TECHNICAL CONSIDERATIONS FOR POWER GRID INTERCONNECTION IN NORTHEAST ASIA

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Cost-benefit analysis

Potential benefits of cross-border interconnection of large systems are great and at the same time the costs for such interconnection are also significant. Potential benefits include economical savings, environmental protection, reliability enhancement, and others. Comparative studies of alternatives of expansion plans, including cross-border interconnections, should be carried out for cost benefit analysis. Probabilistic production costing can be used as a tool for such studies.

Production costing is a standard analysis tool for power system generation expansion that simulates a power system's operation in order to drive costs of production of electricity in the planning period. The simulation is typically carried out for ten, twenty or more years into the future. It started with a forecasted load demand for the system. The additional load for the export is to be added to the exporting system and the import from interconnection is treated as generation for he importing system. The composition of the generation includes existing generation and candidates for future expansion, including import form interconnection for the importing system. Generation scheduling and dispatch are modeled by a merit order of generators. Generators are stacked up, according to the merit order, to meet the load demand at every point in time. The simulation is typically done on a weekly or monthly basis. Uncertainties in generator forced outages, hydro availability, etc. are modeled in probabilistic simulation, which uses a stochastic modeling. The output of probabilistic production costing provides detail information of fuel usage and cost, pollution generated, etc. for each generator and for the whole system, as well as system reliability measures such as system loss of load probability, expected unserved energy, and economic measures such as long-run marginal cost. It can be used to assess benefits (economical and environmental) of interconnection.

Cost of interconnection include capital costs of transmission lines and auxilliary equipment, such as transformers or converters, protective devices, power conditioning devices, etc. One of the most significant component of the operational costs is the costs associated with transmission losses, which include losses in the lines, transformers, or inverters. The higher the voltages, the lower the transmission losses, but the capital costs increase at the same time.

Benefits of interconnection depends on the transfer capability of the interconnection, whereas the costs depend on the interconnection sites, the geography of the land in which the lines will be built, etc., and the schemes used in the interconnection, e.g., HVAC or HVDC and its voltage level.

Operation and Control

Where, what and how much to interconnect affect the operation and control of both systems being interconnected. Existing systems are all AC. AC systems have rather stringent operation and control requirements.

Power flows and voltage distribution in an AC power system are determined by Kirchhoff and Ohm laws. Individual element has very little control over the whole system, whereas changes in an individual element may affect the flows of power in ways not intended. Aside from such steady-state considerations, a local disturbance may cause quick and widespread response from the rest of the system, causing system-wide oscillations or other stability problems. The effect of a disturbance may propagate and amplified through the network, resulting in cascading outages of various elements in the network. Control devices are installed and appropriate setting are made in the design stage to mitigate possible disturbances.

Frequency control is an important aspect of power system operation. Frequency is an indication of power balance between total generation and total load in the system. Frequency deviation from normal (whether it is 50Hz or 50Hz) requires immediate actions to balance supply and demand of electricity. There are limitations on generator response. The ability of a system to respond to frequency variation is built in the design philosophy of the system.

Disturbances or faults, such as short-circuit caused by lightening, tree falling, etc. on transmission lines happen often on a power system. Protective relay systems are used to sense a fault and circuit breakers are used to isolate the fault. Fast clearing of faults is essential to prevent the effect of the fault to spread and propagate. Protective systems are designed and installed to ensure safe operation of the system.

Since unexpected disturbances are unavoidable in a power system, the system should be designed to withstand credible disturbances. Credible disturbances are disturbances, such as line outage due to lightening, or generator outages, that are likely to happen. The system should be able to operate in steady state with no transmission line overload, nor abnormal voltages after any credible disturbance occurs. Moreover, during transient period, there should be no stability problem. The list of credible disturbances is derived based on system's reliability criteria and planning philosophy.

Interconnection Alternatives

There are three basic alternatives in interconnecting two existing networks. The most frequently used, and seemingly most natural, interconnection within a country is the AC interconnection. There are some pre-conditions that must be satisfied for such interconnection. The two systems, once interconnected, must operate in synchronism with a uniform frequency. This imposes additional requirements on the existing frequency controls of the individual systems. First of all, interchange schedule becomes part of the input signal in frequency control. Frequency deviation is thus combined with errors in interchange schedule to form the so-called *area control error* (ACE) that is used to adjust generation. Due to additional burden from the other system, requirements for the ability of the generating system to respond may have to be increased, i.e., there should be enough generators under control to respond fast. The frequency control should be the responsibility of both parties.

Protective system needs to be coordinated and adjustments need to be made when two systems are interconnected. For cross border interconnection, common reliability criteria should be followed, so that no party is imposing on the other party unfairly.

HVDC interconnection provides several advantages. The systems to be connected can be kept asynchronous operation, hence there will be not transient stability and dynamic stability problems between the interconnected systems. The operation and control of the interconnected systems can be relatively independent under HVDC link, compared with the AC link. The interconnected systems have only real power exchange and there is no line charging capacitance-related problems. The exchange power can be controlled accurately and at high speed. Faults on one side will not have noticeable impacts to the other side. The short circuit current on the DC link can be controlled and limited to certain extent. If the system on one side of the DC link has an emergency, the other side can provide fast power supported by changing HVDC power transfer setting, if available, which can improve transient stability of both side systems.

The disadvantages of HVDC are as follows. It will generate harmonics that have adverse effect on the power quality of the power system. Additional filters are required to support its operation. It needs reactive power to support its normal operation. Therefore large reactive source should be installed at the converter station. Another problem is if HVDC control is not well set, it might bring about sub-synchronous oscillation of the power system.

When a weak link is employed to connect two networks or the transmission distance between the two interconnected systems is too long, stability after a fault may become a serious problem. In such a case, a hybrid AC/DC interconnection may offer technical advantages. The HVDC can damp out oscillations and enhancing stability of the interconnected system. An example of such an interconnection is the Pacific Intertie in California and Oregon.

Reinforcement of Existing Networks

Interconnection may necessitate reinforcement of existing networks for stability or other reliability considerations. The reinforcement may be assisted by the deployment of Flexible AC Transmission System (FACTS) devices and computer-controlled energy management system (EMS). Flexible AC Transmission System technologies are aimed to install power electronic devices at the proper places of the existing AC systems to improve their steady-state and dynamic behavior and keep preset power transfer. Generally, the objectives of FACTS technology are to enhance system controllability and to increase power transfer limit. Detailed simulation of possible steady state, dynamic state and transient state operation must be studied based the proposed interconnection schemes, taking applications of various FACTS devices into account.

FACTS devices can be classified into two categories: shunt type and series type. SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator) are shunt type FACTS devices that are usually installed in the middle of the tie lines to provide reactive power injection and voltage support. It can improve system dynamic behavior and enhance the system transfer limit apparently that is desirable in system interconnection. TCSC (Thyrister Controlled Series Compensator), UPFC (Unified Power Flow Controller), SPS (Static Phase Shifter) etc. are series type FACTS devices which are capable of controlling tie line power flow, a feature extremely welcomed in system interconnection. Basically a HVDC converter costs more than a FACTS controller does. If the AC interconnection already existed, the FACTS controller might be the first choice since asynchronous operation of the two interconnected systems is impossible.

Energy Management System (EMS) uses state-of-the-art information technology to monitor and control a power system in real-time. Real-time data are collected through Remote Terminal Units (RTU) and communicated to the computer via high-speed data links every few seconds. Real-time data are analyzed and control actions are devised using advanced software in the EMS. EMS greatly enhances reliability and economic operation of the power system.

System Performance Simulation and Analysis

Detailed simulation and analysis are carried out to ensure acceptable performance of the power system after the interconnection. Both steady-state and dynamic simulations should performed. Power flow analysis is the fundamental steady-state analysis, whereas dynamic simulations include transient stability, long-term dynamics, small signal stability, voltage stability, and subsynchronous oscillations.

Power Transfer Study under normal economic operation conditions or emergency conditions can be used to identify the power transfer quantities according to practical developing conditions of participating countries. Detailed numerical simulations are required to verify the power transfer capabilities in major tie lines and identify potential problems affecting reliability and stability of the interconnected systems. Detailed simulation of possible steady state, dynamic state and transient state operation must be studied. Other emergency control and normal operation dispatch based on optimization and coordination, contract implementation and wheeling should be simulated in details.

Static and Dynamic Security Analysis Power and Frequency Control, detailed simulation of PSS, TCSC, protection relay, inter-area oscillation etc, must be studied. The analysis will verify whether static and dynamic conditions are satisfied.

Reliability Analysis Reliability assessment of Northeast Asia power grid is very complex since it must consider the integrated reliability effects of generation and transmission scattered among several countries with different developing levels. Reliability analysis method for composite system should be utilized to verify whether supply reliability indexes are satisfied.

Conclusion

Technical issues arising from interconnection of Northeast Asia power grids are very complex. Due to long distance for the interconnection, stability and other dynamic problems will be especially serious. Technical studies of interconnection should be carried out side by side with cost benefit analysis. In Northeast Asia countries, because of difference in their stages of economical developments, there exist significant differences in regional networks' strength, planning and operation criteria, and technical standards. The differences need to be worked out before any results of technical analysis can be agreed upon, especially since results of technical analysis depend on models and data used, and assumptions made.

The most likely candidate for interconnecting Northeast Asia grids is HVDC over long distance. With technical considerations included, some of the potential benefits of interconnection may still be valid; on the other hand, some may have to be scrutinized. For example, economic benefits of leveling summer and winter demands from North to South, utilizing remote hydro resources, etc. are likely to hold. However, other benefits such as using interconnection to reduce reserve, as well as joint economic dispatch, are unlikely to achieve. Due to weak connection between regional networks, economical and environmental benefits from exchanging power over multiple regional networks become more questionable.