HVDC Transmission Present Aspects and Review

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Abstract -Increased bulk power transaction in competitive energy market together with large scale integration of energy resources. Control methods for grid-connected parameters are proposed here. The method could be generally applied for all grid-connected Parameter but may be of most importance in high-voltage dc (HVDC) applications. Different from the other control methods, the proposed method utilizes the internal synchronization mechanism in ac systems, in principle, similar to the operation of a synchronous machine. By using this type of power-synchronization control, the VSC avoids the instability caused by a standard phase-locked loop in a weak ac-system connection. Moreover, a VSC terminal can give the weak ac system strong voltage support, just like a normal synchronous machine does. The control method is verified by both   analytical models and time simulations.

I.   INTRODUCTION

The evolving power systems of the world face enormous challenges in the areas of generation, transmission and distribution of the rapidly increasing amounts of electrical energy in demand. This paper addresses the specific problem of supplying electricity to the urban areas. The development of urban networks stands to address the issues of congestion, voltage stability, pollution, acoustical and electrical noise, short-circuit power restriction, permits and scarcity of land area for siting among others. When more AC-circuits are added to a city center network, the short circuit power increases, especially if AC cables are added. In extreme cases, this may lead to an upgrading need on several substations to cope with the new network situation. Compared to the conventional thyristor-based HVDC, VSC-HVDC has a number of technical merits: reactive-power support to the ac system, possibility to connect to very weak ac systems, black-start capability, and lower cable cost, just to name a few. Several control methods of grid-connected VSCs have been proposed. Among them, power-angle control and vector-current control are the two that have been mostly investigated. The principle of power-angle control is fairly simple and easily implemented.

The active power is controlled by the phase-angleshift between the VSC and the ac system, while the reactivepower is controlled by varying the VSC voltage magnitude.Power-angle control has been studied for HVDC, static-synchronous- Compensator (STATCOM), and wind-turbine applications. One disadvantage of power-angle control is thatthe control bandwidth is limited by a resonant peak at the grid frequency. Another disadvantage is that the control systemdoes not have the capability to limit the current flowing into the converter. The latter is a serious problem, as VSCs usually donot have an over-current capability. In high-power applications,it is highly important for the control to limit the valve currentto prevent the converter from being blocked (tripped) at disturbances. Vector-current control is a current-control-based   technology.Thus,   it   can naturally limit the current flowing intothe converter during disturbances. The basic principle ofvector-current control is to control the instantaneous activepower and reactive power independently through a fast innercurrent control loop. By using a decompositiontechniquewith the grid voltage as phase reference, the inner current controlloop decouples the current into and components, whereouter loops can use the component to control

active power ordirect voltage, and the component to control reactive power oralternating voltage. Due to its successful application in ASDs,doubly-fed induction-generator (DFIG) wind turbines, etc.vector-current control has become the dominant control methodfor grid-connected VSCs in almost all applications today.Interestingly, as one of the original purposes to use VSCsfor HVDC applications was its possibility to connect to veryweak ac systems, where the conventional thyristor-basedHVDCis not applicable, some difficulties have been experienced byVSC-HVDC based on vector-current control in weak ac-system connections. One of the problems is the low-frequencyresonance that is typically present. This can interfere with thefast inner current control loop, thereby limiting the VSC controlperformance. The other one has to do with thephase-locked loop (PLL). In almost all VSCs connected to acsystems, a PLL is used to obtain an accurate synchronizationto the ac system. This has since long been believed to bea pre-condition for any grid-connected VSC. However, severalinvestigations have shown that the PLL dynamics might havea negative impact on the performance of VSC-HVDC in weakac-system connections.In some way, power-synchronization control is similarto power-angle control, e.g., using phase angle andvoltagemagnitude to directly control active power and reactive power. Besides, typical problemswith power-angle control, such as the resonant peak at gridfrequency and converter over-current limitation, are properlytreated in the proposed control.

A transmission path or interface refers to a specific set of transmission elements between two neighboring control areas or utility systems in an interconnected electrical system. A transmission path or interface becomes congested when the allowed power transfer capability is reached under normal operating conditions or as a result of equipment failures and system disturbance conditions. The ability of the transmission systems to deliver the energy is dependent on several main factors that are constraining the system, including thermal constraints, voltage constraints, and stability constraints. These transmission limitations are usually determined by performing detailed power flow and stability studies for a range of anticipated system operating conditions. Thermal limitations are the most common and important factor, as warning

and consequently sagging of the lines is caused by the current flowing in the wires of the lines and other equipment. In some situations, the effective transfer capability of transmission path or interface may have to be reduced from the calculated thermal limit to a level imposed by voltage constraints or stability constraints.

Fluctuations

A fluctuation in system voltage is variation of the of the voltage to its desired value to some level depending on the loading condition, that can lead to noticeable changes in light output. Voltage Flicker can either be a periodic or aperiodic fluctuation in voltage magnitude i.e. the fluctuation may occur continuously at regular intervals or only on occasions. Voltage Flicker is normally a problem with human perception of lamp 'strobing' effect but can also affect power-processing equipment such as UPS systems and power electronic devices. A voltage magnitude variation of as little as 1.0% may also be noticeable. The main sources of flicker are industrial loads exhibiting continuous and rapid variations in the load current magnitude. This type of loads includes electric arc furnaces in the steel industry, welding machines, large induction motors, and wind power generators. High impedance in a power delivery system will contribute further to the voltage drop created by the line current variation.

Harmonics

Harmonics are components that make up a waveform where each component has a frequency that is an integral multiple of the fundamental frequency. The term Harmonic is normally applied to waveform components that have frequencies other than the fundamental frequency. For a 50 Hz or 60Hz system the fundamental frequency is 50HZ or 60Hz. A waveform that contains any components other than the fundamental frequency is non-sinusoidal and considered to be distorted.

Nonlinear loads draw currents that are non-sinusoidal and thus create voltage drops in distribution conductors that are non-sinusoidal. Typical nonlinear loads include rectifiers, variable speed drives, and any other loads based on solid-state conversion. Transformers and reactors may also become

nonlinear elements in a power system during overvoltage conditions. Harmonics create many concerns for utilities and customers alike. Typical phenomena include neutral circuit overloading in three phase circuits, motor and transformer overheating, metering inaccuracies and control system malfunctions.

Interruptions

An Interruption occurs whenever a supply's voltage drops below 10% of the rated voltage for a period of time no longer than one minute. It is differentiated from a voltage sag in that the late is not a severe power quality problem. The term sag covers voltage drops down to 10% of nominal voltage whereas an interruption occurs at lower than 10%. A Sustained Interruption occurs when this voltage decrease remains for more than one minute. An interruption is usually caused by downstream faults that are cleared by breakers or fuses. A sustained interruption is caused by upstream breaker or fuse operation. Upstream breakers may operate due to short-circuits, overloads, and loss of stability on the bulk power system. Loss of stability is usually characterized by out-of-tolerance voltage magnitude conditions and frequency variations which exceed electrical machine and transformer tolerances. This phenomenon is often associated with faults and deficiencies in a transmission system but can also be the result of lack of generation resources. The concerns created by interruptions are evident and include inconvenience, loss of production time, loss of product, and loss of service to critical facilities such as hospitals.

Loop Flow

The terms Loop Flow and Parallel Path Flow are sometimes used interchangeable to refer to the unscheduled power flows, that is, the difference between the scheduled and actual power flows, on a given transmission path in an interconnected electrical system. Unscheduled power flows on transmission lines or facilities may result in a violation of reliability criteria and decrease available transfer capability between neighbouring control areas or utility systems.

The reliability of an interconnected electrical system can be characterized by its capability to move electric power from one area to another through all transmission circuits or paths between those areas under specified system conditions. The transfer capability may be affected by the "contract path" designated to wholesale power transactions, which assumes that the transacted power would be confined to flow along an artificially specified path through the involved transmission systems. In reality, the actual path taken by a transaction may be quite different from the designated routes, determined by physical laws not by commercial agreements, thus involving the use of transmission facilities outside the contracted systems. These unexpected flow patterns may cause so-called Loop Flow and Parallel Path Flow problems, which may limit the amount of power these other systems can transfer for their own purposes.
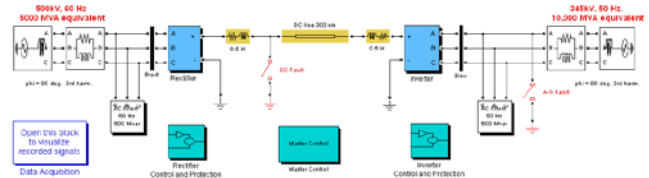

Fig 1.1 Transmission Loop Flows for scheduled Transfer from Area A to Area B in an Interconnected System

Power Factor

Reactive power is defined as the product of the rms voltage, current, and the sine of the difference in phase angle between the two. It is used to describe the effects of a generator, a load, or other network equipment, which on the average neither supplies nor consumes power. Synchronous generators, overhead lines, underground cables, transformers, loads and compensating devices are the main sources and sinks of reactive power, which either produce or absorb reactive power in the systems. To maintain efficient transmission and distribution, it is necessary to improve the reactive power balance in a system by controlling the production, absorption, and flow of reactive power at all levels in the system. By contrast, inefficient reactive power management can result in high network losses, equipment overloading, unacceptable voltage levels, even voltage instability and outages resulting from voltage collapse. Local reactive power devices for voltage regulation and

power factor correction are also important especially for balancing the reactive power demand of large and fluctuating industrial loads.

Sags and Swells

A Voltage Sag or Voltage Dig is a decrease in supply voltage of 10% to 90% that lasts in duration from half a cycle to one minute. A Voltage Swell is an increase in supply voltage of 10% to 80% for the same duration.

Voltage sags are one of the most commonly occurring power quality problems. They are usually generated inside a facility but may also be a result of a momentary voltage drop in the distribution supply. Sags can be created by sudden but brief changes in load such as transformer and motor inrush and short circuit-type faults. A sag may also be created by a step change in load followed by a slow response of a voltage regulator. A voltage swell may occur by the reverse of the above events.

Electronic equipment is usually the main victim of sags, as they do not contain sufficient internal energy to 'ride through' the disturbance. Electric motors tend to suffer less from voltage sags, as motor and load inertias will 'ride through' the sag if it is short enough in duration.

Unbalanced Load

A load which does not draw balanced current from a balanced three-phases supply

An unbalanced load is a load which does not draw balanced current from a balanced three-phase supply. Typical unbalanced loads are loads which are connected phase-to-neutral and also loads which are connected phase-to-phase. Such loads are not capable of drawing balanced three-phase currents. They are usually termed single-phase loads.

A single-phase load, since it does not draw a balanced three-phase current, will create unequal voltage drops across the series impedances of the delivery system. This unequal voltage drop leads to unbalanced voltages at delivery points in the system. Blown fuses on balanced loads such as three-phase motors or capacitor banks will also create unbalanced voltage in the same fashion as the single-phase and phase-phase connected loads. Unbalanced voltage may also arise from impedance imbalances in the circuits that deliver electricity such as untransposed overhead transmission lines. Such imbalances give the appearance of an unbalanced load to generation units.

An unbalanced supply may have a disturbing or even damaging effect on motors, generators, poly-phase converters, and other equipment. The foremost concern with unbalanced voltage is overheating in three-phase induction motors. The present current imbalance drawn by a motor may be 6 to 10 times the voltage imbalance, creating an increase in losses and in turn an increase in motor temperature. This condition may lead to motor failure.

Voltage Instability

Voltage instability is basically caused by an unavailability of reactive power support in an area of the network, where the voltage drops uncontrollably. Lack of reactive power may essentially have two origins: firstly, a gradual increase of power demand without the reactive part being met in some buses or secondly, a sudden change in the network topology redirecting the power flows in such a way that the required reactive power cannot be delivered to some buses.

The relation between the active power consumed in the considered area and the corresponding voltages is expressed in a static way by the P-V curves (also called "nose" curves). The increased values of loading are accompanied by a decrease in voltage (except in case of a capacitive load). When the loading is further increased, the maximum loadability point is reached, beyond which no additional power can be transmitted to the load under those conditions. In case of constant power loads the voltage in the node becomes uncontrollable and decreases rapidly. This may lead to the partial or complete collapse of a power system.

It is sometimes difficult or impossible to connect two AC networks due to stability reasons. In such cases HVDC is the only way to make an exchange of power between the two networks possible.

Several HVDC links interconnect AC system that are not running in synchronism with each other. For example the Nordal power system in Scandinavia is not synchronous with the UCTE grid in western

continental Europe even though the nominal frequencies are the same. And the power system of eastern USA is not synchronous with that of western USA. There are also HVDC links between networks with different nominal frequencies (50 and 60 Hz) in Japan and South America.

Direct current transmissions in the form of classical HVDC or HVDC Light® are the only efficient means of controlling power flow in a network. HVDC can therefore never become overloaded. An AC network connected with neighboring grids through HVDC links may as the worst case loose the power transmitted over the link, if the neighboring grid goes down - the HVDC transmission will act as a firewall against cascading disturbances.

Advantages:
1. The networks can retain their independence
2. An HVDC link can never be overloaded.
3. HVDC transmission will act as a firewall against cascading disturbances.

Expressway for power

A HVDC transmission line costs less than an AC line for the same transmission capacity. However, the terminal stations are more expensive in the HVDC case due to the fact that they must perform the conversion from AC to DC and vice versa. But above a certain distance, the so-called "break-even distance", the HVDC alternative will always give the lowest cost. Therefore many long overhead lines (> 700 km) particularly from remote generating stations are built as DC lines.
Advantages:
1. Lower investment cost
2. Lower losses
3. Lower right-of-way requirement for DC lines than for AC lines
4. HVDC does not contribute to the short circuit current

Long distance water crossing

In a long AC cable transmission, the reactive power flow due to the large cable capacitance will limit the maximum possible transmission distance. With HVDC there is no such limitation, why, for long cable links, HVDC is the only viable technical alternative. There are HVDC and HVDC Light cables from 40 km up to 580 km in operation or under construction with power ratings from 40 to 700 MW.

Advantages:
1. Lower investment cost
2. Lower losses

Interconnected power systems

Loop Flows, or Parallel Path Flows, may be alleviated by the use of HVDC or HVDC Light. In interconnected power systems, the actual path taken by a transaction from one area to another may be quite different from the designated routes as the result of parallel path admittance, thus diverting or wheeling power over parallel connections.

The figure shows how parallel path flow can be avoided by replacing an AC line with a HVDC/HVDC Light link between area A and area C

Advantages:
1. HVDC can be controlled to transmit contracted amounts of power and alleviate unwanted loop flows.
2. An HVDC link can alternatively be controlled to minimize total network losses
3. An HVDC link can never be overloaded!

Grid Voltage Support

Static Var Compensators are used in transmission and distribution networks mainly providing dynamic voltage support in response to system disturbances and balancing the reactive power demand of large and fluctuating industrial loads. A Static Var Compensator is capable of both generating and absorbing variable reactive power continuously as opposed to discrete values of fixed and switched shunt capacitors or reactors. Further improved system steady state performance can be obtained from SVC applications. With continuously variable reactive power supply, the voltage at the SVC bus may be maintained smoothly over a wide range of active power transfers or system loading conditions. This entails the reduction of network losses and provision of adequate power quality to the electric energy end-users.

Advantages:
1. Increased Power Transfer Capability
2. Additional flexibility in Grid Operation
3. Improved Grid Voltage Stability
4. Improved Grid Voltage Control
5. Improved Power Factor

Other applications:
1. Power Oscillation Damping
2. Power Quality (Flicker Mitigation, Voltage Balancing)

Power Flow Control

Loop Flows, or Parallel Path Flows, may be effectively alleviated by the use of entirely or partially thyristor controlled series compensation.

In interconnected power systems, the actual path taken by a transaction from one area to another may be quite different from the designated routes as the result of parallel path admittance, thus diverting or wheeling power over parallel connections. Controlled series compensation is a useful means for directing power flows along contracted paths under various loading and network configurations. Figure shows parallel path flow alleviation by the use of controlled series compensation. With a reduction in the direct interconnection impedance between area A and area B,

: Advantages:
1. Increased Power Transfer Capability
2. Additional flexibility in Grid Operation
3. Lower Transmission Losses
4. Improved Transient Stability
5. Improved Grid Voltage Control
   Other applications:
1. Power Oscillation Damping
2. Sub-synchronous Resonance Mitigation

II.   CONCLUSIONS

In this paper, the concept of power synchronization is proposed for control of grid-connected VSCs. The proposed control is general for grid-connected VSCs, but may be of most importance for VSC-HVDC connected to weak ac systems. By using the power-synchronization control method, VSC-HVDC operates almost in the same way as a synchronous machine. Therefore, in principle, it has no requirement on the short-circuit capacity of the ac system to be connected. On the other hand, VSC-HVDC gives the weak ac system strong voltage support, just like a normal synchronous machine does. However, a weak ac system connection still represents a more challenging operating condition for VSC-HVDC than a strong ac system connection due to the relatively higher load angles. Thus, it is recommended that VSC-HVDC shall run with a control system having a lower bandwidth when connected to a very weak ac system in order to maintain a safe stability margin.

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