Global Journal of Research Engineering
Volume 11 Issue 2 Version 1.0 March 2011
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
ISSN: 0975-5861

# Synchronous Voltage Source Inverter Using FCMLI

By Vikas Kumar Rai, Mohit Gaharwar, Rajesh Kumar, Shobhit Saraswat
*E&C,Sachdeva Institute of Technology*

*Abstract-* The structure and control schemes of a STATic synchronous COMpensator (STATCOM) using Flying Capacitor Multi-Level Inverter (FCMLI) have been discussed in this paper. The STATCOM is realized by a synchronous Voltage Source Inverter (VSI), which generates three-phase ac voltages in phase with the transmission system voltage. Multilevel inverter structure of the VSI is used for the realization of the STATCOM. Three multilevel inverter structures (Diode clamped, cascade and flying voltage source) have been described in this work. The operation of these structures for the general inverter operation and compensation purposes has been studied. FCMLI is a special structure of the flying voltage source topology. A method for controlling the FCMLI is used which ensures that the flying capacitor voltages remain constant. The above inverter structures and control schemes of the STATCOM have been verified through digital computer simulation studies using PSCAD/EMTDC software package.

*Keywords- Flying Capacitor Multi-Level Inverter, STATCOM , VSI , SMIV*

*Classification: GJRE-F Classification: FOR Code: 090699*

SYNCHRONOUS VOLTAGE SOURCE INVERTER USING FCMLI

*Strictly as per the compliance and regulations of:*

© 2011 Vikas Kumar Rai, Mohit Gaharwar, Rajesh Kumar, Shobhit Saraswat. This is a research/review paper, distributed under the terms of the Creative Commons Attribution-Noncommercial 3.0 Unported License http://creativecommons.org/licenses/by-nc/3.0/), permitting all non-commercial use, distribution, and reproduction inany medium, provided the original work is properly cited.

# Synchronous Voltage Source Inverter Using FCMLI

Vikas Kumar Rai[1], Mohit Gaharwar[2], Rajesh Kumar[3], Shobhit Saraswat[4]

*Abstract :* The structure and control schemes of a STATic synchronous COMpensator (STATCOM) using Flying Capacitor Multi-Level Inverter (FCMLI) have been discussed in this paper. The STATCOM is realized by a synchronous Voltage Source Inverter (VSI), which generates three-phase ac voltages in phase with the transmission system voltage. Multilevel inverter structure of the VSI is used for the realization of the STATCOM. Three multilevel inverter structures (Diode clamped, cascade and flying voltage source) have been described in this work. The operation of these structures for the general inverter operation and compensation purposes has been studied. FCMLI is a special structure of the flying voltage source topology. A method for controlling the FCMLI is used which ensures that the flying capacitor voltages remain constant. The above inverter structures and control schemes of the STATCOM have been verified through digital computer simulation studies using PSCAD/EMTDC software package.

*Indexterms : Flying Capacitor Multi-Level Inverter, STATCOM , VSI , SMIV*

## I. Introduction

In this paper, the FCMLIs are used to implement an STATCOM. Three-level and Five-level structures have been used separately to simulate the STATCOM. Two control approaches i.e., Direct Control and Indirect Control are used and comparisons are made based on the results.

For an STATCOM to operate, several important requirements listed below, have to be made.

1. The transformers, interconnecting the inverter and the transmission line, should provide galvanic isolation of the inverter from the line so that the three legs of the multilevel inverter can be connected to a common dc link.
2. To allow the zero sequence currents to flow during faults, it is necessary to connect the secondary windings of the three phase transformers in delta, so that the zero sequence secondary currents flow as the circulating current of the delta.
3. The transformer primary to secondary turns ratio should be such that, it insures that the voltage and currents across the power semiconductor devices do not exceed their ratings.

Keeping in consideration these requirements, an STATCOM can be designed using a voltage source converter. It is seen that FCMLI is able to operate in high voltage and high power conditions, while maintaining constant its flying capacitor voltages. From this paper we proved that FCMLI is a well-suited inverter for the compensation purposes. In the system under consideration, ideally there is no real power transfer between the converter and the lines. For only reactive compensation, the battery of the inverter can be replaced by capacitor of suitable size. The simulation study has been done using PSCAD/EMTDC

## II. Transmission System Under Consideration

A three-phase, Single Machine Infinite Bus (SMIB) transmission system is being considered for the simulation studies. A coupled pi-section model of the transmission line is being considered. The transmission line data is given in Table 1. The phase of the sending end voltage is fixed at 0° while the phase of the receiving end voltage is varied. Initially, receiving end voltage has 30° lag with respect to the sending end voltage phase. At 1.0 second, the phase angle of the receiving end is changed to 0° such that the power transferred over the transmission line is reduced to zero. The phase angle is again changed to – 60° at 1.5 second.

The simulation results for an uncompensated transmission are shown in Fig. 1. The real power transferred from the sending end and the power received at the receiving end is shown in Fig. 1 (a) and the reactive power is shown in Fig. 1 (b). Note that in this figure and the following figures in this paper, the receiving end real power shown with multiplying it by – 1 as this power is entering at the receiving end terminals. Fig. 2 (a and b) shows line current of phase *a* at the

*About [1]: E-mail-hellovikasrai@yahoo.com Working as Assistant Professor,Deptt. of E&C,Sachdeva Institute of Technology ,Mathura.U.P., INDIA Active member IEEE/Branch Counsellor IEEE SB SIT,Mathura,INDIA Life member of ISIAM*
*About [2] : E-mail-mohitgaharwar@rediffmail.com Working As Assistant Professor, Deptt. of E&C,Sachdeva Institute of Technology ,Mathura.U.P., INDIA Active member IEEE/Branch Co-ordinator IEEE SB SIT,Mathura,INDIA Life member of ISIAM*
*About [3] : E-mail-heyrajeshkumar@yahoo.com Working as Assistant Professor, Deptt. of E&C,Sachdeva Institute of Technology ,Mathura.U.P., INDIA Active member IEEE.Life member of ISIAM*
*About [4]: E-mail-shobhit_sar@yahoo.com Working as Assistant Professor, Deptt. of E&C,Sachdeva Institute of Technology ,Mathura.U.P., INDIA Active member IEEE.Life member of ISIAM*

Global Journal of Research Engineering Volume XI Issue II Version I March 2011



©2011 Global Journals Inc. (US)

sending end and the receiving end respectively. Fig. 3 (a and b) shows the line current of phase *a* from 1.49 second to 1.8 second. It shows that the transients die out within 5 cycle. Fig. 4 shows per unit mid point terminal voltage. Table 2 lists the steady state values of the system without compensation.

*Table 1:* Transmission Line Parameter.

| System Parameter | Values |
|---|---|
| Base MVA | 1000 MVA |
| Base voltage | 230 kV (Line-line) |
| Operating Source Voltage | 1.0 per unit |
| Source Impedance type | R= 0.01 Ω (resistive) |
| System frequency | 50 Hz |
| Line length | 2 × 200 km |
| Positive sequence resistance | 0.17816 × $10^{-4}$ [Ω/m] |
| Positive sequence inductive reactance | 0.31388 × $10^{-3}$ [Ω/m] |
| Positive sequence capacitive reactance | 273.545 [M Ω*m] |

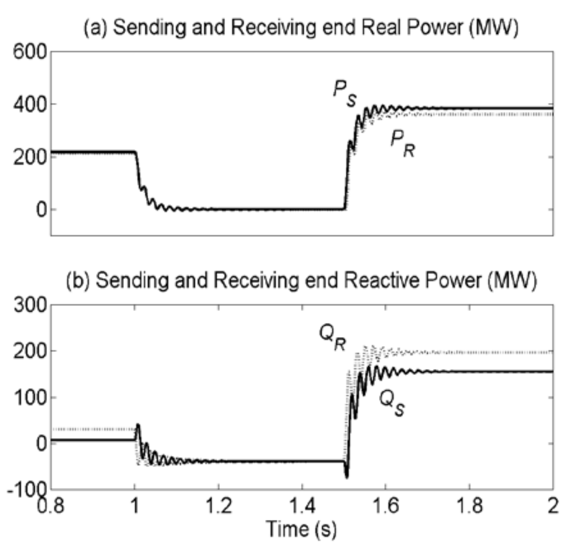


*Fig. 1:* Simulation Results of Uncompensated Transmission System.

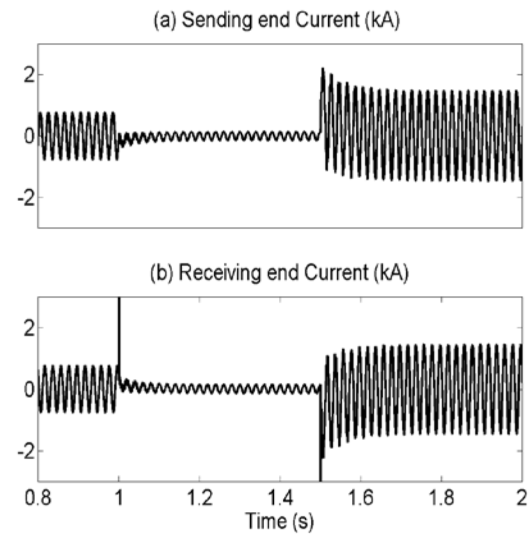


*Fig. 2:* Line current of phase '*a*'.

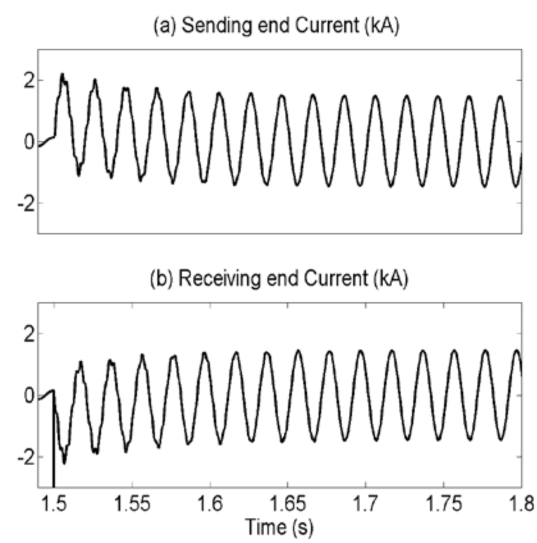


*Fig. 3:* Magnified portion of Line current of phase '*a*' from 1.5 s to 1.8 s.



©2011 Global Journals Inc. (US)

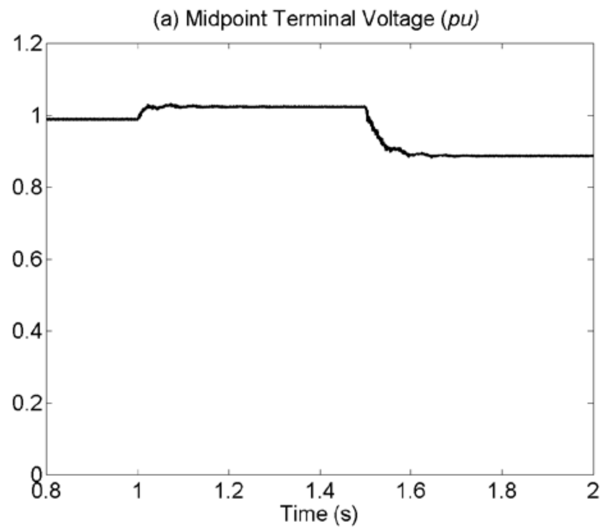


*Fig.4:* mid-point terminal Voltage .

## III. Control Strategy of STATCOM

In STATCOM control, the main objective is to control the output of the VSI through varying the modulation index and the dc capacitor voltage. The control of the STATCOM can be broadly categorized in two categories.

- Indirect control
- Direct control.

*Table 2 :* System parameters of the Transmission line.

| Parameters | Values before 1.0 sec. | Values after 1.0 sec. and before 1.5 sec | Values after 1.5 sec. |
|---|---|---|---|
| $P_s$ (MVA) | 218.17 | 0.048 | 384.28 |
| $P_r$ (MVA) | 211.68 | –0.032 | 360.27 |
| $Q_s$ (MVA) | 6.45 | –39.13 | 155.01 |
| $Q_r$ (MVA) | 30.46 | –39.13 | 196.58 |
| $V_m$ (pu) | 0.989 | 1.024 | 0.888 |

The output voltage of the VSI depends on the magnitude of the dc side voltage and the modulation index $m_a$. In the indirect control, the dc side voltage of the VSI is varied by keeping $m_a$ constant while in the direct control, the $m_a$ is varied keeping the dc side voltage constant. The parameters of the switches, which are being used for the realization of VSI is listed in Table 3. The same ratings of anti parallel diodes are used. The simulation results for both these controls are discussed below.

*Table 3:* Switching device parameters.

| | |
|---|---|
| Main device type | IGBT |
| IGBT *ON* resistance | 0.01 Ω |
| IGBT *OFF* resistance | $1.0 \times 10^6$ Ω |
| Forward voltage drop | 0.0 kV |
| Forward breakover Voltage | $1.0 \times 10^5$ kV |
| Reverse withstand Voltage | $1.0 \times 10^5$ kV |
| Snubber Resistance | 5000 Ω |
| Snubber Capacitance | 0.05 $\mu$F |

### 1) Indirect Control

A STATCOM is connected at the midpoint of the transmission line. The transmission line discussed in the previous section has been again taken in this case. The PSCAD/EMTDC simulation diagram of a STATCOM connected to transmission line at the midpoint line through a coupling transformer and a smoothing reactor is shown in Fig. 5. The data of the coupling transformer is given in Table4. The VSI is connected to the transformer through a coupling inductor whose inductance is 1 mH. Main capacitor and capacitors of clamping leg are 20000 $\mu$F each. Only one capacitor in each clamping leg is taken for simulation but it is of different voltage rating. The instantaneous value of the main capacitor voltage is passed through a moving average (MA) filter [5]. The output of the MA filter is compared with the actual value of the other clamping capacitor to get the error. This error is used to get the proper switching combination for different voltage levels.

Now the midpoint voltage is measured and compared to its reference value. This error is passed through a proportional plus integral (PI) controller and then subtracted from the synchronizing signal. It gives the reference signal for switching of the power electronic devices used in VSI, the output of the PI controller provides the required phase shift between the midpoint bus voltage and the VSI output voltage. This phase shift controls the real power exchange between the midpoint bus and the VSI. This leads to charging or discharging of the dc capacitor. There is an additional phase shift of 30° to compensate the phase shift due to star delta connection of the transformer.



©2011 Global Journals Inc. (US)

March 2011

4

Global Journal of Research Engineering Volume XI Issue II Version I

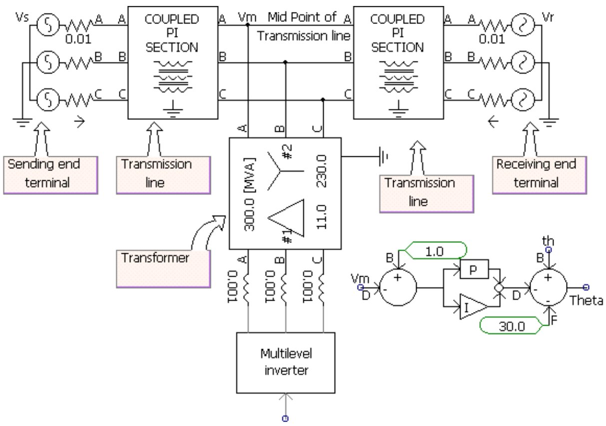


*Fig. 5:* Indirect controlled STATCOM.

*Table 4:* Transformer Parameters.

| Parameter | Values |
|---|---|
| System frequency | 50 Hz |
| Base MVA | 300 MVA |
| Connection | Delta-star with neutral ground |
| Delta winding voltage | 11 kV (line-line) |
| Star winding voltage | 230 kV (line-line) |
| No load losses | 0.01 per unit |
| Positive sequence leakage reactance | 0.1 per unit |

Let us consider that $V_m$ is less then its reference value. Then the error will be positive and hence the phase shift provided by the PI controller is increased. This leads to increase in the real power flow from the midpoint bus to the VSI, which increases the dc capacitor voltage, and hence the VSI output voltage. Therefore reactive power supplied by the inverter also increases, which increases the midpoint terminal voltage to its reference value. The proportional gain and the integral time constant of the PI control are chosen as 500 and 0.0009 second respectively. The simulation results for the indirect controlled STATCOM are given in Figures.6 to 11. From Fig.7 (a), it can be seen that the midpoint voltage approaches to its reference value. When the receiving end phase angle changes from –30° to 0° at 1.0 second, the midpoint terminal voltage increases. When the phase angle of the receiving end changes, the reactive power demand by the line also changes. But the dc capacitor voltage can not be changed suddenly and hence the reactive power supplied by the STATCOM does not change fast. In the meanwhile the midpoint terminal voltage deviates from its reference value. Now once the dc capacitor regulates its voltage to supply the required reactive power, the midpoint terminal voltage returns to its specified value. It can be seen that the midpoint terminal voltage does not change much for a small disturbance occurred at 1.0 second but it has a large fluctuation for very large transient at 1.5 second. However the voltage approaches its reference value within 15 cycles. Now consider the case when power transfer from sending end to receiving end increases suddenly. For this, more reactive power is required by the line. It needs to increase the dc capacitor voltage. Therefore the real power flow from the system to STATCOM which also increases the line drop and reduces the midpoint voltage. As the dc capacitor charges to the required value, the midpoint terminal voltage reaches to its reference value. The real power and the reactive power at the sending end and receiving end are shown in Figures 6 (a and b) respectively. It shows that the power at both ends vary at the time of transient. Fig. 6 (c) shows the real and reactive power supplied by the STATCOM. It can be seen that a large amount of real power exchange occurs at the time of transients while a very small amount of power flows from the line to the STATCOM. This power accounts for the compensation of the losses in the STATCOM and transformer under steady state. Fig. 7 shows the dc capacitor voltage magnitude maintaining the mid point terminal voltage. The dc capacitor voltage is high for large real power transfer while its value is low under light load condition. Note that for the above, the capacitor voltage varies between 16 kV to 35 kV.

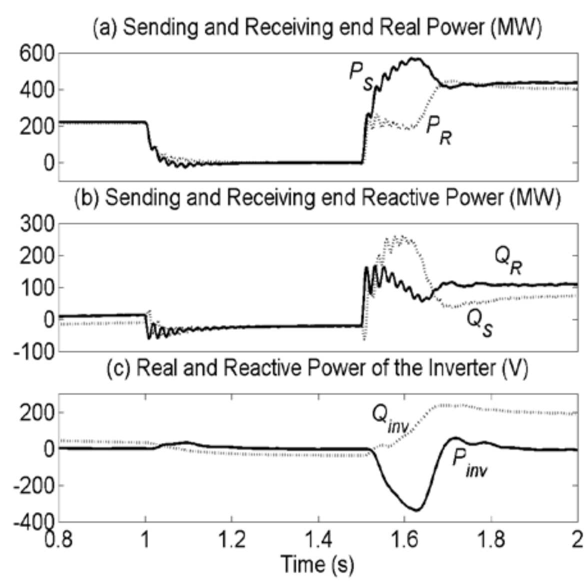


*Fig. 6:* Real and reactive powers.

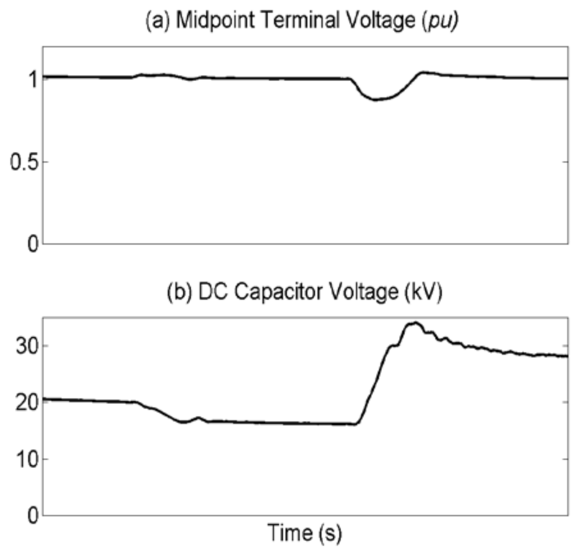


*Fig.7:* Midpoint terminal voltage and dc capacitor voltage.

Figs. 8 and 9 shows the current of phase *a* at sending end, receiving end and the current supplied by the STATCOM. It can be seen that all currents are sinusoidal and balanced under steady state condition. In comparison of sending end currents, the receiving end currents have a large variation at the time of transients. This is due to the transients at the receiving end. Note that the transients in the currents die out within 15 cycles for large system variation at the time of 1.5 second.

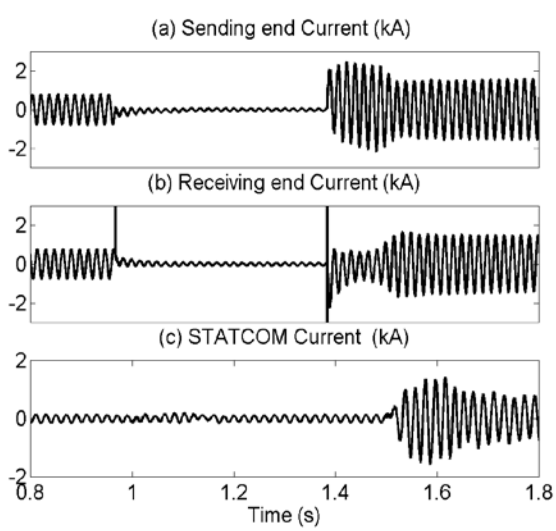


*Fig.8:* Phase *a* line current at various terminals.

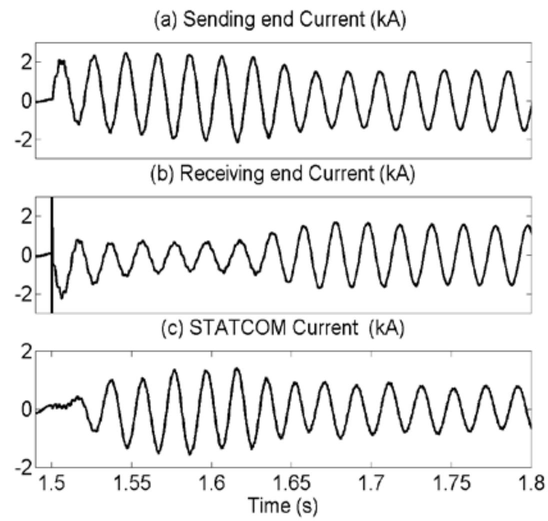


*Fig.9* : Magnified portion of Phase *a* line current at various terminals from 1.5 s to 1.8 s .

Fig. 10 shows the line voltage in the inverter side. It is measured between the smoothing reactor and the coupling transformer. It can be seen that the line voltage is approximately sinusoidal. Third and multiples of third harmonics are removed due to delta-star connection of the transformer. With higher value of smothing reactor and higher switching frequency, the other harmonics can also be removed.

Fig. 11 shows the clamping capacitor voltages of various leg and main capacitor voltage. The main capacitor voltage shown is obtained after passing it through a MA filter while other voltages shown indicate instantaneous values. Table 5 lists the steady state system quantities for different phase angles of the receiving end. Note that, there are large variations in the reactive power supplied by the STATCOM for various system conditions.

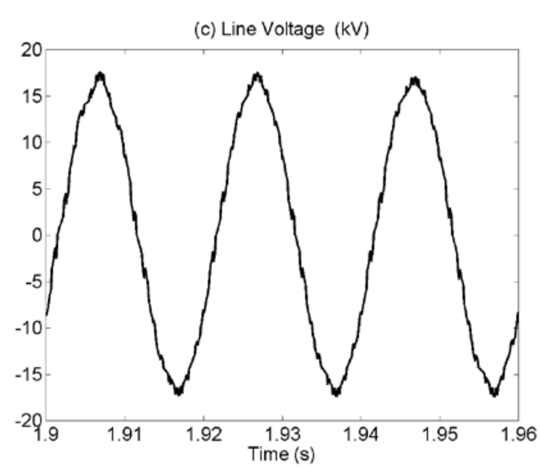


*Fig.10:* Line voltage before the transformer.



©2011 Global Journals Inc. (US)

Global Journal of Research Engineering Volume XI Issue II Version I March 2011



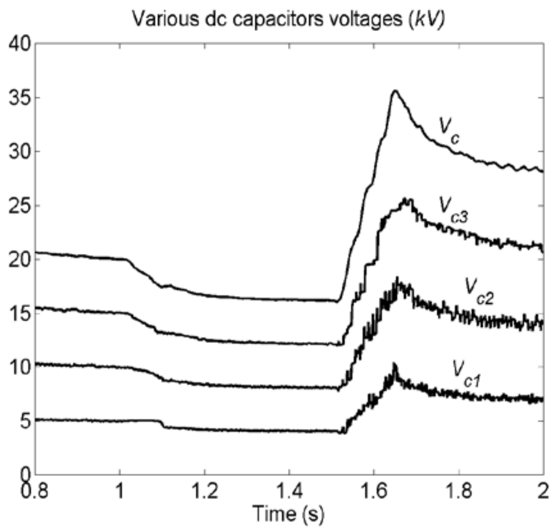


*Fig. 11:* Various capacitor voltages.

*2) Direct control*

In this case, the control strategy of the STATCOM is different than indirect control. The system parameters are assumed to be same as in the case of indirect control. The modulation index ($m_a$) is varied for controlling the output of the VSI while keeping the dc capacitor voltage constant. The error between midpoint terminal voltage and its reference value is passed through a PI controller. The output of the PI controller gives the $m_a$ for the switching of the VSI that decides the output voltage of the VSI.

*Table 5:* System parameters of the Transmission lin with STATCOM

| Parameters | Values before 1.0 sec. | Values after 1.0 sec. and before 1.5 sec | Values after 1.5 sec. |
|---|---|---|---|
| $P_s$ (MVA) | 222.37 | 1.06 | 438.31 |
| $P_r$ (MVA) | 221.37 | –1.06 | 405.27 |
| $Q_s$ (MVA) | –10.04 | –19.94 | 79.11 |
| $Q_r$ (MVA) | 14.01 | –19.94 | 112.28 |
| $P_{inv}$ (MVA) | 0.72 | -2.35 | 13.31 |
| $Q_{inv}$ (MVA) | 34.33 | -37.05 | 181.04 |
| $V_m$ (pu) | 1.011 | 1.003 | 1.002 |

It influences the midpoint terminal voltage. The dc capacitor voltage is compared to its reference value and the error is passed through a PI controller. The output of the PI controller gives the necessary phase shift for the VSI, which controls the real power flow between the STATCOM and the transmission line. The output of the phase shift PI controller is subtracted from the synchronizing signal. A small amount of real power is required for the losses in the STATCOM and coupling transformer. The PSCAD/EMTDC simulation diagram of a STATCOM connected to transmission line at the midpoint is shown in Fig. 12. The proportional gain and integral time constant of the PI controller (for $m_a$) are chosen as 4.0 and 0.002 second respectively while that for the phase shift controller are 8.0 and 0.005 second respectively.

Figures 13 to18 show the simulation results of the direct control of STATCOM. Figs. 4.13 (a and b) show the midpoint terminal voltage and dc capacitor voltage respectively. The midpoint terminal voltage and the dc capacitor voltage are nearly constant under all transients. However, a small fluctuation occurs in the midpoint terminal voltage under heavy transients but it is much smaller as compared to the case of indirect control.

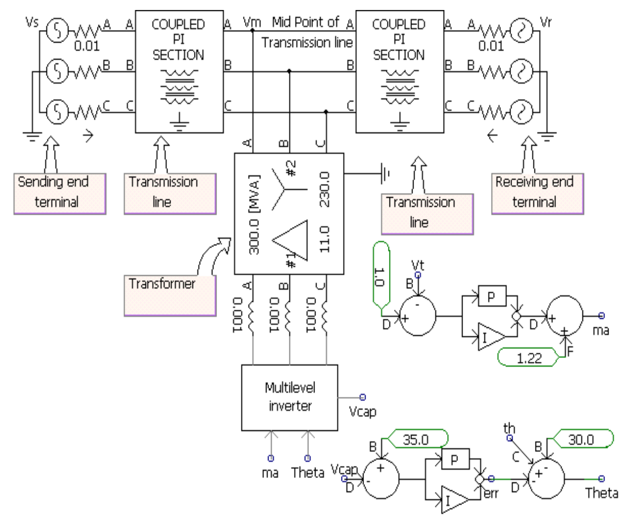


*Fig. 12:* Circuit diagram of Direct control STATCOM.

Fig.14 (a) shows the real powers at the sending end ($P_s$) and the receiving end ($P_r$). Fig. 14 (b) shows the respective reactive powers and Fig. 14 (c) shows the real power ($P_{inv}$) and reactive power ($Q_{inv}$) flowing from the VSI to the line. It can be seen that the reactive power demand of the line increases with real power transfer and a large amount of reactive power is supplied by the STATCOM to maintain the midpoint terminal voltage. The negative value of $P_{inv}$ under steady state shows that there is a small amount of real power flow from the line to the STATCOM. $Q_{inv}$ has positive value for the inductive compensation and negative value for the capacitive compensation.

©2011 Global Journals Inc. (US)

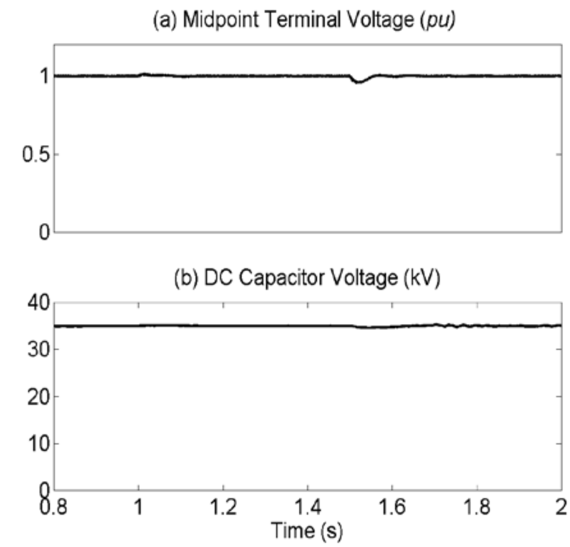


*Fig. 13:* Midpoint voltage and dc capacitor voltage.

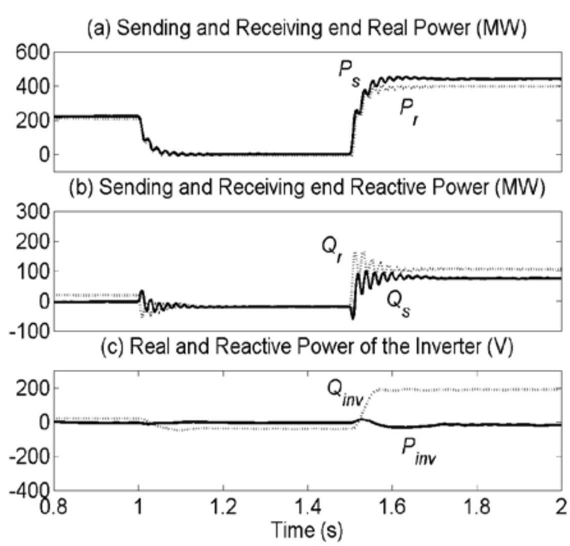


*Fig. 14:* Real and Reactive Powers at various end.

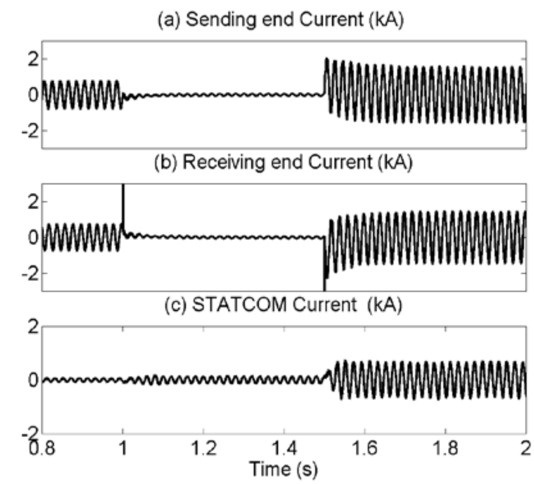


*Fig. 15:* Phase *a* line current at various terminals.

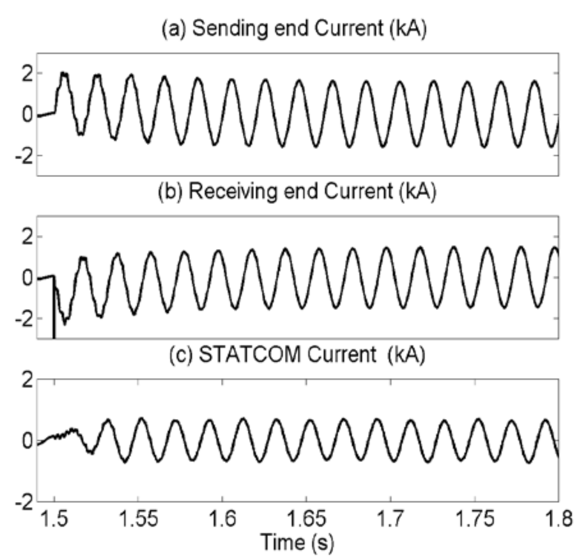


*Fig. 16:* Magnified portion of phase *a* line current from 1.49 s to 1.8 s.

Figs. 15 shows the sending end, the receiving end and the STATCOM currents respectively. It can be seen that there are large transients in all the three curents at the time of receiving end phase angle ($\delta$) change. Fig. 16 shows that these transients die out with time. The magnitude of the STATCOM currents show the amount of reactive power exchange between the line and the STATCOM. The STATCOM currents are sinusoidal except at the time of transient as of sending end and receiving end currents.

Fig. 17 shows the main capacitor voltage and various clamping capacitor voltages. It can be seen that all the capacitor voltages are nearly constant at their reference value.

Table 6 lists the steady state system quantities for different phase angle of the receiving end. Note that, there are large variations in the reactive power supplied by the STATCOM for various system conditions without high transient as in the case of indirect control.



©2011 Global Journals Inc. (US)

*Table 6:* System parameters of the Transmission line with STATCOM.

| Parameters | Values before 1.0 sec. | Values after 1.0 sec. and before 1.5 sec | Values after 1.5 sec. |
|---|---|---|---|
| $P_s$ (MVA) | 223.9 | 2.54 | 442.37 |
| $P_r$ (MVA) | 211.15 | – 2.53 | 398.27 |
| $Q_s$ (MVA) | – 2.68 | – 18.09 | 76.0 |
| $Q_r$ (MVA) | 19.78 | – 18.09 | 106.93 |
| $P_{inv}$ (MVA) | – 6.02 | – 4.8 | – 20.15 |
| $Q_{inv}$ (MVA) | 19.79 | – 39.94 | 190.56 |
| $V_m$ (pu) | 1.002 | 1.00 | 1.00 |

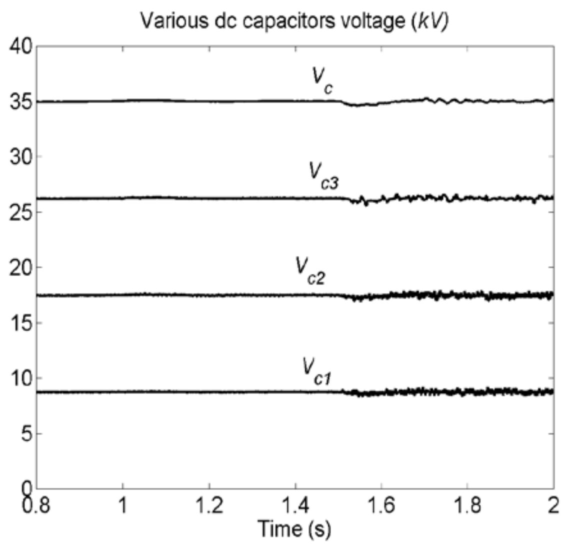


*Fig..17 :* Various capacitor voltages.

Fig. 18 shows the line voltage at the inverter side. It can be seen that line voltage is nearly sinusoidal. Third harmonic and its multiple harmonics are reduced by delte-star transformer connection. If the switching frequency of the inverter is increased, the amplitude of harmonics in the output line voltage can be further reduced. As said earlier the harmonic amplitude can also be reduced by increasing the value of smothing reactor.

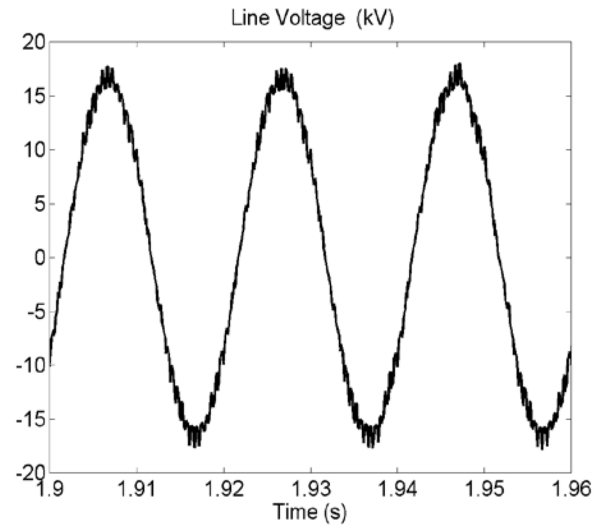


*Fig.18:* Line Voltage before the transformer.

## IV. Conclusion

The simulation results of a STATCOM are discussed. It has been observed that the real power transfer is increased with the shunt compensation while the reactive power supplied by the sending end and the receiving end is decreased. The midpoint terminal voltage remains near to its specified value under low as well as high transients. The response of the direct control is faster than indirect control. It can therefore be concluded that the direct control of the STATCOM is much more superior to indirect control.

## References Références Referencias

1) N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and technology of Flexible AC Transmission Systems," *IEEE Press*, New York, 2000.
2) A.Edris, "FACTS Technology Development: An Update", *IEEE Power Engineering Review*, 2000.
3) N. G. Hingorani, "High Power Electronics and flexible AC Transmission System", *IEEE Power Engineering Review*, 1988.
4) L.Gyugyi, "Dynamic compensation of AC transmission lines by solid-state synchronous voltage sources," *IEEE/PES Summer Meeting*, paper No. 93SM431-1 PWRD, 1993.
5) N.H Yukseler, "The line-length effects on voltage stability of series compensated power transmission lines", *AFRICON '92 Proceedings., 3rd AFRICON Conference*, 22-24 Sep 1992 pp. 479 –482



©2011 Global Journals Inc. (US)

6) D.N.Kosterev, W.A Mittelstadt, R.R. Mohler, and W.J Kolodziej, "An application study for sizing and rating controlled and conventional series compensation" *IEEE Technical Applications Conference and Workshops Northcon95*, Northcon 95, pp. 280 –286, 1995.
7) Y.Besanger, S. Maginier, N. Hadjsaid, and R. Feuillet, "Thyristor controlled series compensation: some aspects of different circuit parameters and voltage stability margin" *International Conference on Energy Management and Power Delivery*, Volume: 2 , 21-23, pp. 753 –758, 1995
8) L.Gyugyi, C.D.Schauder and K.K Sen, "Static synchronous series compensator: a solid-state approach to the series compensation of transmission lines", *IEEE Transactions on Power Delivery*, Vol. 12, pp. 406 –417, No. 1, 1997
9) B.Han, S. Moon, J. Park and G. Karady, G "Dynamic characteristic analysis of SSSC based on multibridge inverter", *IEEE Transactions on Power Delivery*, Vol. 17 Issue 2, pp. 623 –629, 2002
10) H.F Wang, "Modelling STATCOM into power systems", .*International Conference on Electric Power Engineering, PowerTech Budapest 99*, pp 302, 1999
11) M.R. Iravani and D Maratukulam, "Review of semiconductor-controlled (static) phase shifters for power systems applications" *IEEE Transactions on Power Systems*, Vol. 9 No. 4, pp. 1833 –1839, 1994.
12) S. L. Kumar and A. Ghosh, " Modelling and control design of a static synchronous series compensator ", *IEEE Transactions on Power delivery*, Vol. 14, No. 4, , pp. 1448-1453, 1999
13) A.Ghosh and G. Ledwich, "Power Quality Enhancement Using Custom Power Devices", *Kluwer's Power Electronics and Power System Series*, 2002.
14) M.H. Rashid, "Power Electronics Handbook", Academic Press, 2001.
15) A.Nabae, I. Takahashi and H. Akagi, "A New Neutral-Point-Clamped PWM Inverter", *IEEE Transactions on Industry Applications*, Vol. IA-17, No. 5, pp. 518-523, 1981.
16) N. S. Choi, J. G. Cho and G. H. Cho, "A general circuit topology of multilevel inverter", Power Electronics specialist conference, *PESC 1991 Record, 22nd annual IEEE*, pp. 96-103, 1991.
17) J. S. Lai and F. Z. Peng, "Multilevel Converters-A new breed of Power converters", *IEEE Transactions of Industry Applications,* Vol. 32, No. 3, pp. 509-517, 1996.
18) X. Yuan and I. Barbi, "Fundamentals of a New Diode Clamping Multilevel Inverter", *IEEE Transactions on Power Electronics*, Vol. 15, No.-4, 2000.
19) C. Ying and M.L Crow, "A diode-clamped multi-level inverter for the StatCom/BESS", *IEEE Power Engineering Society Winter Meeting,* pp. 470 -475 Vol.1, 2002
20) B. R. Lin, Y. P. Chien and H. H. Lu, "Multilevel Inverter with Series Connection of H-bridge Cells", *IEEE International Conference on Power Electronics and Drive Systems*, pp. 859-864, 1999.
21) F. Z. Peng, "A Generalized Multilevel Inverter Topology with Self Voltage Balancing", *IEEE Transactions on Industry Applications*, Vol. 37, No. 2, pp. 611-618, 2007.




©2011 Global Journals Inc. (US)

This page is intentionally left blank

©2011 Global Journals Inc. (US)