VSC Converter Systems to Enhance Grid Stability and Ensure Reliable Power to Cities

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Summary

Large amounts of power, so called bulk power can be transmitted over long distance by HVAC transmission systems or High Voltage Direct Current (HVDC) transmission systems. Since the 1980´s and 1990´s, the HVDC technology became the predominant technology for transmission of bulk power. The change was ushered in by the rapid development of power electronics, which benefited the HVDC technology, by cheaper equipment for conversion of power from ac to dc and vice-versa, as well as enhancing reliability and availability. In the recent years further development of the converter technology has brought in revolutionary changes for enabling highly reliable transmission and distribution for a wide range of applications; with minimum permitting issues, to integration of renewables and other specialized grid enhancement applications covering also black start. The Voltage Source Converter (VSC) technology earlier employed for industrial applications has now attained range and capacity for EHV transmission, primarily due to the rapid enhancement of the semiconductor voltage and current ratings. The device most utilized here is the Insulated Gate Bipolar Junction Transistor (IGBT). In this paper the discussion will be focusing on the potential application of HVDC back-to-back schemes employing IGBT based VSC converters to improve stability and impart reliability to a large urban power network with multiple in feeds.

Keywords

HVDC Systems –VSC Converter – Stability – City infeed

1. Introduction

The creation of bulk power transmission, has taken place in stages. Initially 400 kV and 500 kV EHVAC transmission systems were developed to increase power transmission capacity, 400 kV mostly in Europe and 500 kV in North America. During the 1960's and 1970´s the need for transmitting very large quantity of power from large power stations to far away load centers triggered the development, of the 800 kV transmission system. At that time, increasing the transmission voltages appeared to be the only practical and economical means available to provide higher transmission capacity and necessary system reliability. However in recent years getting right-of-way (ROW) and permitting is increasingly becoming a major hurdle for planners. Also, the need to source more power from environment friendly energy alternatives such as the integration of wind and solar power has added to the challenges for transmission system planners.

Fortunately, the rapid strides made in the development of VSC technology with wide and varied control capabilities, has opened up several transmission options to overcome ROW constraints including infeed to congested urban areas using underground DC cables, and also to increase the reliability and availability of power. This paper attempts to discuss the potential for grid stability enhancement for a urban centre like Delhi and the adjoining National Capital Region (NCR).

2. City Infeed

Cities have different power transmission (or sub-transmission) configurations or topologies depending on their layouts and geographical spread. Some cities are elongated in nature, for example, Mumbai in India while some are spread more or less in a circular form, like Delhi/NCR. Some others are spread out in a particular direction with the densely populated areas in certain parts and generation located elsewhere.

Usually, most cities or large urban conglomerations are not fully self-sufficient in terms of power generation and have to import power from outer regions or far flung areas to complement the local generation. This calls for proper and seamless integration of an EHV transmission coming from outside the city boundaries into the local sub-transmission and distribution network.

Depending on the location of the load centers and available ROW, the city sub-transmission and distribution network will have to be covered by a combination of overhead lines, some of which could be very long depending on where the power is sourced from, and cables. The presence of cables further adds to the reactive power management issues due to the varying nature of the loads and load levels from daily as well as seasonal point of view.

Apart from AC cables causing voltage swings, which are often controlled by switching in and out reactive compensation equipment, the long lines which link load centers to generating centers far away can be the cause for voltage collapse situations unless reverse corrective actions like series capacitive compensation is also applied to counteract the fall in SIL due to shunt reactors.

3. Reliability and Security of Power Supply

The consequences of a grid failure can be enormous for modern cities as apart from affecting the power sources to commercial and residential establishments, emergency services like hospitals and transportation is also severely affected.

The biggest challenge is by far ensuring a secure and reliable power supply to a city network from the point of view of insulating it from external faults and grid disturbances in the peripheral or outer EHV networks.

One way (probably the only way) of effectively insulating a specific area (like a city) from grid disturbances, while still ensuring reliable and adequate power flow under normal conditions is to adopt an HVDC based fire wall – this will ensure the following:

- Allow asynchronous interconnection with the external grid meeting the primary objectives of isolation from grid disturbances while ensuring normal power flow
- Limit short circuit levels as loads (and generation) increase thus ensuring cost deferment (for switchgear replacement/ upgrades)

With advances in semiconductor technology and the advent of VSC based HVDC systems, a very effective solution for configuring a safe and reliable power network has come in vogue. VSC networks can be configured in point-to-point, back-to-back and radial or ring configurations to suit the geographical nature of a city or urban area. In addition to above advantages offered by HVDC in general VSC systems also offer the following benefits:

- Ensure black start or start up power and fast restoration in case of complete grid collapse
- Smoother reactive power management and voltage control (due to four-quadrant control/ inherent SVC mode)
- Amenable to easier multi-terminal expansion

4. The Delhi-NCR Power Network

For the following discussion we take the Delhi/NCR network as an example. The Delhi-NCR network presently consists essentially a larger outer 400 kV AC ring network and multiple inner 220 kV AC networks. The generation within the Delhi area consists of major thermal generation like Badarpur, Rajghat Thermal, Pragati Power station and Bawana Gas, totaling about 2500 MW, feeding the inner 220 kV system through a network of substations and 220kV/110 kV transmission lines. The control area operators/ load dispatch centers strive to match the generation and load within their own control area in order to prevent any unscheduled power flow between neighboring areas. This is a complex and onerous task, as there are only AC interconnections with the rest of the Northern Region network. In addition about 1500 MW of power is injected from external sources into the Delhi/NCR network to meet demand exceeding local generation. In addition, the bigger issue is the safe and secure isolation of the system in case of major grid disturbances elsewhere in the Northern Region or under fault conditions. All networks being synchronous proliferation or spread of disturbances is unavoidable.

Sometimes the disturbance in itself is initiated by unscheduled power flows/withdrawals with no control mechanism. This leads to overloading of lines and also can cause wide voltage variations in the affected parts creating one or more conditions for a grid collapse.

5. Securing Power Supply to Delhi/NCR System

5.1 Relay based Islanding/ Isolation

The usual method to isolate a zone or area within a larger power network, in case of destabilizing trends due to faults or load – generation imbalance is to go for an automatic islanding scheme of the zone/ area of interest. Such identified zone(s) or area(s) will need to have its' own generation, balanced to a net load within. This is accomplished by identifying the critical connection points/nodes at the boundaries and effect separation of the transmission lines/ transformers to outer areas through a relay based tripping scheme which could operate on low frequency and/or rate of change of frequency (df/dt) criteria.

Such schemes although simple in principle, are a major challenge to implement and to get them to function effectively in a major grid disturbance situation - with many interconnections and multiple power feeds. With many feeds entering a major metropolitan area, like Delhi/NCR, at multiple voltage levels, coordination of the relays in a sequential/ stepped manner could prove to be a very difficult exercise considering the unpredictability of power swings vis-à-vis pre-disturbance voltage, frequency and power flow levels.

To prevent cascading outages in connection with major system disturbances, all tie-lines between control areas must have regulated power flow. For example, all tie lines must be able to withstand the inrush currents that may occur in connection with any single contingency in the two interconnected networks (e.g., an unplanned trip of the largest generating unit in one of the control areas) without jeopardizing grid reliability criteria. Other conditions to be satisfied are:

- Voltage of each bus shall be kept within limits
- Synchronous operation of all generators shall be maintained
- The thermal capacity of any line or transformer shall not be exceeded

In order to satisfy these reliability criteria, an agreed amount of generating capacity must be held in reserve in all control/ separable zones/areas. Furthermore, since synchronous operation must be maintained in connection with any single contingency event, the capacity of AC tie-lines typically must be many times higher than the capacity needed for scheduled power transfers in steady state.

5.2 Islanding/ Separation with HVDC based Schemes

When an HVDC (back-to-back) scheme is used as a tie between two control areas or used as a separator, this procedure becomes much simpler as the flow of power can easily be maintained at the pre-set value or within a range/dead-band between intended zones/areas.

Since an HVDC link can control the power flow at all times and therefore needs to be rated only for scheduled power transactions and agreed emergency support, a back-to-back HVDC station is normally a more economical alternative, for interconnection of two relatively large ac networks or for isolating a particular priority network zone/area. An HVAC tie-line, on the other hand, has to be rated for handling the severe inrush currents and voltage oscillations that may occur on the tie in connection with a forced outage of a major generator or load in one of the two networks. Furthermore, an HVDC tie capacity can be expanded in stages, with corresponding stage-wise allocation of funds (e.g., the expansion of the Pacific Intertie transmission), figure 1.0.

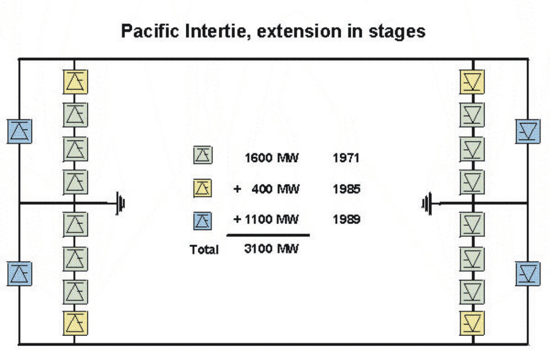

Figure 1.0 Expansion of Pacific Intertie in Stages

5.3 Stabilizing Scheme with Back-to-Back Ties

In the case of a large urban network like Delhi/NCR the main AC transmission system around it with its own and common generating stations (common to other states/regions) can be tied together and interconnected at select few (2 or 3) locations with HVDC back-to-back units of adequate capacity to handle the power transfer/ exchange requirements with the rest of the synchronous network in the Northern Region.

With such a scheme the following can be ensured:

- Delhi/NCR loads are fed by it's own reasonably strong asynchronous generating system maintaining a stable frequency
- Active power transfer can take place either way within transfer limits, without risk of fault or disturbance proliferation to/from either side
- Short circuit levels are contained to confined generating system

At any given point of time the power transfer should be preferably on export mode from the Delhi/NCR system thus ensuring excess capacity in case of an external grid disturbance or collapse. With HVDC it is quite easy to ensure power transfer (even cumulatively) at a stable fixed level or within a window.

Such a system would be immune to external disturbances and faults and in the event of an external grid problem the back-to-backs can be ramped down fast to quiescent power levels or zero exchange, with the additional surplus within the enclosed network, being controlled in a stable manner by frequency control to allocated internal generators. In such a scenario, the control of the reasonably strong island (of about 3000 – 5000 MW) can be easily done, avoiding coordination and tripping of many external lines. Moreover in case of major external disturbances it is very difficult to ensure proper and successful islanding with relays on multiple AC circuits with unpredictable power swings prone to take place.

The topology of such a configuration is shown at Figure 2.0. The strategy is to have maximum possible generation within the network fulfilling the internal normal maximum load with excess to meet export needs. This would not only ensure a larger island which will be more stable but also optimize the number of back-to-back units and ratings. Therefore, in addition to the generation within Delhi/NCR area stations nearby just outside Delhi like Dadri Gas/Thermal and Jhajjar have to be included to impart the minimum mass and capacity of the post island system.

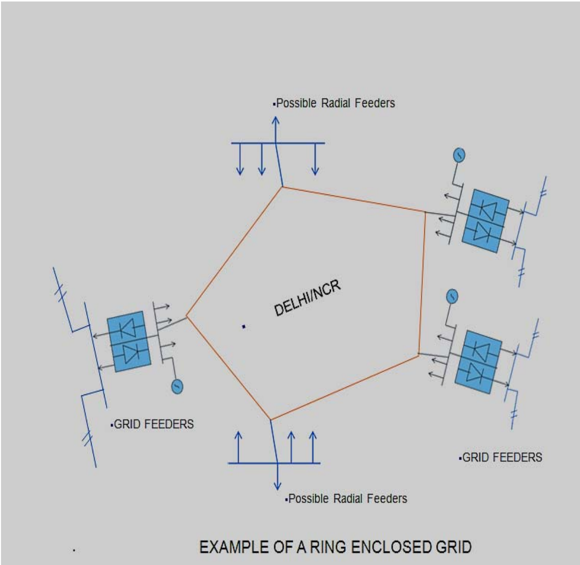

Figure 2.0 Ring Grid enclosed by HVDC back-to-backs

5.4 Other Examples and their Relevance

During the 1970s and 1980s Quebec experienced some network-wide blackouts affecting the whole province as well as its power sales to the United States. These black-outs were the result of virtual system voltage collapses at the load centers in southern Quebec due to the dynamic response to network disturbances in the remote northern generating complexes and the long 800 kV lines from James Bay and Churchill Falls.

One of the main contributing factors for the system collapse was the large reactive power variations experienced while operating the long 800 kV transmission lines. Primarily due to concerns with the reliability of the extensive 800 kV lines from James Bay and Churchill Falls, it was decided to construct the 2000 MW Quebec-New England multi-terminal HVDC transmission, still keeping Quebec and New England asynchronous.

Until the completion of a major upgrade of its 800 kV AC network, the Quebec-New England HVDC transmission was provided with a dynamic isolation scheme that disconnected the multi-terminal HVDC system from the rest of the 800 kV AC system during major system contingencies. This scheme isolated the HVDC system together with a dedicated group of generating units from the rest of the Quebec network to assure that system-wide problems in Quebec did not interrupt the power supply to New England area.

The upgrade program, to meet NERC reliability standards has, apart from installation of series compensation of many of its 800 kV AC line sections and large SVCs at critical locations in the network, also included the construction of a new 1250 MW back-to-back station at the border to Ontario in order to be able to supply replacement power from Ontario in case of major disturbances in the Quebec network, such as the large ice-storm in the winter of 1997.

As the Indian network is growing rapidly and soon will equal and even surpass in size, large global networks like in North America, isolation of critical parts of the network, through HVDC will be prudent, if not inevitable to ensure high grid reliability.

6. Development Trends

In recent years VSC transmission systems have become well established with a large number of projects of capacities up to 900 MW in operation or under implementation. The number of new VSC projects in the pipeline is increasing every year as also the size of the projects.

VSC technology affords:

- Less or little need for reactive power compensation
- Robust operation
- Smooth, fast and independent control of active and reactive power (inherent SVC functionality)
- Easier amenability for multi-terminal interconnections

VSC projects are also implemented specifically for stabilizing and increasing security of power supply to major cities. One example is the Cross Sound project in USA which feeds the Long Island part of Greater New York, where the converters utilizing VSC technology are pulse width modulated. They also have a small footprint.

6.1 Multi-Terminal HVDC Systems

The Quebec-New England multi terminal transmission, Figure 3.0, based on Current Source Converters (CSC) has been in operation now for more than ten years with very good results. Many more HVDC projects using converters interconnected in a multi-terminal mode, are expected to come up in the future with VSC technology. With VSC, the current direction is reversible without need to change voltage polarity, and thus it will be possible to connect a new station into a network of existing voltage source converters very easily.

With VSC converters for the back-to-back stations in the islanding scheme, in addition to frequency isolation and security, voltage control independent of the active power transfer can be accomplished, thus enhancing the operational flexibility as this introduces the functionality of an SVC at the point of connection.

The other big advantage with the VSC stations is the facility for black start which is extremely useful for grid restoration of the other collapsed part. This very feature is also concomitant with the immunity to any SCR levels and the absence of commutation failures.

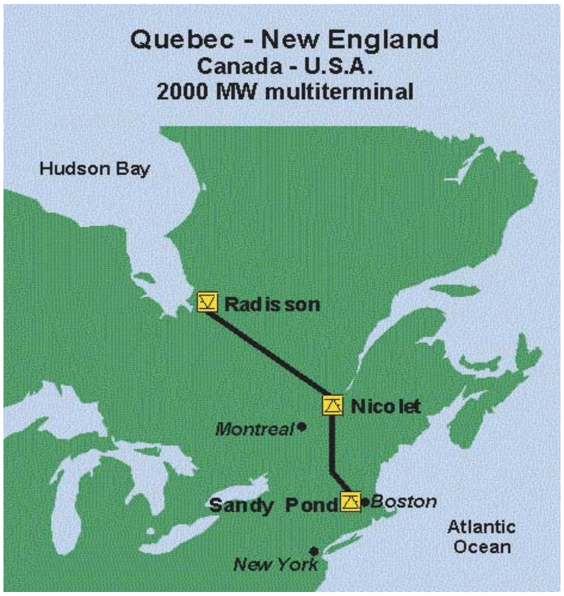

Figure 3.0 The HQ- NE Mutli-Terminal DC System

6.2 Stability improvement/ Frequency Control

Further features like frequency control and stabilization modulation can be appropriately introduced in the proposed islanding scheme which will enhance the utility of the scheme under normal operation as well as help in tiding over disturbance situations. The frequency control principle is highlighted in Figure 4.0 below:

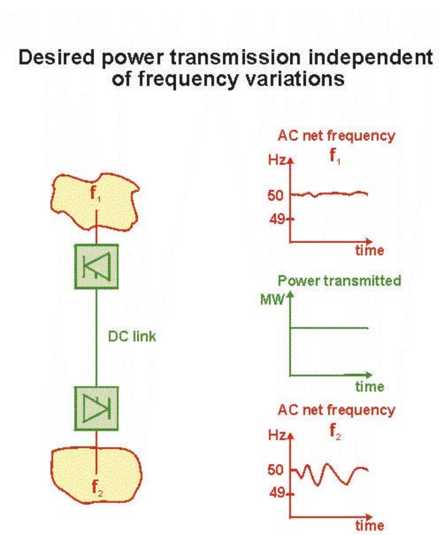

Figure 4.0: Frequency Control Principle

Other configurations like radial or loop form can also be easily accomplished with VSC Converters as seen from the figure below, depending on the network geography and requirements for isolation.

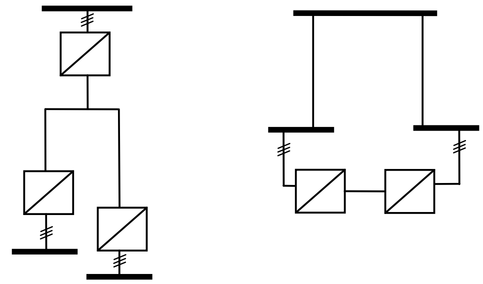

Figure 5.0: Configurations of VSC converters in Radial and Closed Loop Form

The topology can be re-configured quite easily as the system grows with minimal additional investment while maintaining isolation/asynchronism as required in a optimal manner. Very flexible connection patterns are thus made possible in the application of VSC's.

7. Conclusion

As of today, VSC technology is well established to have converters up to 1000 MW power transfer levels. This provides the means for seamlessly integrating selectively AC grids in any desired manner enabling controlled power exchange, without the hazards of fault or disturbance proliferation during contingencies, from one network to the other and increase of short circuit levels. Thus they become the right solution to secure networks like Delhi/NCR considered here.

The possibility to extend or upgrade VSC grids as networks expand without need for reconfiguring already built networks and while wheeling power in any direction as required further enhances their utility and versatility for expanding networks. The independent active/ reactive power control feature not only helps in grid stabilization but also enables hassle free integration of renewables. Their modular construction and low foot print aids in easy implementation.

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