PRESENTED AT MINNESOTA POWER SYSTEMS CONFERENCE, NOV 1999, USA

ASYNCHRONOUS BACK-TO-BACK HVDC LINK WITH VOLTAGE SOURCE CONVERTERS

Michael Bahrman
ABB Power Systems
1021Main Campus Dr.
Raleigh, NC 27606
919-856-2383
919-856-2412 Fax
mike.p.bahrman@us.abb.com

Abdel-Aty Edris
EPRI
3412 Hillview Ave.
Palo Alto, CA 94304
650-855-2311
650 855 8997 Fax
aedris@epri.com

Rich Haley
Central and South West
Two West Second St.
Tulsa, OK 74121
918-594-4108
918 594 4402 Fax
rhaley@csw.com

Summary

Interconnection of asynchronous networks via back-to-back HVDC links with voltage source converters (VSC) rather than conventional line-commutated or phase-commutated converters (PCC) offers several system advantages. Advanced VSC technology with pulse-width modulation (PWM) permits rapid, independent control of active and reactive power in all four quadrants. Control of both active and reactive power is bi-directional and continuous across the entire operating range. Reactive power control capability allows each VSC converter to act as a Static Synchronous Compensator (STATCOM) to regulate the ac voltage at either terminal independently. Converters can be located at points in the network with relatively low short circuit levels minimizing the need for network reinforcements or remedial measures. In fact, the converters can even serve passive load should it become isolated. In such a case, the converters would control the voltage and frequency until the network was restored. This paper describes a VSC-based, back-to-back HVDC link with special dynamic voltage regulation features which is currently under development as a project cosponsored by Central and South West Services, EPRI and ABB Power Systems.

Introduction

Central and South West Corporation (CSW) and Comision Federal de Electricidad (CFE) are installing an asynchronous electrical tie using a High-Voltage Direct-Current (HVDC) Tie based on voltage source converter technology. The electric Tie will link the transmission system of CSW’s Central Power and Light Company (CPL) subsidiary with the Mexican transmission system owned and operated by CFE.

The Tie is a 36-megawatt HVDC back-to-back voltage source converter (BTBVSC) and will be installed at CPL’s Eagle Pass substation. The Tie will allow energy exchange to occur across the existing 138 kV tie-line between Piedras Negras and Eagle Pass. The existing 138 kV line is currently used only in emergency situations and requires a short interruption of power supply to move customer load from CFE to CPL or vice versa. The new technology will provide strong dynamic voltage support independently to Piedras Negras, Mexico, and Eagle Pass, Texas, while providing for reliable power delivery between the two electric grids without sectionalizing and its associated power disruption.

CPL will operate the tie at Eagle Pass and the tie will be available for use by other utilities though the Electric Reliability Council of Texas (ERCOT) Independent System Operator. Power exchanged over the Tie will be provided on a non-firm basis and subject to interruption for reliability needs in the area.

Converter Technology

Conventional HVDC converter technology is based on the use of line-commutated or phase-commutated converters (PCC). Although converter designs have progressed to solid state components with higher power ratings, the basic principle of PCC has remained the same. Modern industrial motor drive technology has mostly migrated from PCC based systems to voltage source converter (VSC) based systems. VSC technology requires use of gate turn-off switching devices. Gate turn-off devices with higher switching frequency capability, such as the IGBT, permit more sophisticated VSC control and simpler circuit configuration by taking advantage of pulse width modulation (PWM) technique. A VSC can be controlled to synthesize an ac sinusoidal voltage by switching between different fixed dc voltage levels. By changing the PWM pattern, the phase angle, frequency and magnitude of the ac voltage can be controlled. The maximum pole-to-ground dc voltage is based on the maximum virtual converter phase-to-ground voltage, U_{Cvirt} , the PWM method, and the modulation index, M, according to the following formula:

$$U_{dmax} = U_{Cvirt} / ((2 \cdot \sqrt{}\, 2)/ \pi)\cdot(\pi / 4)\cdot M)$$

The term $\pi / 4$ corresponds to sinusoidal PWM and the term M is the modulation index. A modulation index of 0.9 gives a 10 % control margin.

Figure 1 illustrates the development of a single-phase sinusoidal voltage using PWM for a two-level VSC. A two-level VSC switches between two dc voltage levels. For a three-phase system the two-level VSC topology resembles that of a three-phase, two-way bridge circuit.

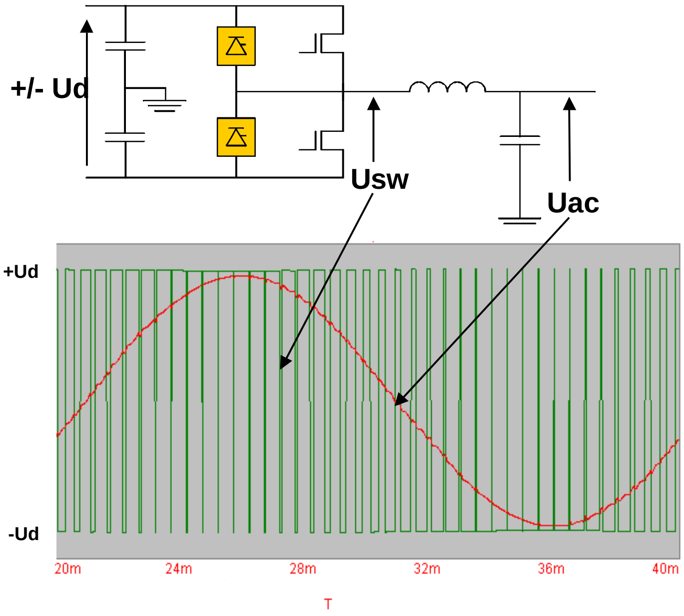

Figure 1. Single Phase of Two-Level VSC with PWM and Fundamental Frequency Voltages

Loss pass filtering separates the fundamental frequency from the raw PWM waveform. Shunt filtering for the switching frequency is rated relatively small compared to the converter rating. The series reactors consist of simple air core devices. No special converter transformers or phase shifting transformers are needed. Voltage matching can be accomplished with regular transformers. Transformer load tap changers and ac filter switching are not required to regulate ac voltage, maintain nominal firing angles or help match reactive power demand as with conventional HVDC converters.

Since the PWM pattern can be changed almost instantly, rapid control of both active and reactive power can be achieved independently of each other. Changing the fundamental frequency voltage phase angle across the series reactor controls the power; whereas, changing the fundamental frequency voltage magnitude across the series reactor controls the reactive power. If two VSC converters are connected together as shown in Figure 2, an asynchronous transmission link is formed. The converters can be connected in back-to-back configuration or at either end of a transmission line or cable. Each converter can be controlled in all four quadrants while maintaining constant dc voltage. Reactive power at either terminal can be controlled to regulate ac voltage independently of the power transmission level up to the MVA or voltage rating of the converters. Figure 3 shows a typical P-Q diagram and a representative phasor diagram for a VSC based transmission system using PWM.

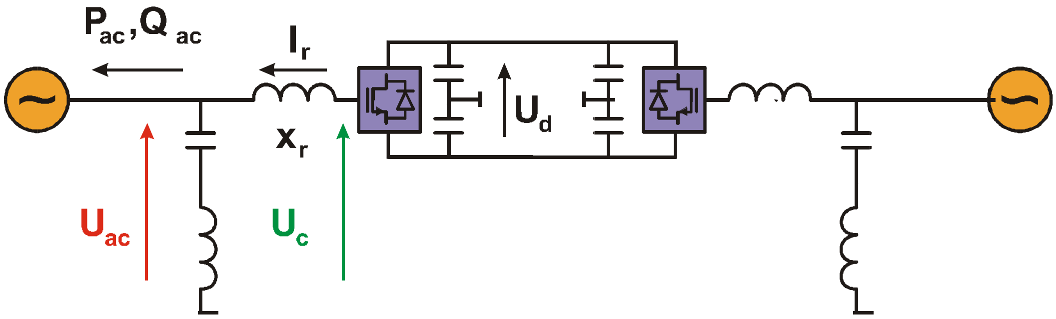

Figure 2. Single Line Diagram for VSC HVDC Link.

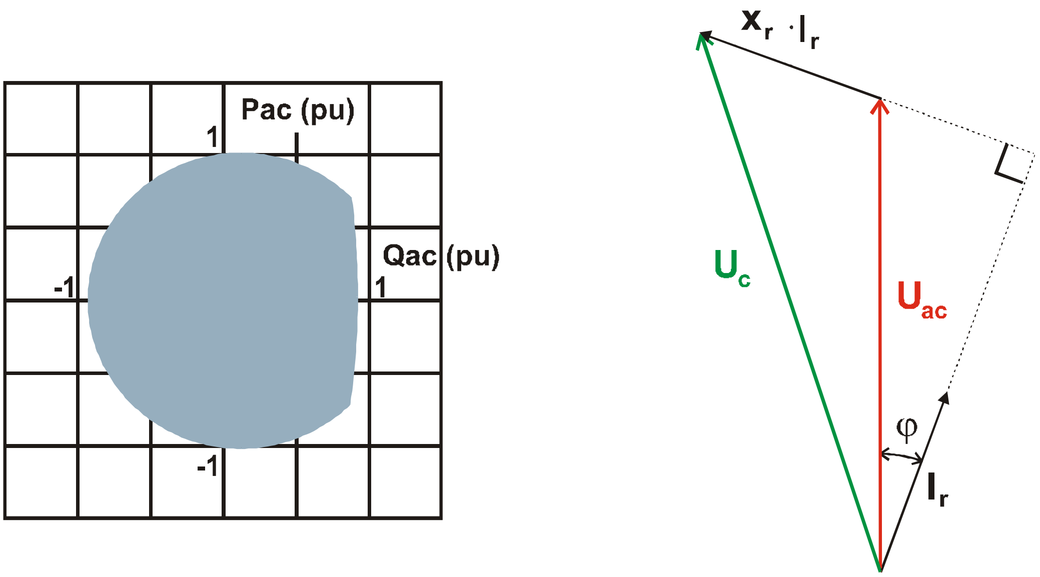

Figure 3. P-Q Diagram and Phasor Diagram for VSC HVDC Link.

The converter valves consist of assemblies of IGBT and diode stacks. Each valve is comprised of series connected IGBT semiconductors with one being redundant to allow operation even with one IGBT level failed/shorted. Even voltage distribution is achieved during all phases of operation with a special gate unit and a voltage divider for each IGBT level. The gate drive unit is mounted in the stack along with its associated IGBT. A heat sink is located between each IGBT level. The heat sinks are connected in parallel to a water cooling system inlet and outlet header. The cooling media is a water/glycol mixture with low conductivity.

The IGBTs used in Eagle Pass have a voltage rating of 2.5 kV. Valves are arranged in a three-level circuit topology. The maximum ambient temperature and the cooling system capacity result in a design having a continuous rms current of 1.0 kA at nominal rating. Figure 4 illustrates a VSC with IGBT valves for use in a back-to-back HVDC Link or in a STATCOM. For transmission voltages more IGBT levels with higher voltage ratings would be connected in series. For higher power ratings, higher voltage or current ratings can be used or converters can be connected in parallel.

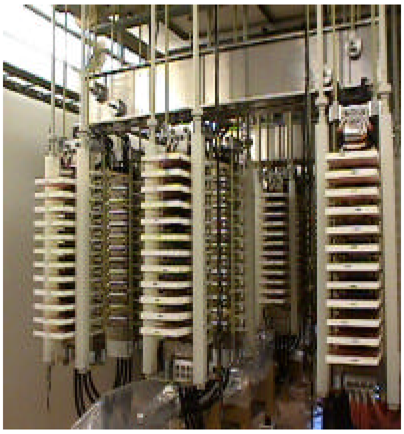

Figure 4. VSC with IGBT Valves

System Application

Although the 36 MW back-to-back asynchronous tie at Eagle Pass, Texas permits continuous power transfers between Texas and Mexico, its primary objective is to provide dynamic voltage support to the two networks following contingencies. The TIE will connect Central Power and Light's (CPL) Eagle Pass 138 kV substation at the US side to Comisión Federal de Electricidad's (CFE) Piedras Negras 138 kV substation on the Mexico side. The Tie will provide a reliable power link with the capability to operate at a short circuit ratio as low as unity while also providing strong dynamic voltage support at its terminals. Central and South West Services, (CSWS) is acting as agent for CPL on this project. CSWS and CPL are subsidiaries of the Central and South West Corporation. The Tie is scheduled to be in service June 15, 2000.

Eagle Pass is located in the western part of the CPL system in the Electric Reliability Council of Texas (ERCOT) and is served by two 138 kV transmission lines. The first line, Asherton to Eagle Pass is a 4 /0 ACSR, 61.16 mile long line tying Eagle Pass to the South and the second line, Hamilton Road to Eagle Pass is a 336 ACSR, 54.83 mile long line tying Eagle Pass to the North. Eagle Pass has an approximate load of 52 MW at peak load conditions. Loss of the Hamilton Road to Eagle Pass line produces low voltages in the Eagle Pass area today while load growth in the area continues requiring a new source into Eagle Pass.

Piedras Negras substation is located in CFE's División Gulfo Norte directly across from Eagle Pass substation. A 1.5-mile, 138 kV 477, AAC transmission line crosses the Mexico/US border and connects the two substations. There are two 138 kV transmission lines that connect back into the 400 kV grid at Rio Escondido. The CFE system at this location is relatively strong compared to CPL's system.

Currently, load is transferred over from one system to the other if network conditions are such that the load can not be supported from its own grid. Customers have a momentary outage as load is dropped from the CFE system and picked up by the CPL system or vice versa. The ERCOT and CFE electrical grids are never tied synchronously with each other. Figure 5 shows the ERCOT network in the vicinity of Eagle Pass.

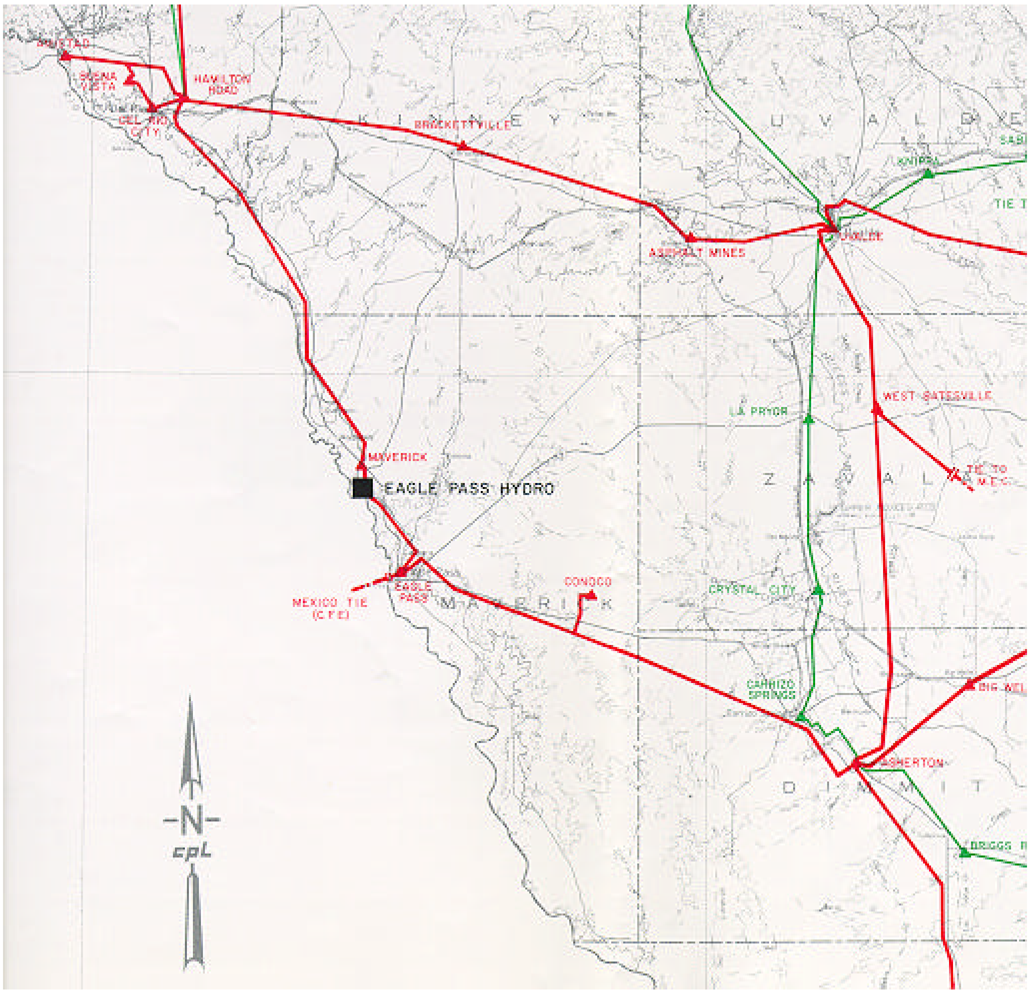

Figure 5. ERCOT Network near Eagle Pass

In steady state operation the asynchronous tie will transfer the scheduled power while regulating the ac voltages at both terminals utilizing up to the full MVA rating of the converters. Following contingencies, however, such as loss of one of the two transmission lines feeding Eagle Pass, dynamic voltage control will have priority even if it curtails the scheduled power transfer. Dynamic voltage support will take full advantage of the dynamic overload capacity of the converters. Under some conditions dc power reversal will even take place if deemed more effective in supporting the load.

The Tie is required to provide black start capability for either CFE or CPL. The nearest CPL generation is located 120 miles to the south in Laredo. Black start of the CPL system would take place from the Tie over a 60 mile 138 kV line to Asherton substation and a 60 mile 138 kV line from Asherton to Laredo power plant. The Tie must be capable of serving part of the load at Eagle Pass or Piedras Negras substations in the event either substation is isolated from the rest of the systems. CSW will define margins of real and reactive power the Tie can support while maintaining 1 p.u. voltage. When it is time to connect the substation back to the grid, the loaded Tie must be able to close back into the system without dropping load. Black start will be accomplished by energizing the isolated system from the VSC converter by deblocking in voltage control mode regulating both the voltage and frequency.

<u>Station Design</u>

The Eagle Pass Tie is connected to the 138 kV networks of CPL and CFE through ordinary transformers. Converter ac phase voltages are 17.9 kV. High pass filters are provided to take care of the harmonics generated by the switching frequency. A bypass circuit is provided so that the two systems can still be block loaded during emergencies if the converter station is unavailable. The HVDC Light Tie configuration is shown in the simplified single line diagram in Figure 5. Use of the bypass switch and the line switch on the line to CFE permits paralleling the two VSC converters as STATCOMs thereby doubling the reactive power capability for dynamic voltage support.

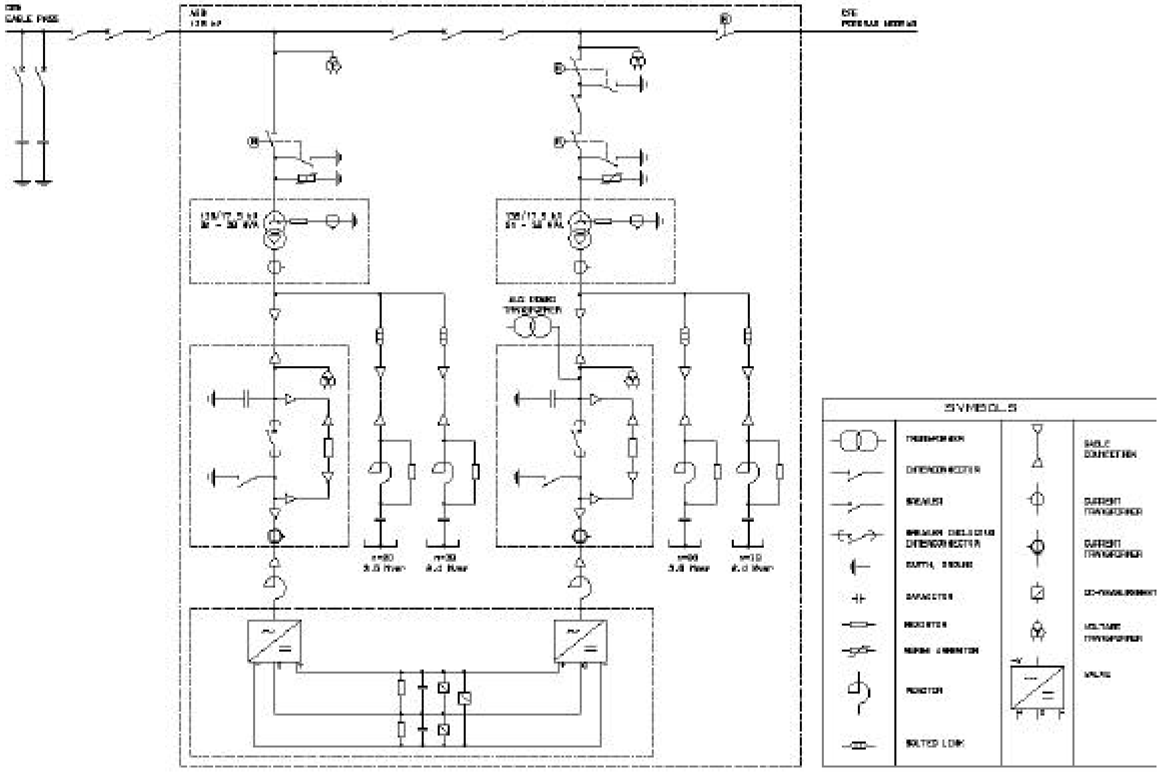

Figure 5. HVDC Asynchronous Tie Single Line Diagram

The VSC Tie is comprised of the following main components and subsystems:

- High voltage bus
- Three phase step down transformers
- Low voltage “buses” and switchgear
- Phase reactors
- IGBT converters
- DC capacitors
- Cooling system

- Control system
- Protection system
- Auxiliary AC power supply

An artist's rendition of the Eagle Pass Tie is shown in Figure 6.

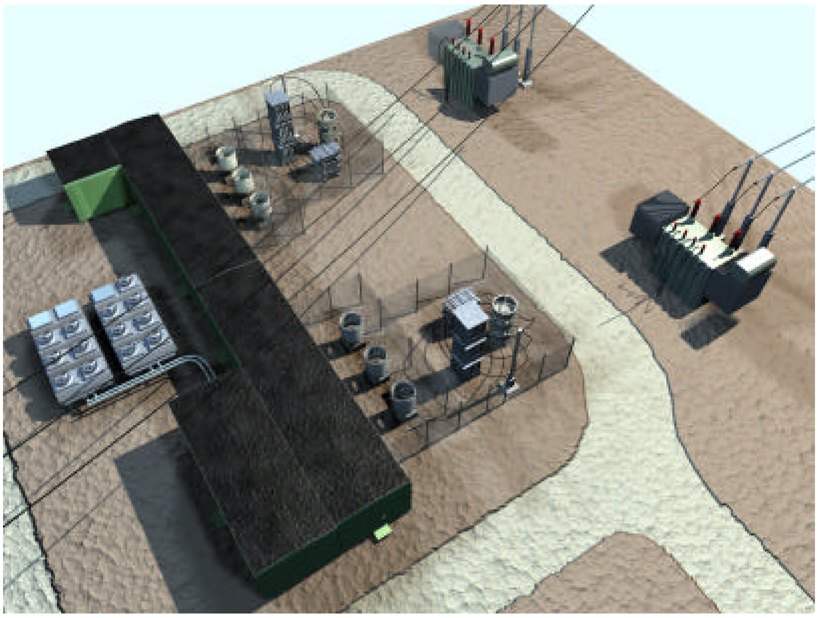

Figure 6. Artist's Rendition of Eagle Pass Tie.

Conclusion

A back-to-back asynchronous tie comprised of VSC converters employing PWM may well represent the ultimate FACTS device. Besides controlling the through power flow, it can supply reactive power and provide independent dynamic voltage control at its two terminals. The two converters can be paralleled to double the reactive power capability supplied to one side or the other. The back-to-back converters can be used for black start or to supply a passive load. Higher voltage designs can be used with transmission lines or cables to form point-to-point or multi-terminal transmission links. More sophisticated controls can be used to provide additional network benefits. With the Eagle Pass project, CSW has realized the system advantages of deploying a VSC based back-to-back asynchronous Tie with standby dynamic voltage control during network contingencies. The controlled power transfer capability allows the exchange of power between the two networks while the voltage control stabilizes the voltage following line outages especially during peak load periods.