Expanding Power Systems in the Republic of Korea

Feasibility Studies and Future Challenges

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AS A POWER NETWORK ISOLATED FROM NEIGHboring countries, the electricity infrastructure in South Korea (also called the Republic of Korea) requires a high level of preparation for adopting future grid technologies. System plans must provide a practical solution for power system expansion that complies with strict reliability performance criteria, including contingencies (faults) on the 765-kV transmission system. System improvements must also provide a practical solution for exchanging power between the mainland and Jeju Island, which is viewed as a carbon-free area because of the expected development of wind generation. Addressing these concerns led to the development of two upcoming high-voltage dc (HVdc) projects with unique objectives.

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The first project is a gigawatt-scale line-commutated converter (LCC) HVdc system, which connects massive nuclear complexes with a metropolitan area. This project will replace an originally planned 765-kV transmission project that faced strong public opposition because of siting concerns. The HVdc project design offers environmental, public policy, and technical advantages while also meeting reliability performance standards.

The second project consists of a modular multilevel converter (MMC)–based voltage source converter (VSC)–HVdc connection between the mainland and Jeju Island. This project will deliver bidirectional power flow and coordinate with two existing LCC-HVdc ties.

The two new HVdc projects require complicated and novel operating strategies. Therefore, comprehensive feasibility studies must be conducted that surpass the scope of feasibility studies commonly conducted for conventional technology. Many advanced planning and simulation methods and tools were considered by the Korea Electric Power Corporation (KEPCO) and partner universities to efficiently and accurately achieve practical and credible solutions.

This article presents the imminent issues and challenges for developing the future South Korean electric power system, the procedures used for enhancing public acceptance of projects, and the studies conducted for addressing power system stability problems. The article also describes innovative methodologies for improving the accuracy of power system planning results as well as the identification of planning upgrades that increase levels of power system transfers.

Unique Power System Infrastructure of the Republic of Korea

The electric power system of the Republic of Korea, shown in Figure 1, is totally isolated from neighboring countries because of political and geographical issues. Its electricity consumption per capita was 10,320 kWh/capita in 2017, which exceeds that of most of the European countries that have relatively larger land areas [see Figure 2(a)]. Because of the large amount of power generation and consumption relative to population [see Figure 2(b)], the generation and transmission facilities in the Republic of Korea are densely packed, with few opportunities for new greenfield sites. In addition, the ratio of peak load relative to generation capacity is high, as shown in Figure 2(c).

The major generation complex (on the east coast) and load center (around the capital, Seoul, in the northwest) are approximately 350 km apart and are connected by several 345-kV lines and one 765-kV double circuit, as shown in Figure 3. KEPCO plans to interconnect more bulk power plants in the major generation area, such as nuclear and coal-fired generation plants in the east, which will increase the regional generation capacity from 7 to 22 GW by 2022.

Currently, even when a power plant is constructed, it is difficult to build new transmission facilities because of social acceptance. The contingency study shows that a severe disturbance (*N*–2) resulting in the loss of two of the existing 765-kV lines would cause instability without tripping at least five nuclear generators (totaling approximately 6,000 MW) through

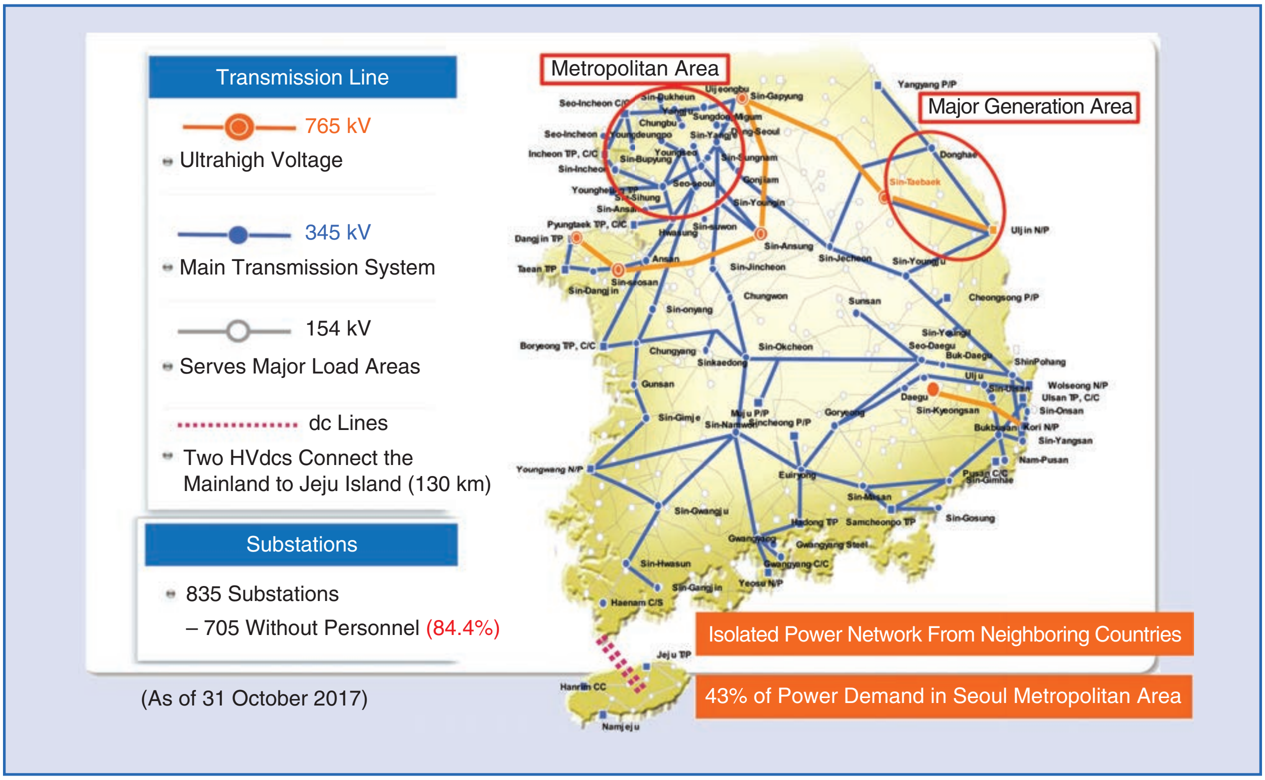

figure 1. The electric power system of South Korea.

activation of a special protection scheme (SPS). However, the loss of 6,000 MW of generation would be too severe and could subsequently cause a blackout without grid reinforcements.

The introduction of more high-voltage ac (HVac) lines to the system was planned to prevent catastrophic consequences and comply with the KEPCO reliability performance criteria by which no more than two nuclear generator units (totaling 3,000 MW) may trip offline during the most critical contingency without load shedding. However, the HVac transmission expansion option was strongly opposed by the public because of societal and environmental issues related to building new transmission towers and lines. As a result, KEPCO sought alternative solutions for expanding the transmission capacity to meet reliability constraints and satisfy social requirements.

Motivations for Alternatives

KEPCO's grid planners developed solutions that added 345-kV transmission facilities with the understanding that contingencies on these facilities would have fewer adverse effects on the system than 765-kV contingencies. However, study results showed that at least 24 additional 345-kV lines connecting the east and west of the country would be required to meet the reliability performance criteria for contingencies on the 765-kV lines. The problems with the 345-kV system expansion plans include a large number of lines needed, voltage stability concerns caused by the long-distance connections, and an increase in the short circuit availability to unacceptably high levels throughout the system.

Against this backdrop, KEPCO sought alternatives that would meet reliability requirements, maximize the utilization of the existing system, and reduce the need for new transmission facility rights of way, which would avoid adverse environmental impact and meet social requirements. The plan called for LCC-HVdc transmission, static synchronous compensators (STATCOMs), and thyristor-controlled series capacitors (TCSCs).

Unique Capabilities Available With HVdc

There are many reasons for developing HVdc projects that drove consideration of the LCC-HVdc project in the Republic of Korea. The proposed project connects large power plants (including nuclear power generation) with distant load centers, keeps short circuit availability within acceptable levels, requires minimal right of way, and uses fast power modulation and other controls to minimize the adverse effects of extremely high-impact contingencies. The LCC-HVdc project required multiple feasibility studies to ensure that it could provide a solution to the many complex issues presented by the system in the Republic of Korea.

To meet the reliability performance standard when a critical 765-kV line contingency occurs, the project utilizes a sophisticated control strategy that rapidly ramps the dc power output in combination with other controls and an SPS. HVdc power modulation is a common industry application, especially for ramping down the HVdc system to protect its

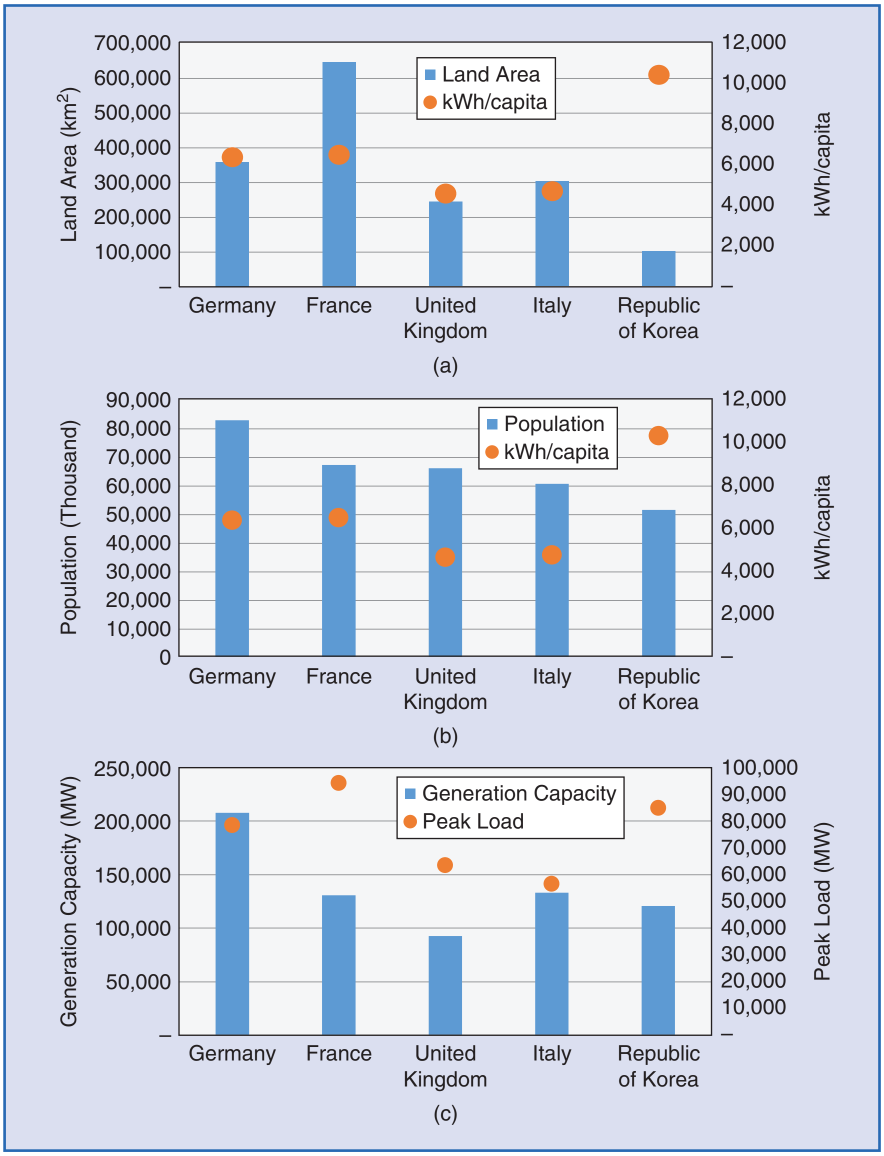

figure 2. A comparison of (a) land area and kWh/capita, (b) population and kWh/capita, and (c) generation capacity and peak load of different countries.

figure 3. A photo of a 765-kV double-circuit line in Korea. (Photo courtesy of KEPCO.)

equipment in response to a contingency. However, this project also utilizes an overload capability for the HVdc system in coordination with controls of flexible alternating current transmission system (FACTS) to minimize generation rejection. Critical contingencies accelerate generators in the east, but they remain stable when HVdc transfers west are suddenly ramped up, which provides a cost-effective solution for these rare system events. Ramping the HVdc up also relieves potential thermal overloads of other transmission facilities. The plan still requires SPS actions to reconfigure the ac transmission system, reject some generation, and provide reactive power support.

Combined LCC-HVdc and FACTS Feasibility Study

The study of this HVdc project began in 2013 with a conventional feasibility study to estimate its size and terminal locations. The short circuit ratio (scr) and effective scr (Escr) provide critical indices used to compare the strength of an ac system with acceptable HVdc expansion options. The short circuit levels and scr were examined for the most severe transmission outages for base case conditions with up to two generators normally out of service.

Analysis using a transient stability analysis (TSA) tool evaluated numerous credible operating scenarios to identify the optimal connection points for the HVdc stations. Five locations on the 765-kV transmission lines were identified and simulated as the worst-case three-phase bus faults in the studies. However, KEPCO engineers performed TSA of all credible contingencies throughout the system and particularly at the HVdc terminals. All results for a given plan must be stable to fulfill the intended role of the HVdc that supports continuous power delivery, even if there is a three-phase fault on the double-circuit 765-kV transmission lines.

However, this LCC-HVdc project needs more than the conventional approach normally used for planning HVdc facilities. To meet the high degree of accuracy required for studying the complex power system in the Republic of Korea, additional modeling, tools, studies, and analyses for this specific project were performed as follows:

- ✔ a maximum power curve analysis with STATCOM (MPCWS) for examining the initial overloading capability of HVdc based on different system strengths
- ✔ an equal area criterion (EAC) analysis for estimating the initial overloading amount of HVdc
- ✔ a feasibility study of a proposed TCSC with overload capability
- ✔ a feasibility study of a STATCOM to support the HVdc
- ✔ a TSA using an advanced HVdc model
- ✔ an analysis to determine the HVdc ramping rates for automatic operation and scheduling changes
- ✔ an electromagnetic transient (EMT) simulation analysis, including detailed models of the HVdc and FACTS.

Analyses based on the EAC with HVdc and MPCWS turn out to be useful for analyzing the initial required overloading capability of the HVdc before refining the amounts using TSA analysis. Both analyses are different from conventional approaches because they can provide initial parameters for the detailed study. The EAC analysis with HVdc can provide an initial overloading amount for the HVdc, which makes it possible to manage the deceleration of generators near the rectifier side of the HVdc. This analysis can estimate the level of overloading amount that secures enough stability margin so that the number of generators required to trip by SPS can

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be within the reliability standard. The aggregation process of generators is required to perform such analysis. MPCWS offers an expected overloading capability of the HVdc system under different system strengths and provides an initial rating of the STATCOM required to maintain the voltage on the inverter terminal in steady state. These procedures can prevent iterative tasks when performing further studies.

The use of advanced HVdc stability models, such as the CDC7T model in PSS/E, provides the most accurate results in planning studies. Through detailed modeling of the dc line and control algorithms, the model allows the simulation of HVdc performance as close as possible to the simulation results achieved with an EMT program. In addition, the stability model includes a controlled dc ramp-up rate, which is an important factor in determining the required overloading capacity of the HVdc for properly decelerating the generators after a contingency.

E-TRAN simulation provides detailed and accurate EMT studies after converting network data and dynamic models of TSA to those of EMT. EMT analysis is required to determine parameters, such as dc voltage and current sensor time constants, the size of the dc smoothing reactor and line parameters, voltage-dependent current order limit coordination, proportional integral controller values, and firing angle and extinction angle ranges. The analysis can tune controls and identify the abnormal operation of the HVdc converter valves that would be observed in the field but not seen by TSA simulation results. For example, commutation failures can be observed in EMT simulations but not in the TSA. An examination of the EMT simulation results can inform interpretation of TSA results and improve TSA models.

A feasibility study showed that the installation of FACTS resulted in improved HVdc performance and achieved better utilization of existing transmission assets. Series capacitors reduce line impedances that increase ac power flows, but a TCSC can also dynamically modulate the amount of series compensation and control line flows. The study examined a TCSC with dynamic overload capability to increase ac power transfer during transient conditions and reduce dependency on the HVdc overload capability. The analysis determined the TCSC firing angle, compensation level, and capacitor and inductor ratings. Studies also ascertained the dynamic-mode range of compensation and expected operating ranges for normal and dynamic modes to avoid undesired resonances and enable estimates of the optimal firing angles for the TCSC.

Installation of a STATCOM would instantaneously provide needed reactive support and was selected as the best option for obtaining more stable LCC HVdc performance. The location of the STATCOM electrically near the inverter side of the HVdc system must be determined prior to establishing its rating. Proper reactive power support and dynamic capability of the STATCOM improve HVdc performance by avoiding commutation failures under severe contingencies and maintaining acceptable ac and dc voltages at the inverter terminal.

Expected Commissioning

Figure 4 is a diagram for the planned power system in the area of interest. The east side is the main generation area, equipped with large-scale nuclear and coal plants; the west side of the system is the main load center of the country that includes Seoul, the capital city of the Republic of Korea. The project aims to stabilize the power system by coordinating the controls of the HVdc system with the FACTS, consistent with planning criteria that allow for up to two generators to trip offline upon occurrence of the most severe contingency: a three-phase fault on the double-circuit 765-kV transmission lines resulting in their loss. The addition of the HVdc system, the STATCOMs, and TCSCs replaces the original plan of building new 765-kV transmission lines. After reviewing various scenarios and strategies, two bipolar LCC-HVdc lines with a total rating of 8 GW have been planned. Two TCSCs, each with a rating of 500 Mvar, will support HVdc performance as well as maximize the ac power transfer capability under *N*–2 contingency conditions.

Choice of Tool and Expectations for the Detailed Studies

The tool choice for conducting the feasibility study is quite important in this LCC-HVdc project because of the complicated nature of the future power system. Traditionally, steady-state analysis and TSA use PSS/E or a similar transient security assessment tool. These practices and tools are industry accepted and appropriate for the simulation of large power systems. These studies determine the optimal size and location of the HVdc systems.

However, a TSA tool is not appropriate for investigating dynamics requiring types of studies or simulations modeling a small time step used to analyze commutation failures, valve control response, filter control, subsynchronous torsional interaction, and negative sequence behaviors. EMT tools are more appropriate for studying the detailed characteristics of power electronic components. The utilization of E-TRAN enables the conversion of TSA files into EMT files reflecting the power system's dynamic model information for components such as generators, transmission lines, and loads. Detailed modeling of the HVdc scheme, STATCOMs, and TCSCs provides the ability to thoroughly observe the dynamic behavior of each device. The time and effort required to build a case study for accurately representing such characteristics are significantly greater than those for TSA cases. In addition, the computation burden is much larger than that in TSA, which makes EMT tools inefficient when simulating large power systems and conducting system-wide impact studies. Therefore, network equivalents represent portions of the system electrically far from the HVdc converter terminals. However, this use of equivalent circuits weakens the accuracy of the results. Both TSA and EMT approaches have their own strengths and weaknesses as well, which leads to research opportunities to combine their strengths.

KEPCO invested in developing real-time simulation (RTS) cases of the entire Korean power system. Detailed RTS models of each component in the power system were used to verify all of the influences from various HVdc operating modes. However, because of its complicated nature and the difficulty in making changes to the entire network as compared with those possible with TSA tools, KEPCO investigated the concept of cosimulation or hybrid simulation that combines the detailed modeling available in EMT packages with the bulk power system simulation of TSA tools while compensating for the weaknesses of both TSA and EMT.

Jeju: Toward a Zero-Carbon Island

A serious concern for KEPCO planners is the difficulty in performing accurate power system analysis with the increased use of power converters with HVdc and FACTS. The problem of choosing an appropriate simulation tool has arisen again with the Jeju HVdc number 3 project. Jeju Island is the largest island in Korea, and it connects to the mainland through HVdc lines, as shown in Figure 5. The Jeju electric power system has different characteristics as compared with the Republic of Korea mainland power system. Because of the abundant renewable energy sources, the Jeju special self-governing body declared a vision of becoming a carbon-free island by 2030.

The multi-infeed HVdc system presently in operation has had two LCC-HVdc lines (HVdc number 1 is 300 MW and HVdc number 2 is 400 MW) since 2010. The renewable power capacity on the island was 380 MW in 2017, and the Republic of Korea government aims to install further renewable energy sources totaling approximately 2 GW on Jeju by 2030. Although there are eight synchronous generators, three or four are typically in service, with minimal power generation during the off-peak load condition to support the minimum scr required by the LCC-HVdc converters. The peak load of Jeju was approximately 930 MW in 2017. In the future, when Jeju's wind power penetration surpasses its peak load,

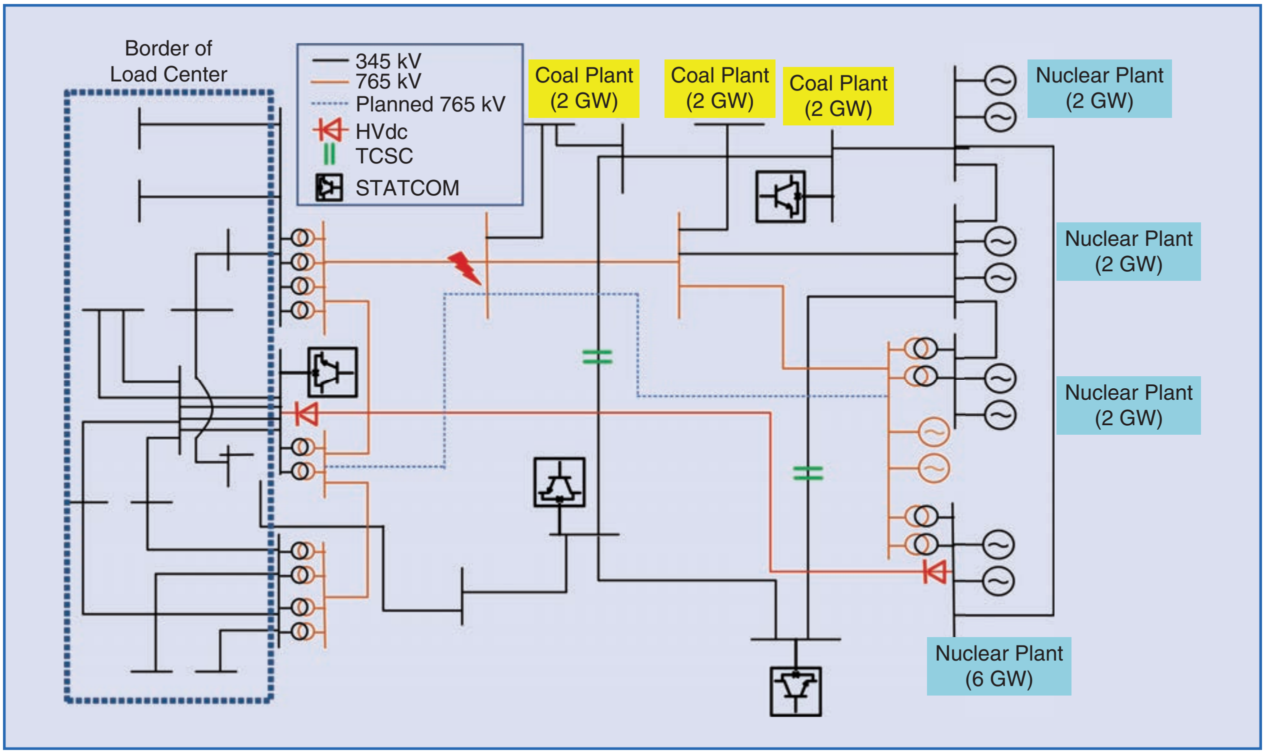

figure 4. A simplified network from the generation complex to the Seoul metropolitan area with HVdc and FACTS. The single transmission lines above are double-circuit lines.

the island will require the capability of transmitting power back to the bulk power system, as shown in Figure 6. Therefore, HVdc number 3, which is in the planning stage, must be flexible and bidirectional. It is most likely to be an MMC-based VSC scheme.

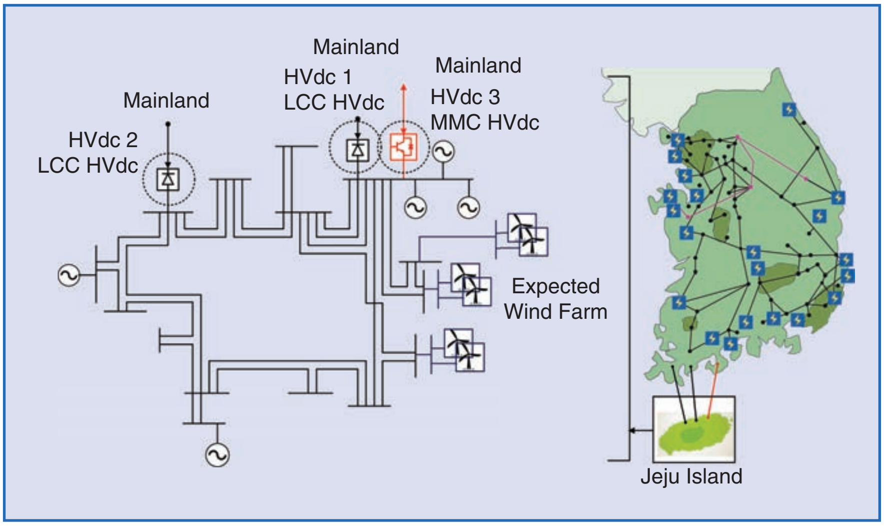

figure 5. A simplified power system representation of Jeju Island.

Feasibility Studies for Jeju HVdc Number 3

Since 2010, KEPCO has conducted numerous feasibility studies for Jeju HVdc number 3. KEPCO first needs to determine the type of HVdc (LCC or MMC). Regarding power-reversal capability, MMC-HVdc is more flexible than LCC-HVdc and has less negative influence on the operation and reliability of the Jeju power system. The feasibility studies address key issues that include active power reserve, reactive power compensation, Escr, multi-infeed Escr, effective inertial constant, hosting capacity of renewables, and TSA. In particular, LCC-HVdc requires must-run synchronous generator operation to maintain a suitable short circuit availability, and this constraint reduces the hosting capacity for the renewables. An EMT study determined the power reversal procedure and its influence on the Jeju power system. Although MMC-HVdc would not need any additional controls, LCC-HVdc requires many steps to reverse the power transfer. Application of LCC-HVdc requires the use of a mass-impregnated dc cable and a converter transformer with high insulation levels to cope with the dc voltage polarity change during the LCC-HVdc power reversal.

An economic feasibility study was conducted. When HVdc number 3 is installed, and the penetration of the renewable energy source increases on Jeju, the island's system marginal price (SMP) can be significantly reduced; the SMP with the addition of the MMC-HVdc would be lower than that with the addition of an LCC-HVdc tie. This means that KEPCO can reduce the cost of purchasing power with the addition of the MMC-HVdc for HVdc number 3. However, the MMC converter station costs are higher than those for LCC. Therefore, KEPCO determined the type of HVdc based on the results of the economic and technical feasibility studies, and MMC-HVdc was chosen for HVdc number 3 because of the flexible power transfer capability.

Technical Challenges for the Jeju Power System

The future Jeju power system, which includes a high penetration of renewable energy sources, will encounter many technical challenges with multi-infeed (multiple HVdc system installations) and hybrid-infeed (different types of HVdc converter stations) HVdc systems located electrically close to each other in an area with low scr and inertia. The massive penetration of wind power generation could threaten the stability performance of the Jeju power system. The two LCC-HVdc systems require reactive power compensation for power transfer. Overvoltage conditions may occur during ramp-down and recovery operations. Transient voltage depression may also occur because of the simultaneous

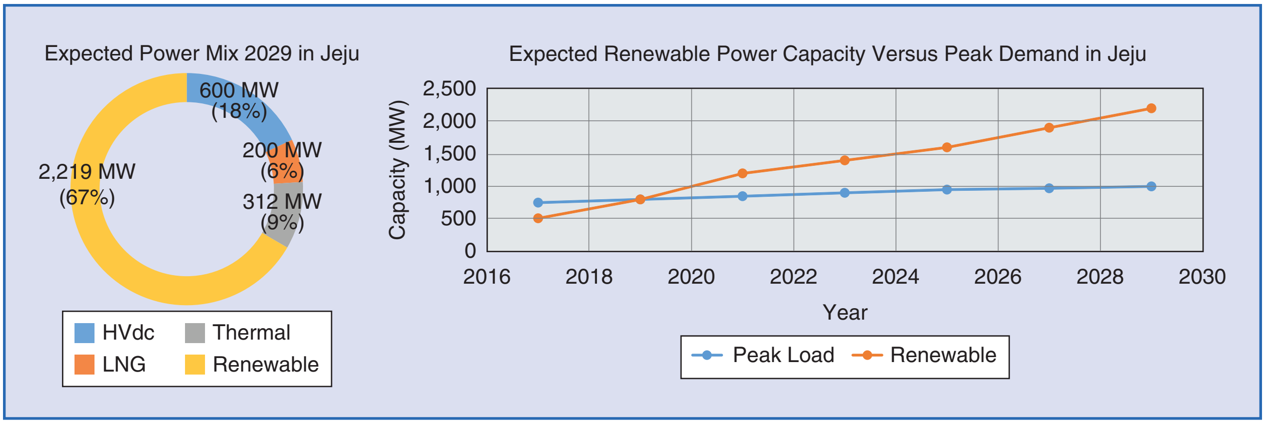

figure 6. Future capacity (nameplate) on the Jeju Island power system. LNG: liquefied natural gas.

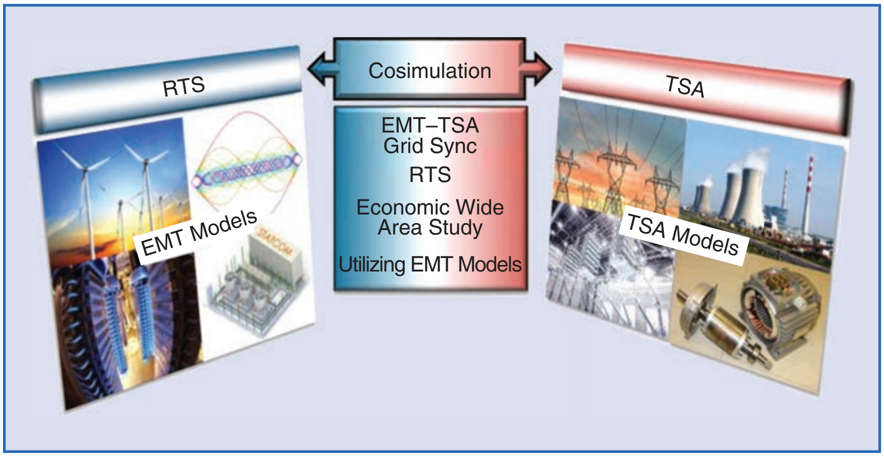

figure 7. The concept of the HS.

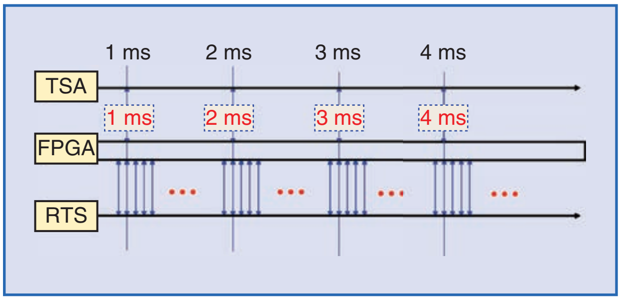

figure 8. The clock synchronization for matching TSA tool simulation in real time with the RTS.

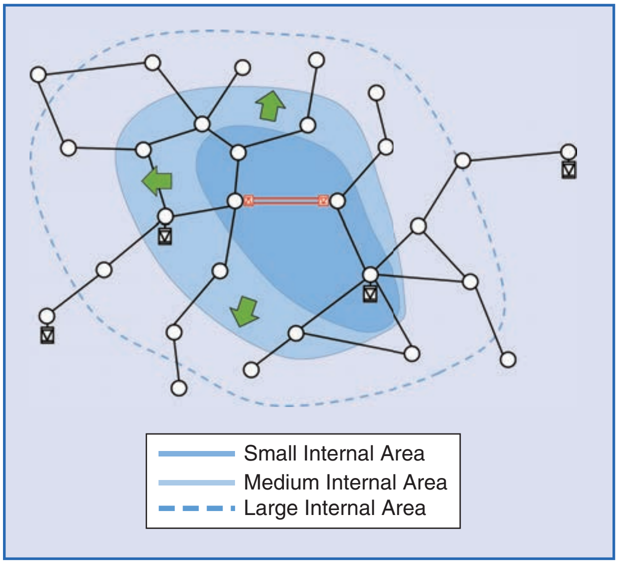

figure 9. The boundary selection for dividing internal and external areas for accurate simulation.

recovery of the HVdc after an ac fault, a dc fault, or a commutation failure. Although the synchronous generators in Jeju provide ac voltage regulation, the number of must-run synchronous generators needs to be reduced to increase the penetration level of renewables. Research on HVdc role allocation and coordination control is also needed. In this complex operating situation, a feasibility study with hybrid simulation proved useful for KEPCO planners.

Development of Hybrid Simulator Tool

To overcome the aforementioned technical issues and achieve more accurate simulation results, KEPCO, Powertech Labs, and Yonsei University jointly developed a hybrid simulator (HS). This platform synthesizes TSA with the RTS to perform cosimulation studies, as shown in Figure 7. This approach of interleaving either offline or real-time EMT simulation with TSA has been explored by researchers in several countries in the past several decades to help engineers simulate much larger systems while reducing the cost, effort, and time needed to set up and run the system. Additionally, the engineer can analyze the aspects of system dynamic behavior that were possibly missed in a pure EMT or TSA study. The value of such simulation has been acknowledged by some entities, and these studies have successfully produced a meaningful outcome to realize the idea of cosimulation.

Fast and Efficient Simulation

The RTS uses a powerful computing processor. It performs transient simulations with inputs and outputs to external hardware in real time and can communicate in nanoseconds using fiber-optic communication. The TSA tool allows for fast and accurate computation for large power systems using a fast computation algorithm, and the tool offers a user-friendly interface with the RTS. The HS can conduct RTS by TSA and RTS interleaving buffer memory of a field-programmable gate array (FPGA). As shown in Figure 8, TSA and RTS access FPGAs at every time step to interchange solutions because the correct timing and synchronization of data exchange between the TSA and RTS platform are critically important in HS.

Convenient Simulation

A system-wide impact analysis is needed for planning the HVdc system. However, this would involve large hardware requirements to meet the computation needs using only RTS. The HS classifies the area of interest simulated with the RTS as the internal system and the remaining system simulated with the TSA tool as the external system. This process significantly reduces the time required for modeling each component of the power system on the EMT level because most models used in the TSA tool can be utilized directly. Moreover, it allows a significant reduction in the number of RTS processors required to perform studies.

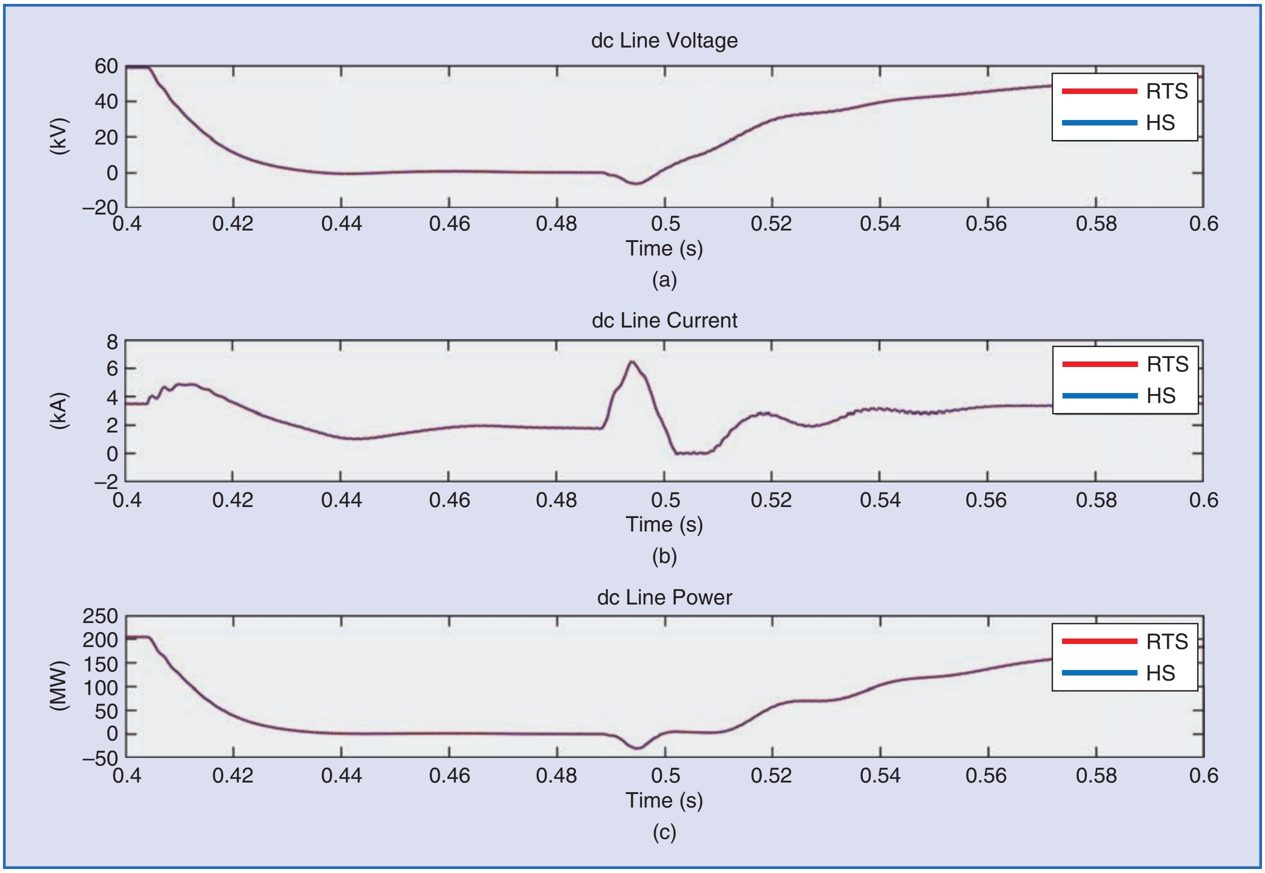

figure 10. A performance comparison between RTS and HS on the IEEE 39 bus with an HVdc system shows very similar results.

Simulation Accuracy

Existing TSA tools have limitations in observing phenomena, such as commutation failures, system imbalances, some types of load dynamics, and the effects of large penetrations of converter-based generators. However, the HS directly enables the analysis of EMT characteristics. Because the EMT tool performs calculations with instantaneous phase values, whereas the TSA tool does so with root mean square–positive sequence values, a method that interfaces these differences is required. Conventionally, approaches such as curve fitting and fast Fourier transforms have been used. However, these methods have raised concerns about the loss of values at the interface and the computations limiting RTS. The project team, therefore, utilized the energy balance method to transfer active and reactive power through the boundary interfaces to interconnect two different tools in real time. Artificial transients or oscillations exist because the TSA uses positive sequence-analysis, which requires engineers to have a sound understanding of the true nature of oscillations in power system dynamics and select appropriate boundaries for the purpose of analysis. The project team observed that the criteria based on electrical distance and voltage sensitivity are useful for identifying the areas vulnerable to artificial transients and determining the adequate interface buses. As shown in Figure 9, increases in the internal area represented by more detailed modeling can be used to increase the accuracy of the overall simulations.

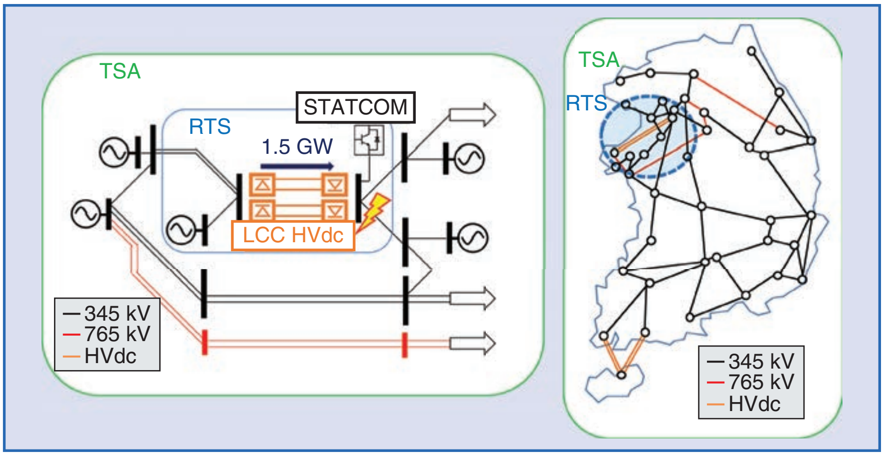

figure 11. A representation of RTS and TSA boundary for performing an inverter-side fault of HVdc to compare the performance between full RTS and the HS.

Current Updates and Future Plans Using the HS

To ensure the validity and applicability of the developed tool, the project team conducted various studies to compare the results of simulation using the HS with those of pure RTS studies. Fundamental functionalities, such as real-time communication and power flow synchronization, of the developed HS have been tested on example test cases, such as the IEEE 39 bus systems, for ensuring a successful connection between the two different tools.

Figure 10 shows the performance of full RTS and the HS on the IEEE 39 bus system modified with an HVdc system. When there is a three-phase fault on the inverter side, both simulators show the same results for dc voltage, current, and HVdc power after a contingency.

Furthermore, the performance of the HS was validated using the manufacturers' data of the HVdc system and the STATCOM that is currently in the middle of commissioning in the western side of the Republic of Korea. On the basis of 2019 Korean power system data, the HVdc and peripheral components, such as generators and STATCOM, are modeled with the RTS, and the rest of the Korean power system is modeled with the TSA tool. The cases for an inverter-side contingency of the HVdc and a peripheral 765-kV double-circuit contingency were established for HS validation, as shown in Figure 11. The simulations compared favorably.

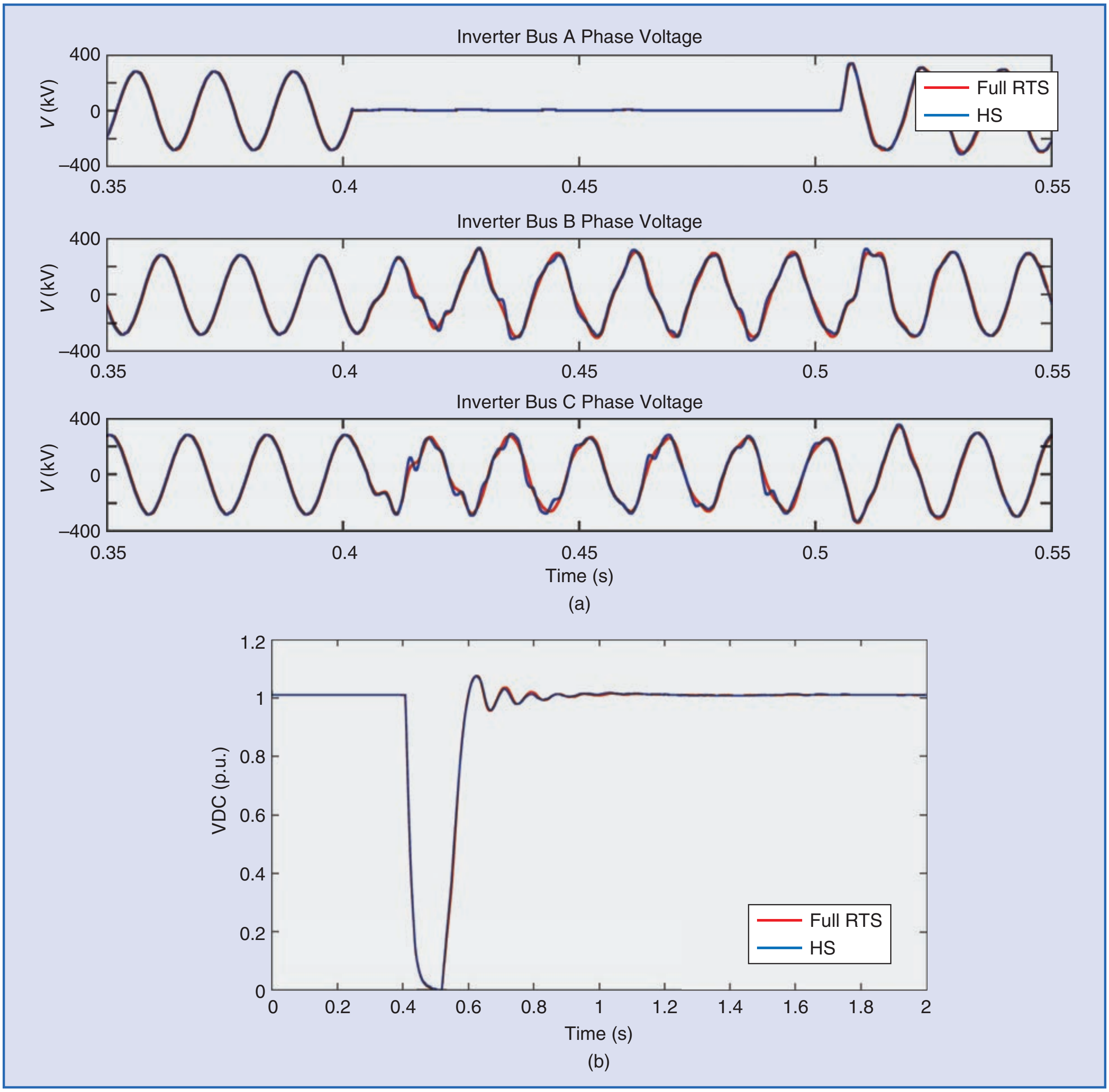

figure 12. The simulation result comparison between the full RTS and the HS under (a) single-phase and (b) three-phase faults on the inverter side of the HVdc. The results are very similar. p.u.: per unit.

Figure 12 shows the results from the full RTS and the HS. The red lines represent the result from RTS, and the blue lines represent the result from the HS. The results show nearly the same outcomes for the single-line and three-phase faults. An appropriate boundary selection allows the HS to perform similarly to an RTS and requires only a small number of processors to configure the entire power system network, including detailed power electronic device models. In addition, the HS significantly shortens the preparation time to configure the simulation case.

The cases for a 765-kV double-circuit contingency near the HVdc and generator tripping were established to compare results between the TSA tool and the HS, as shown in Figure 13. As shown in Figure 14, the results of the TSA of a 765-kV double-circuit contingency near the HVdc with the HS are quite different from those of the TSA tool with the generic HVdc model. Accurate analysis is required to identify both technically and economically feasible mitigation or correction measures to ensure noninterruptible power transfer to the metropolitan area. It is interesting to note that pure TSA studies show that the system is stable with four generators tripped, whereas the results from the HS find that the stable system response occurs by tripping only three generators. The HS incorporates the EMT model of the HVdc and runs with the same TSA model for the remaining network. Therefore, it assists engineers in identifying a cost-effective remedial action scheme for the same contingency. As the network information is updated and the models are refined, the scheme requires more rigorous and continuous investigation based on many other credible scenarios. However, the project team has made an interesting observation and learned an important lesson regarding the importance of modeling and its implications in the analysis and consequent decision making.

The HS is currently being adopted for investigating the MMC-HVdc project in the Jeju power system. The project team is building various planning cases that successfully incorporate the detail dynamics and interaction between the existing two LCC-HVdcs and the expected MMC-HVdc and the expected wind farm. The use of the HS should help grid planners better understand the effects of the emerging equipment, refine the grid requirements, and develop optimal network expansion and operational strategies.

Because the MMC-HVdc will play an important role in the Jeju power system, an analysis will be conducted using the HS to address some technical issues, including low-frequency oscillation, harmonics, and voltage imbalance concerns; HVdc frequency control; dc fault-blocking capability; and HVdc recovery after ac contingency. The efficacy and the accuracy of continuous data exchange between the TSA tool and RTS in the HS will be continuously examined.

Outlook for Feasibility Study of HVdc Projects in the Republic of Korea

Currently, the Republic of Korea is going through a huge transition in its power system to increase public acceptance of system expansion and address environmental concerns.

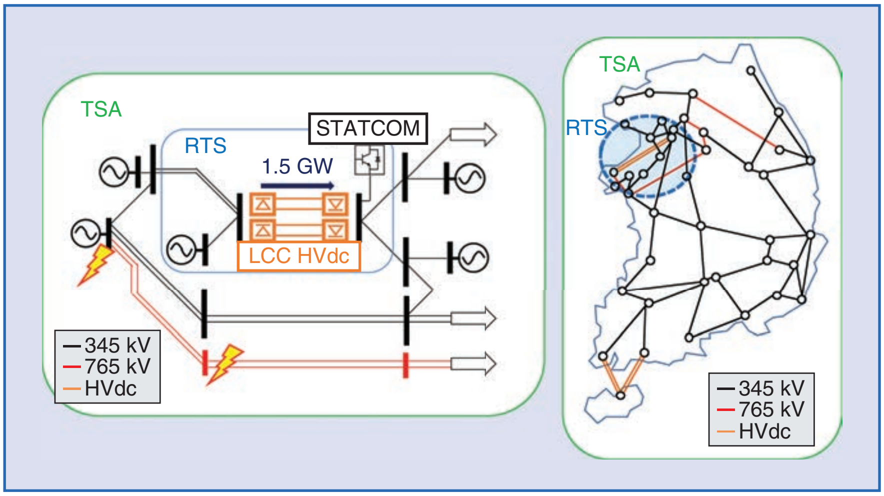

figure 13. A representation of RTS and the TSA boundary for performing 765-kV double-circuit contingency near HVdc to compare performance between full RTS and the HS.

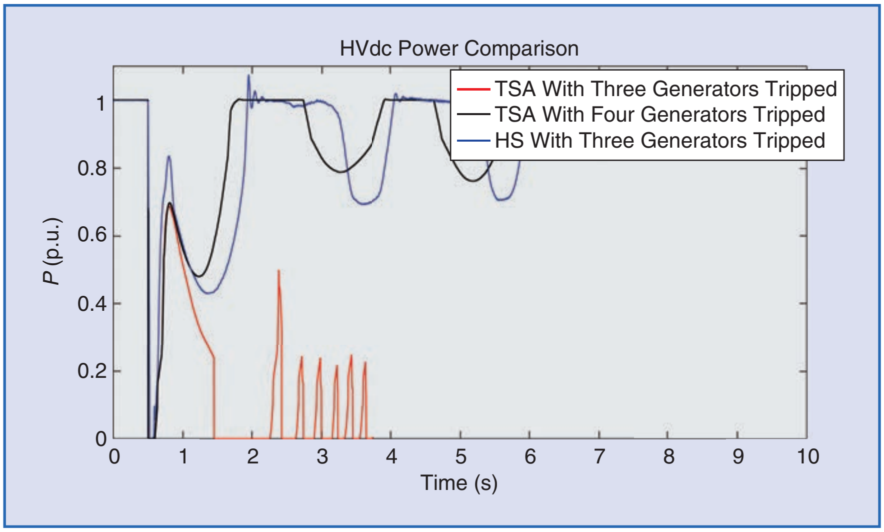

figure 14. The simulation result comparison between the TSA tool and the HS under the 765-kV double-circuit contingency.

Pure TSA studies show that the system is stable with four generators tripped, whereas the results from the HS find that the stable system response occurs by tripping only three generators.

Several HVdc projects are planned to be built in conjunction with numerous FACTSs to reinforce the power transfer capability and reliability, mitigate operational risks in the mainland, and integrate massive renewable energy growth on Jeju Island. In this situation, the planners have to carry out various feasibility studies with several tools and weigh the results of studies against each other, and these studies should be resolved as existing power systems evolve into future power grids where power electronics–based components dominate networks.

The temporary overload performance of HVdc and FACTS should be considered as options to stabilize the power system and prevent cascading blackouts. This study, which was conducted using various tools, provides valuable insights into planning a power system with fast yet sophisticated converters. However, the accuracy of the results is not yet sufficient to make a firm conclusion. The feasibility study of the MMC-HVdc, which connects the mainland and Jeju Island for flexible power transfer, also requires more than just the conventional approach. Because modeling at the TSA level cannot capture the unique and crucial dynamics and features of MMC in harmony with the two existing LCCs, the HS should be useful in complementing the insights provided by the pure TSA-based, system-wide feasibility studies. Advanced modeling with the HS should help grid planners better define the grid requirements of the emerging equipment. Such modeling is also beneficial from the manufacturers' perspective because it provides clear design criteria, which avoids unnecessary conflicts after delivering the equipment to KEPCO planners. The project team will continue making efforts to improve their planning practices for meeting the upcoming changes and challenges of the future power grid and for fully exploiting the opportunities.

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