MODELLING AND TRANSIENT ANALYSIS OF HVDC BIPOLAR LINK

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ABSTRACT

The purpose of this study is modeling and transient analysis of proposed 500MW/±400V bipolar HVDC interconnection in between India and Sri Lanka. For this analysis EMTDC/PSCAD simulation software was used and the Cigre Benchmark model for mono polar HVDC system (1000MW /500kV) was referred. The dynamic behaviour of the dc link and the AC systems under start up, shut down, load rejections and fault conditions are analyzed in the paper.

This paper proposes HVDC as an attractive alternative for the power transmission in between two countries, which leads to fully integrated international grid. Because the conceptual scheme of the control strategy represented here have the advantages in terms of reliability and controllability.

1. PROJECT BACKGROUND

In Sri Lanka, electrical power consumption growth rate is around 10%, but power generation growth rate is below 7%. Hence the expansion of Sri Lanka power generation system is an urgent need. As an alternative, pre feasibility studies have been carried out to establish a power transmission interconnection between Sri Lanka and India through a 500 MW HVDC link. This would lead to facilitate the bilateral power transmission between two countries.

Figure 1:*Indu-Sri Lanka transmission interconnection*

Out of several alternatives identified in the pre feasibility analysis, Madurai-Anuradhapura bipolar HVDC interconnection is selected for our analysis due to its highest reliability, controllability, moderate investment cost and highest analytical capability.

A bipolar configuration offers the highest reliability as such a configuration can actually serve as a double-circuit system (2x250 MW), since each pole can operate as an independent unit when the other pole is unavailable. Each circuit in that case would carry half of the total power.

2. SYSTEM DESIGN

2.1 System Configuration

The maximum power transmission capability of the Madurai – Anuradhapura HVDC network is limited to 500MW and the HVDC converters are designed as a bipolar system with a ground electrode. The rated DC voltage is ±400kV, hence the rated DC current is 625A. Modeling and transient analysis of the network is involved with;

AC systems

- AC network in the inverter and rectifier side (Sri Lanka and India AC systems) are represented as a Thevinin's equivalent circuit with equivalent source voltage and its short circuit impedance.
- Harmonic elimination filters to eliminate 11th, 13th and higher order harmonics.
- Fixed capacitor banks to supply required reactive power.

HVDC converters

- A bipolar rectifier station with associated ancillary equipment adjacent to the Madurai 400 kV substation.
- A bipolar inverter station with associated equipment adjacent to the Anuradapura 220 kV substation.

HVDC link

- An overhead HVDC transmission line from Madurai to Dhanushkodi (200 km)
- An under-sea HVDC (submarine cable) transmission line from Dhanushkodi to Talaimanar (30 km)
- An overhead HVDC transmission line from Talaimanar to Anuradhapura (150 km)

2.2 AC System Representation

The stability of the ac systems with HVDC link is governed by the Short Circuit Ratio (SCR).

For a strong system, SCR values should be more than 2. In the case of low SCR systems, the changes in the AC network or HVDC system could lead to voltage oscillations. The AC system at Madurai is relatively strong with SCR value of 2.5 and 84 deg. of damping angle (based on the equivalent impedance of 11.156+j127.517Ω), but Anuradapura AC system is relatively weak with SCR value of 1.634 and 87.85 deg. of damping angle (based on impedance of 2.22+j59.02Ω). Hence it would need special control strategies such as Voltage Dependent Current Limiter (VDCL) to reduce voltage oscillations under transient conditions.

2.3 Converter Transformers and Valve Groups

HVDC power converters with thyristor valves are assembled in a converter bridge of twelve-pulse configuration. Each valve group operates from its own internal phase locked oscillator. Two three-phase converter transformers with one valve group side winding as an ungrounded star connection and the other as a delta connection are used for each pole. AC side of each transformer is star connected with solid ground.

A series R-L-C branches are used as single tuned filters to eliminate 11th and 13th harmonics. For attenuating a range of higher frequencies (23rd and beyond) high-pass damped filters are used.

Total reactive power requirement (300MVA$_r$) for both rectifier and inverter is supplied by fixed capacitors and harmonic filters. 70% of total reactive power is supplied by the harmonic filters and rest is given by fixed capacitor banks. 11th, 13th and high pass filters supply 25%, 25% and 20% of reactive power to the system respectively.

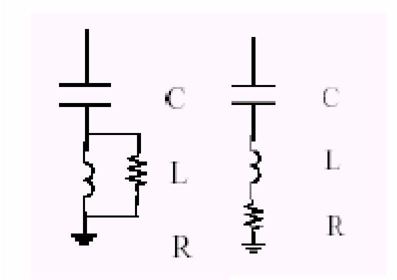

Figure 2: High pass & single tuned filters

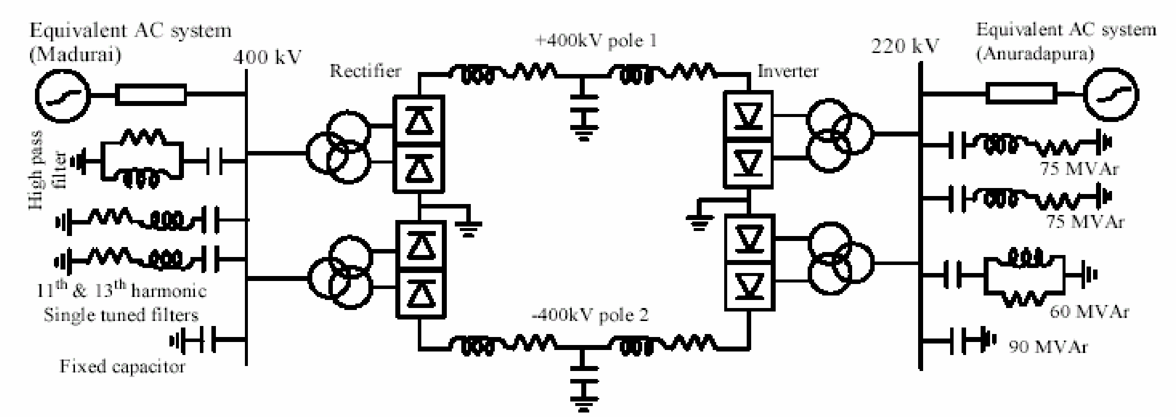

Figure 3: Model Bipolar HVDC system

Parameters of the valve groups and the converter transformers are selected to give DC voltages of +400kV for pole 1 and –400kV for pole 2 and current flow of 625A. Reference point of each twelve-pulse valve groups are connected together and solidly grounded.

2.4 DC Links

The DC system used for the model is a simple T-section. The inductance and capacitance values selected result in an impedance maximum near fundamental frequency of 50 Hz and gives lower voltage ripple in the DC link.

2.5 Filters and Capacitor Banks

In HVDC System, shunt filters are used on the DC and AC sides to reduce the harmonics generated by the converter from propagating into the AC or DC systems. On the AC side, filters provide a low impedance side to ground; and in addition, they are also a source of reactive power.

By the proper design of the harmonic filters, total harmonic distortion (THD) could be reduced to 1% at both rectifier and inverter AC systems.

3. RECTIFIER AND INVERTER CONTROLS

HVDC transmission systems must transport very large amount of power and hence there should be a tight controlling system.

D.C. current and voltage is precisely controlled to affect the desired power transfer. It is necessary therefore to continuously and precisely measure system quantities, which include at each converter bridge- the DC current, DC voltage, delay angle α and for an inverter, its extinction angle γ.

Under steady state conditions, the inverter is assigned the task of controlling the DC voltage.

Thus it may do by maintaining a constant extinction angle γ which causes the DC voltage to droop with increasing DC current in the minimum constant extinction angle γ characteristics. This means that the extinction angle γ must increase beyond its minimum setting 18^{O}.

If the inverter is operating in a minimum constant γ or constant voltage characteristics, then the rectifier must control the DC current. It can do so long as the delay angle á is not at its minimum limit (usually 5^{O}).

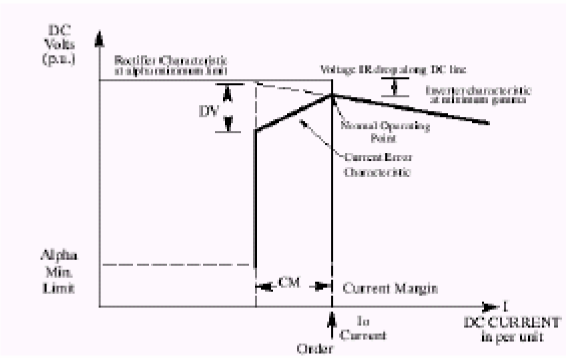

Figure 4: *Converter control characteristics*

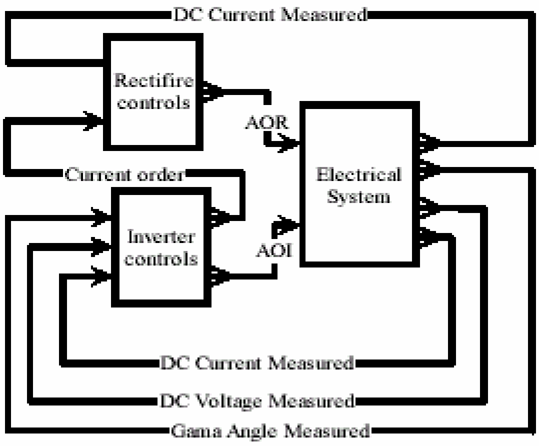

Figure 5: *HVDC control system*

The control models for both the rectifier and inverter are based essentially on proportional and integral function blocks. While the rectifier controls consist only of a current control loop, the inverter controls contain both current control and gamma control loop. Voltage dependent current limits are included in the controls other wise during disturbances, the AC voltage at the rectifier or inverter is depressed and it will not be helpful to a weak AC system.

The voltage dependent current limit (VDCL) is implemented by monitoring the inverter side DC voltage, and compounding it using the measured current to that at the mid–point of the cable. The computed mid–point voltage is then used as input to a non–linear gain in order to modify the basic control characteristics.

4. SIMULATION

4.1 PSCAD/EMTDC Software

PSCAD/EMTDC simulation software is used to simulate the bipolar HVDC system.

EMTDC is most suitable for simulating the time domain instantaneous responses, also popular for analyzing electromagnetic transients of electrical systems.

PSCAD allows to assemble the circuit, run the simulation, analyze the results, and manage the data in a completely integrated graphical environment. Together, PSCAD/EMTDC is a very efficient tool for electromagnetic transient simulation of power systems.

4.2 Transient Analysis

Modeled 500MW bipolar HVDC system is used to determine transient behaviours of the DC link as well as AC systems. These transients include behaviours under start up & shut down of HVDC system, AC and DC system faults, load rejections and small change in power flow.

Start up of HVDC link

At fundamental frequency, a damping angle of 90_{o} indicates an undamped system. When it is in between 70^{o} to 75^{o}, the system can be considered as well damped system. Since damping angle for Madurai and Anuradapura are $^{84}{}_{o}$ and 87.85^{o} respectively, AC systems are relatively undamped. Hence AC systems take about 10 cycles to reach steady state.

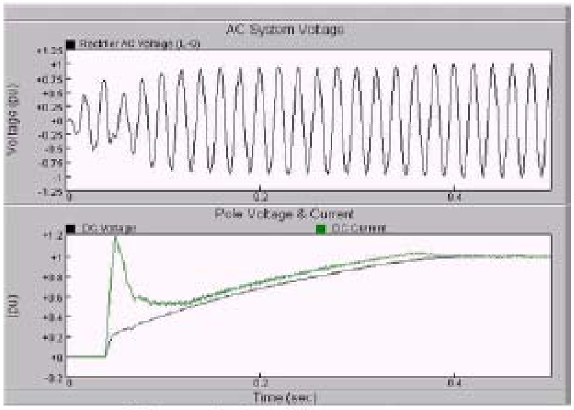

Figure 6: *Start up transients*

AC system faults

The fault cases include AC system faults with single-phase, phase-to-phase as well as three-phase faults. Fault duration could be changed and used as 0.05S in the simulation and the time instant that the fault is applied could also be altered. Some of these faults are quite severe faults with respect of initiation of oscillations and may in some cases cause transient instability. This could be overcome by proper design of control system.

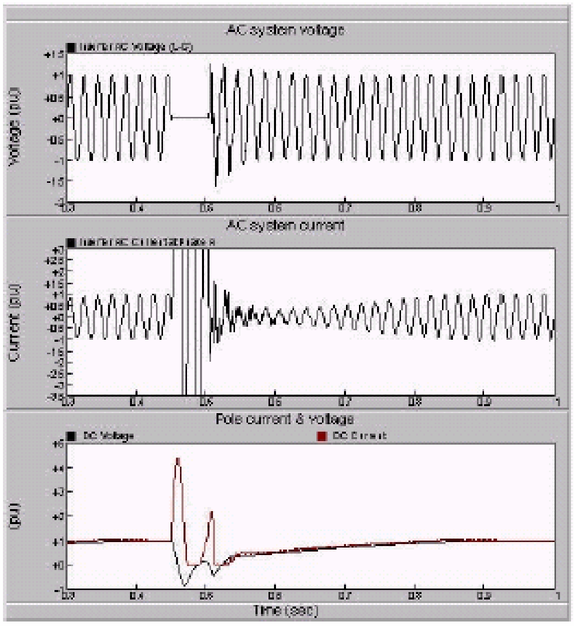

Figure 7: *3-Phase line to ground fault transients*

After an initial overcurrent the DC current is brought to zero by the converter controls. When the fault is extinguished, both the systems recover to their normal values.

Load rejection

Load rejection of the system is simulated by changing the current order of the inverter control. Current order of the DC link is decreased from rated value to 75% of rated value.

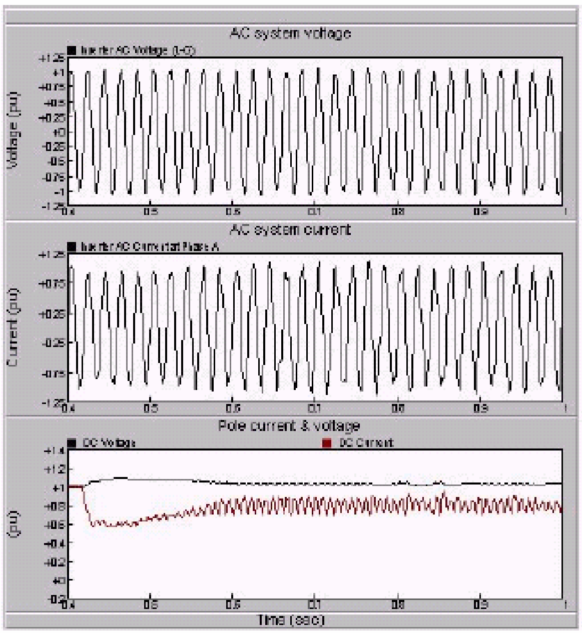

Figure 8: *Load rejection transients*

Due to the decrease of the reactive power consumption of the converters, the AC bus voltage rises and hence DC voltage also rises. This can be minimized by using Static Var Compensators (SVC) rather than using fixed capacitors. Since the system is not a well damped, it takes some time to stabilize.

5. CONCLUSION

In this paper, we described the modeling of 500MW, ±400 kV bipolar HVDC link between Madurai and Anuradapura using EMTDC/PSCAD simulation software. This model can be used to simulate any bipolar HVDC system by changing necessary parameters. According to SCR values at two ends, although both AC systems are not too strong, a relative stable HVDC interconnection could be modeled using proper control system. Precise AC system data is necessary to represent well-defined frequency dependent AC systems. But such study is still not done for both systems, as we could not found those data. Investigation of the transient performance under start up shut down and the fault conditions for inverter system shows that the recovery time is higher. This is because of the poor damping. It may be possible to implement much stable HVDC system using Capacitor Commutation (CC) control rather than the conventional (line commutation) HVDC control scheme used in this modeling.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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