Velocity of Angular in Mechanical

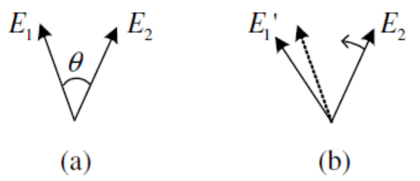

Figure 3. Phasor figures relating power synchronization

The synchronization method has been completed through the transferring of transient power.

4.2 PSC Loop

The PSCs are increasingly being used with VSCs integrated with weak AC systems [1]. Power Synchronization Loop (PSL) which is shown in Figure 4, upholds synchronism between the VSC and the AC network. This is the loop of real power control that is mentioned in Equation (10).

$$\theta_{ref} = K_i \int (P_{ref} - P) + \omega_0 t \qquad (10)$$

where,

P_{ref} - Reference Real power in PSC

P_e - Real power output

ω_0 - The grid frequency

K_i - PSC Integrator gain

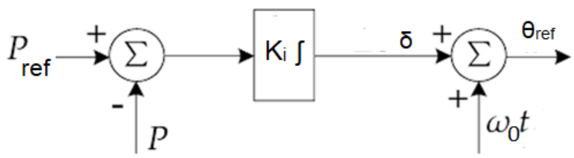

Figure 4. Loop of Power Synchronization Control

4.3 Grid Connected VSC with PSC

The transient power transfer is the PSC. The transferring of power contains a current which is decided by the interconnecting system network. The power synchronization done for controlling the VSC could not control the Vector Current Controller (VCC) without the knowledge of the reference current [6]. The current valve limits the converter under severe network faults in an AC system.

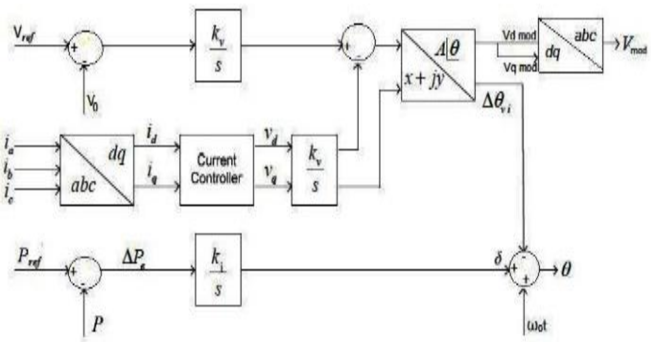

Figure 5. Block diagram of PSC

5. Simulation Results and Discussion

5.1 Standalone Mode

The model is carried out using Matlab R2018a. The Simulink model of VSC under standalone mode is shown in figure 6. The DC source is connected to the VSC which will be used to convert DC to AC systems. Output from VSC is linked with LC filter to decrease the harmonics. After filtering, the output is given to load.

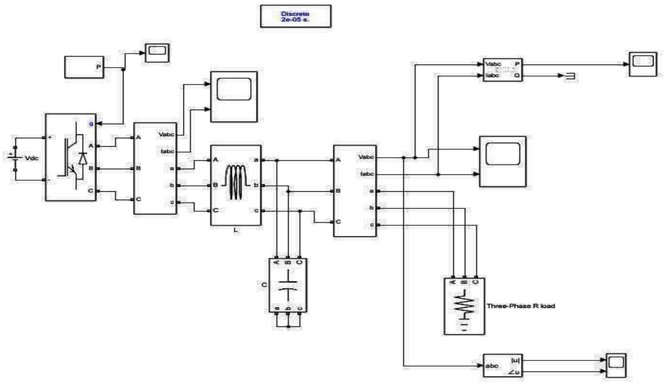

Figure 6. Simulink model of standalone VSC

Table 1. Voltage Source Converter Parameters

DC Source	700 V
Filter Capacitor	50 µF
Filter Inductance	50 µH
AC output	400 V (Line to Line)

The VSC parameters are tabulated in Table 1. The peak voltage and current are 565 V and 20 kA respectively. The output power (7.54 W) waveform of Standalone VSC is shown in figure 7 and the output voltage and current waveform for standalone approach is shown in figure 8.

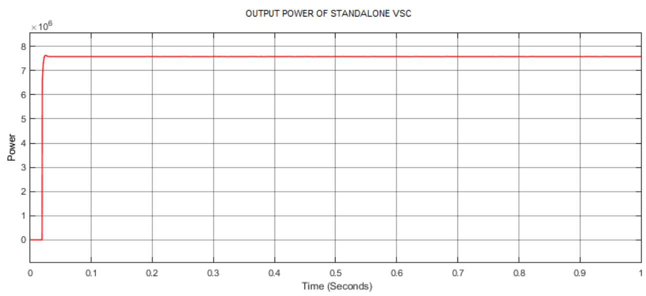

Figure 7. Output Power waveform of Standalone VSC

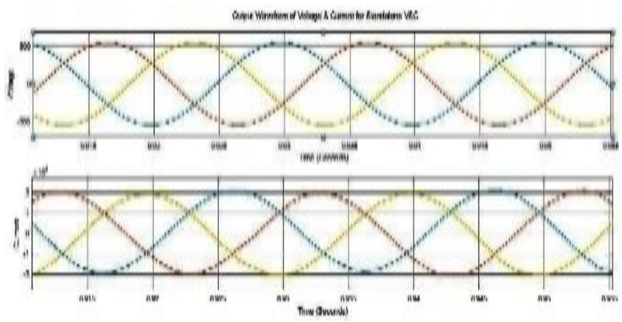

Figure 8. Output waveform of Voltage & Current for Standalone VSC

Grid Connected VSC

The simulink model of grid integration of VSC with PSC is shown in figure 9. The input to VSC converts 700 V DC to 400 V (line to line) AC voltage. The output is filtered and given to load. Voltage source converter is integrated with grid using PSC loop. A load is connected between VSC and grid. The simulink model of Power Synchronization Control is shown in figure 11 [9]. The PSC parameters are tabulated in Table 2

.

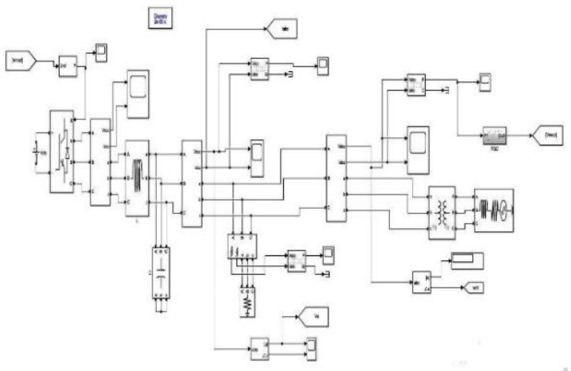

Figure 9. Simulink model of PSC – VSC

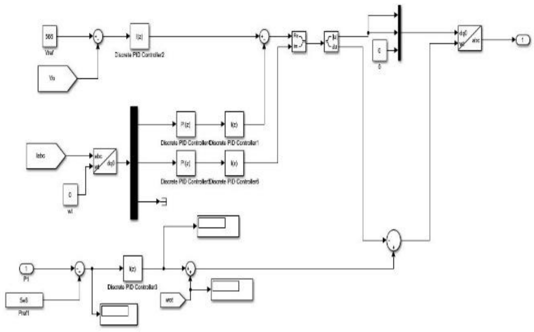

Figure 10. Simulink Model of PSC Block

Table 2. Power Synchronization Control Parameters

Grid Inductance	0.05 μH
Grid Resistance	0.8929 Ω
Grid Voltage	11 kV
Transformer Rating	11 kV/400 V
AC voltage at PCC	400 V (Phase to Phase)
DC Source	700 V
Filter Capacitor	20 μF
Filter Inductance	40 μH

Case 1:

The current and voltage at PCC is shown in figure 13. It is observed that the voltage and current waveforms are almost sinusoidal with less harmonics as per grid code. As shown in figure 14, the output power from VSC is 8.58 MW. The energy consumed by the load (2.27 MW) is shown in figure 11. The excess power (6.31 MW) from voltage source converter is injected to grid as shown in figure 12.

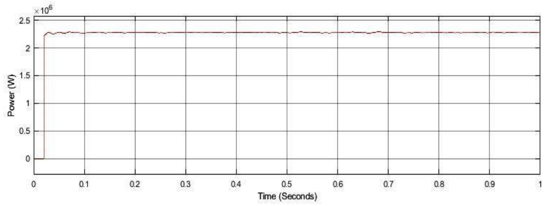

Figure 11. Load Power – Case 1

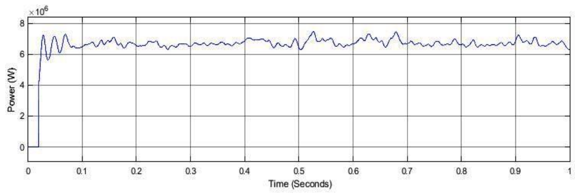

Figure 12. Real power injected to grid – Case 1

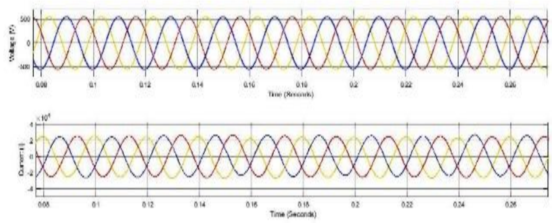

Figure 13. PCC voltage and current waveform - Case 1

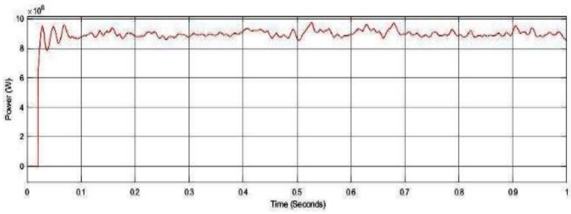

Figure 14. Real Power from PCC - Case 1

Case 2:

The waveforms of current and voltage at PCC are represented in figure 17. The power output from the voltage source converter is 8.55 MW as shown in figure 18. The load power is 1.9 MW as shown in figure 15. The excess power of 6.65 MW from the VSC is injected to grid as shown in figure 16.

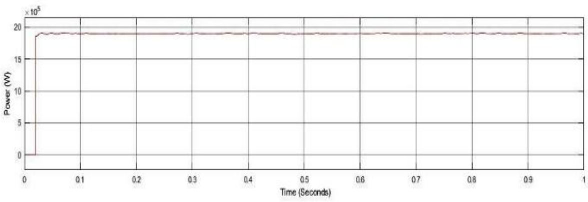

Figure 15. Load Power - Case 2

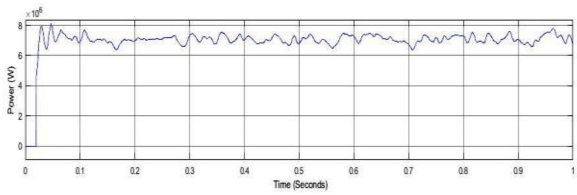

Figure 16. Real power injected to grid - Case 2

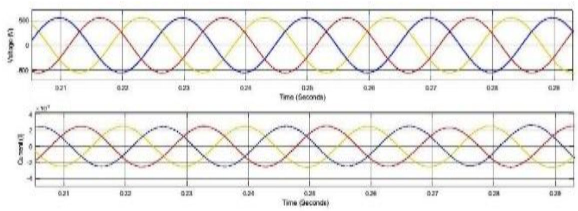

Figure 17. PCC voltage and current waveform - Case 2

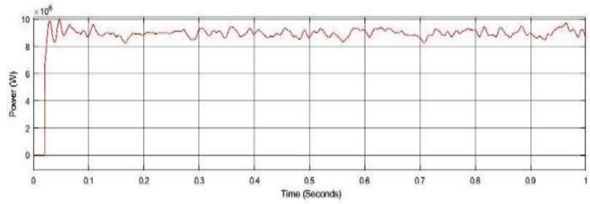

Figure 18. Real power from PCC - Case 2

Case 3:

The current and voltage waveforms are presented in figure 21. It is observed that the PCC voltage is 565 V (Peak) and current at the PCC is 26 kA. The output power from the voltage source converter is 9.18 MW as shown in figure 22. The power used up by the load is 180 kW as shown in figure 19. The excess power of 9 MW from the VSC is injected to grid as shown in figure 20.

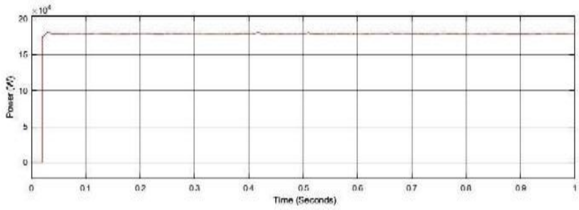

Figure 19. Load Power- Case 3

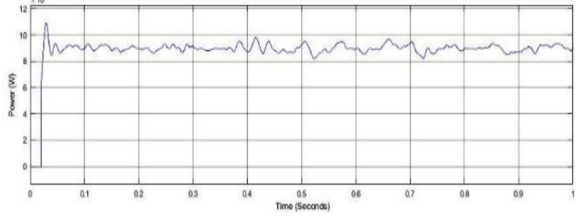

Figure 20. Real power injected to grid - Case 3

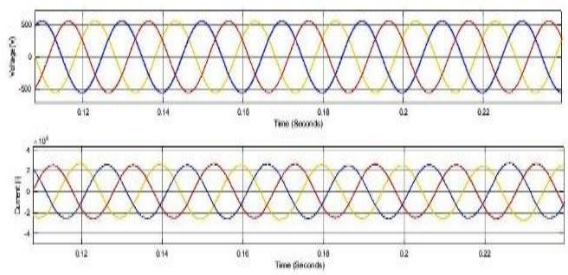

Figure 21. PCC voltage and current waveform - Case 3

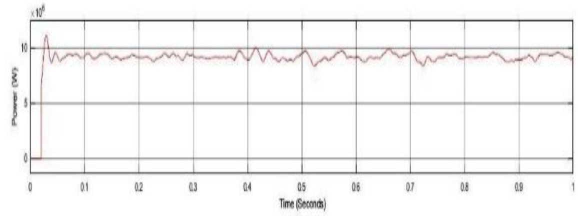

Figure 22. Real power from PCC - Case 3

6. CONCLUSION

In this research work, a suitable control approach for integration of grid with VSC using power synchronization has been modelled and simulated. This type of power synchronization control for the grid integrated Voltage Source Converter removes instability caused by the standard PLL in a weak AC device. The performance of control strategy has been analysed under different loading conditions. Simulations are obtained in MATLAB/Simulink. From the simulation results, it is evident that the control scheme provides effective active power sharing between load and the power grid. Also, it is found that the current and voltage waveforms are very nearly in-phase and sinusoidal.

References

[1] Heng Wu and Xiongfei Wang, "Design-Oriented Transient Stability Analysis of Grid-Connected Converters with Power Synchronization Control", IEEE Transactions on Industrial Electronics, Vol. 66, No. 8, pp. 6473-6482, August 2019.

[2] Seena. K. R and Sindhu.T.K, "Power Synchronization Control of VSC-HVDC Transmission for Weak AC System", International Journal of Power System Operation and Energy Management ISSN, Vol. 2, pp. 2231 – 4407, July 2013.

[3] Lidong Zhang, Lennart Harnefors and Hans-Peter Nee,” Power-Synchronization Control of Grid-Connected Voltage-Source Converters”, EEE transactions on power systems, vol. 25, no. 2, pp.809-820, May 2010.

[4] Daniel Remon, Antoni M., Cantarellas, Elyas Rakhshani, Ignacio Candela and Pedro Rodriguez, “An Active Power Synchronization Control Loop for Grid-Connected Converters”, IEEE PES General Meeting, Conference & Exposition, Oct. 2014.

[5] Vijaya Raghavan S and Dr. Jayabharathi R, “Simulation and Analysis of Power Synchronization Control for Voltage Source Inverter”, Conference on Recent developments in control, Automation & power engineering (RDCAPE), IEEE, Oct. 2017.

[6] S. Nanou and S. Papathanassiou, “Grid code compatibility of VSC-HVDC connected offshore wind turbines employing power synchronization control”, IEEE Trans. Power Syst., Vol. 31, No. 6, pp. 5042–5050, Jan. 2016.

[7] P.Mitra, L. Zhang, and L. Harnefors, “Offshore wind integration to a weak grid by VSC-HVDC links using power-synchronization control: A case study”, IEEE Trans. Power Del., Vol. 29, No. 1, pp. 453–461, Feb 2014.

[8] L. Zhang, H. P. Nee, and L. Harnefors, “Analysis of stability limitations of a VSC-HVDC link using power synchronization control”, IEEE Trans. Power Syst., Vol. 26, No. 3, pp. 1326–1337, Aug 2011

[9] Arif Haider, Noman Ahmed, Lennart Angquist and Hans-Peter Nee, “Open-loop Approach for Control of Multi-Terminal DC Systems based on Modular Multilevel Converters”, 14th European Conference on Power Electronics and Applications, IEEE, Aug 2011.