Large-scale AC/DC EMT Level System Simulations by a Real Time Digital Simulator (RTDS) in KEPRI-KEPCO

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Abstract

Recently, the Korea Enhanced Power system Simulator (KEPS) was upgraded with new processor cards and various peripheral devices. The purpose of the upgrade is for the large-scale AC/DC simulation studies for different purposes such as FACTS, PMU applications, and SPS. The need for such study is now growing in KEPCO network. Frequently, traditional ways of performing the necessary study had been found to be less adequate for guiding the key decisions in the company. Therefore, the growing needs, as well as the revealed inadequacy of the traditional system studies, had been attributing to the momentum for the upgrade project. This paper explains the details of the upgrade project. As an example of presenting the effectiveness of the upgraded RTDS system in KEPRI-KEPCO, a large-scale AC/DC real time simulation case which includes the entire Korean network and a planned MMC-HVDC system is introduced.

Keywords: HVDC, EMT, RTDS, PMU, KEPS

I. INTRODUCTION

More emphasis is now being brought to the special technology such as HVDC [1]-[4] and STATCOM [5]-[10] systems in the transmission systems. One substantial reason for the growth of the special technology application is the change in the acceptance of the transmission facility by general public. In recent years, such change became more noticeable. One extreme instance showing the very low level of tolerance was the incident KEPCO experienced in Mil-yang 765 kV overhead line construction between the year 2012 and 2015. One consequence of the change in the trend is that the level of difficulty in acquiring the necessary permit for a transmission facility expansion project becomes higher than ever. In many places, such attempt was met with insurmountable objections. Meanwhile, more high capacity generation station complex is now on the horizon. Such expansion in the generation capacity is inevitable because of the constant growth in the load. Also, the geographical constraints in the country enforce the selection of the location of such generation capacity expansion projects into a small number of candidates, many of them are on the existing generation station premises. As a result, such power complex is to be located from the load center which is the population concentration in a great distance. Hence, expansion of the transmission becomes mandatory for almost any generation capacity expansion.

The two factors mentioned hitherto make clear that any transmission expansion project must consider the application of special or new technology. In the utility engineers view, such application would be less preferred than the traditional way of transmission expansion because the risk associated with the new or special technology cannot be assessed with the same level of confidence as the traditional way. One conspicuous example is the EP-HVDC project. Because of the anticipated level of the general public acceptance level for such a large-scale transmission expansion project, the project was decided to be on the combination of underground cable system with a high capacity LCC-HVDC system based transmission system. However, the peculiar requirements arising from the project is asking many unprecedented undertakings by KEPCO.

In order to ensure the successful completion of technologically complex projects such as the EP-HVDC project, many different levels of studies are necessary. One such level is EMT (Electro-Magnetic Transient) level [11]-[14], which allows more detailed view over many different aspects of the intended system. The traditional system study has been based on transient stability analysis (TSA). Its two fundamental assumption is the balanced three phase system in the study subject, and the main focus of the study is to be on the mechanical dynamics of large-capacity three phase synchronous machines which are connected to the transmission system. The result of the second assumption is that the time step of the necessary simulation would be in the range foretold by the system frequency. In the 60 Hz power system, usually the size of the time step is half of the period determined by the system frequency, which is 8.33 ms. The traditional way of system studies can be utilized in many different levels of studies and can offer valuable insights regarding the application of the special technology. However, those above two fundamental assumptions begin to reveal their limitation once the study requirement goes over into a different ground. The first assumption loses its effectiveness when asymmetrical contingencies such as a single phase fault need to be considered. Unfortunately, frequently it was found that such asymmetrical faults can contribute to severe consequences in the application. The second assumption loses its ground once higher switching frequency devices are employed as a vehicle of the special technology application in transmission systems. The usual time step size under the traditional study indicates that the maximum frequency of dynamics is the fundamental frequency of the system, which is

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Table 1. Maximum size of network

Type of hardware	Maximum number of three phase buses per rack	Remark
GPC	22	
PB5	24	
PB5 w/HSBP	30	
PB5 w/HSBP	60	2 processors required.

Fig. 1. RTDS in KEPS lab after 2011 upgrade project.

usually far less than the fastest dynamics expected from the higher switching frequency systems. Thus, it becomes more likely to see that vital part of the system transient response would be missed as long as such low sampling frequency simulation as the traditional study is conducted. Therefore, these compelling reasons necessitate that the application of the proper level of study method, an EMT level study in such cases.

The apparently easier choice when it comes to select the necessary simulation tool at the level is off-line simulation tools. PSCAD [15]-[19] would be a representative of such choice. However, two new factors come with the new level of study if an easier selection is made. The one is the necessary simulation time taken when a study is performed for a large scale AC/DC transmission network. The amount of simulation time grows in hand in hand with the size of the study subject. In the case of KEPCO transmission network, the number of buses would be more than thousands. Moreover, the network comes with numerous power system apparatus, such as synchronous generators, transformers and transmission lines. Frequently, the resulting simulation case becomes hugh; the necessary simulation time becomes prohibitedly long, if not practically impossible. The second factors from the more practical side of the requirement of the necessary study for the special technology applications. On the ground of the utility company's own benefit, it is desirable to see the model representing a device in a transmission system is complete. The completeness means that the model would reveal every corner of the physical device, leaving nothing in doubt. However, such modeling is practically impossible. Moreover, frequently the interest of the utility company becomes tangential against the interest of the device vendor. While the utility company desires to acquire the all the necessary information regarding the modeling of a device supplied by a vendor, some part of such information would be regarded as a trade secret, belongs to the supplier as proprietary knowledge. Hence, the supplier is either unwilling to or hesitating when it comes to the point of facing such request. The output from such simulation would be at the exactly same level as the quality of the input data. In other words, it goes with the famous saying that 'Garbage in, Garbage out'. Therefore, the simulation output would become unable to address its original purpose unless the detailed and enough information is put into the off-line simulation case.

The two factors associated with the off-line simulation tools such as PSCAD point that the highest level of simulation output quality would be coming from a real-time EMT level study tool, such as RTDS [20]-[23]. Therefore, KEPRI-KEPCO made the decision regarding the establishment of the KEPS simulation lab close to 20 years ago. Since then, the lab has been successfully serving various study needs throughout KEPCO.

II. OVERVIEW OF THE RTDS UPGRADE PROJECT

Two major upgrade projects preceded by the project described in this paper. The first one was in the year 2006. The purpose of the project was to increase the size of the network by adding a GPC card per a rack. The total number of racks in the installation was 26. Therefore total 26 GPC cards were added onto the existing RTDS hardware. The second major upgrade project was completed in 2011. The purpose of the second upgrade project was similar to the first one, increasing the size of the network in real time simulations by adding more processing power. During the second project, total 72 GPC cards were installed. With the pre-existing GPC cards in the installation before the upgrade project, the new total number of GPC cards became 100. The first 22 racks among 26 racks were equipped with 4 GPC cards, while the last four racks were equipped with 3 GPC cards. In addition to the installation of the new GPC cards to the system for the purpose of the processing power increase, the backplane of each rack in the installation (total 26) were replaced with a newer and faster backplane named 'HIGH-SPEED BACK PLANE (HSBP)'. By introduction of the HSBP into the simulation hardware the data transfer between the processors through the backplane became faster, resulting in shorter simulation time step size. During the operation of the large-scale RTDS installation, it was found that the usual bottleneck arising from the large-scale AC network simulation is the number of data transfers and the amount of transfer time necessary to finish all the necessary data transfer. The backplane upgrade contributed to the alleviation of such issues. At the same time, the backplane upgrade opened the new possibility of utilizing faster processing hardware. The HSBP was designed with the second point in mind, which is the higher power consumption by a newer and more powerful, but more power demanding simulation processing hardware. Fig. 1 shows the RTDS system at the lab at the completion of the upgrade.

One lingering issue associated with the AC transmission system representation in RTDS at KEPS lab was the hardware requirement. After the two major upgrade of the system, still the issue came in the middle of the ways in many applications which required the full representation of KEPCO transmission network above 154 kV voltage level. The very rigorous restriction of the real time characteristic of the simulation in RTDS requires that the size of the simulation hardware needs to grow as the larger extent of the AC transmission is to be represented in a simulation case. Even with the scale of hardware installation at KEPS lab, cutting the entire KEPCO transmission network into a smaller portion which would fit with the given size of hardware was

Table 2. Total load unit of transmission lines

Type of transmission line	Amount	Load units
1 circuit	519	5190
2 circuits	723	21690
3 circuits	17	680
4 circuits	2	120
Total load units		27680

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"2015 YEAR  100 % LOAD (80416MW) CASE ,,,,,",,,,,,,,,,,,,
2015 KEPCO POWER SYSTEM PLANNING DATA,,,,,,,,,,,,,,,,,,,,,,

            BUSES        PLANTS      MACHINES  WIND MACHINES  MACHINE OWNERS
TOTAL        2228           407           412              0             412
MAXIMUM     50000         10000         12000            880           24000

              S H U N T S                         INDUCTION
            FIXED      SWITCHED         LOADS      MACHINES
TOTAL           0           559          1350              0
MAXIMUM     50000          4000        100000            240

                     T R A N S F O R M E R S
         BRANCHES   TWO-WINDING THREE-WINDING ZERO IMPEDANCE  BRANCH OWNERS        MUTUALS
TOTAL        3732          1266           308            296           3732              0
MAXIMUM    100000         20000          5000          25000         200000           6000

             MULTI-SECTION LINE
        GROUPINGS      SECTIONS         AREAS          ZONES         OWNERS      TRANSFERS
TOTAL           0             0            26            109              9              0
MAXIMUM      1600          4000          1200           9999           1200           2000


       2-TERM. DC    N-TERM. DC        VSC DC  FACTS DEVICES    GNE DEVICES
TOTAL           0             0             0              5              0
MAXIMUM       100            20            40            250             40

                                         SWITCHING DEVICES
      SUBSTATIONS         NODES IN SUBSTATION          TOTAL
TOTAL           0             0             0              0
MAXIMUM     12500         50000        100000         100000
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Fig. 2. KEPCO transmission system statistics.

inevitable. This issue has been known for a long time. During the time, many different approaches were attempted for the purpose of representing the larger section of KEPCO's transmission network in RTDS. Once such approach was network equivalent, but it came up with only limited amount of success. Moreover, the complexity associated with the necessary steps for such procedure, network equivalencing, was less preferred by the RTDS operating engineers at the lab. Always the first choice had been in the way that the entire network would be put on the RTDS at once, with no further hassle of manipulating the network. The size of network an RTDS rack can simulate in real-time is dependent upon the type of the processing hardware it employs. Table 1 shows the details.

With the new simulation hardware and power powerful processors, the possibility of executing the entire KEPCO transmission network began to dawn on the engineers at both sides, KEPRI-KEPCO and RTDS Technologies Inc. In the year 2015, after a long series of discussion, the engineers at KEPRI-KEPCO decided to upgrade the large-scale RTDS in KEPS lab. Many different transmission networks and contingency scenarios went through profound and exhaustive investigations were performed bu KEPRI engineers at KEPS lab. The size of the potential upgrade project might become substantial and the corresponding amount of the project budget compelled those engineers to make better and more thorough review upon every possible candidate ideas regarding the upgrade project. As mentioned, one strong driving force behind the upgrade project was the possibility of executing entire KEPCO transmission network simulation in real time with no artificial manipulation of the network data. Here is one of the candidate KEPCO transmission system which was considered during that stage of the project. The system represents a certain operating point (~80 GW load level) during the year 2015. Fig. 2 shows the case statistics from PSS/e software.

A simple calculation would produce the conclusion that 38 RTDS racks would be able to accommodate the transmission system into a real-time simulation case. However, the total

Table 3. The amount of major hardware components in the upgrade project scope

Type of hardware	Amount	Remarks
Rack	34	26 existing + 8 new
GTWIF	7	
PB5 card	194	
GTNETx2	17	
GTAO	5	
GTAI	4	
GTDO	5	
GTDI	3	
GTSYNC	1	

number of buses appeared in Fig. 2 also includes many buses to be eliminated when an equivalent RTDS simulation case is constructed. The generator buses, the bus between the machine and the step up transformer, would be included as a part of the generator models themselves. Thus, that number, the same number as the total number of generators, must be eliminated from the total. As well, there are many bus separators, which were added to the real system in order to reduce the level of fault current. In usual EMT level studies, such bus separators are unnecessary. Therefore the buses representing the bus separators must be deducted from the total bus number as well. After eliminating those buses to be removed. The total number of buses to be included in the real-time simulation case was found to be 1306. If that number was the only factors to be considered when it comes to deciding the scope of the RTDS project, the total number of 22 racks would have been enough. However, that was only the starting point. Another major restriction regarding the simulation hardware was the maximum amount of real time calculation a single rack can perform. The number is represented by a concept of load unit in RTDS. A three-phase synchronous machine takes 20 load units. A simple three phase two winding transformer takes 10 load units. Meanwhile, a single processing unit (a processor) can hold up to 120 load units. Each processing card in a rack is equipped with 2 such processing units. Each rack can take up to 6 of such processing cards. Therefore, another simply calculation would yield that a sigle rack can hold up to 1,080 load units. Therefore, the next factor to be considered was to check the intended upgrade scope would be able to accommodate all the necessary load units. During the investigation, it was found that largest amount of load unit would be consumed by transmission line models. Table 2 shows the total amount of transmission line lad units which was considered during the stage:

If all the available load units from those rack participating the real time simulation is allocated for the transmission line load, total 26 racks would be enough. However, that scope is still missing the rest of load units expected from different power system equipment, such as transformers and three phase synchronous machines. Therefore, conducting such investigation was found to be more strenuous than anticipated at the earlier stage of the scope estimate. However, the effort carried on. The similar investigation continued over many different candidate transmission systems. The results from those investigation regarding proper size of RTDS began to converge into a conclusion. Table 3 presents the amount of major components in the final scope of the upgraded project.

Another important requirement to be fulfilled by the RTDS upgrade project is the preparation for the HILS (Hardware In Loop) testing with the replica controls from future HVDC projects and other special technology applications. As the first of such endeavor, KEPCO decided to purchase one set of replica

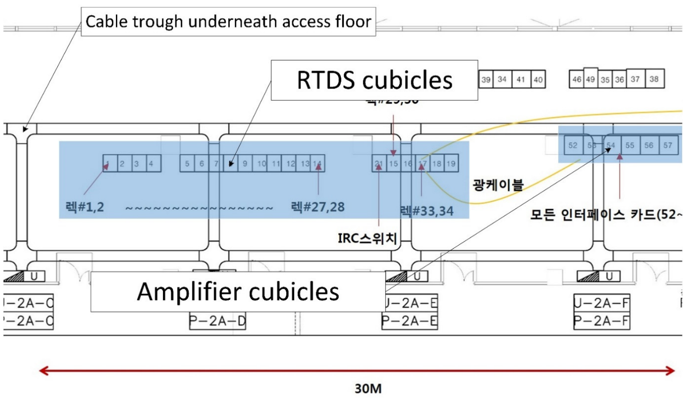

Fig. 3. New KEPS lab layout.

Fig. 4. Interface amplifier cubicles.

control for an HVDC project. The project is regarding the construction of HVDC link between Danjin generation complex at the west coast of the country and Godeuk substation which is in charge of supplying power to a new industrial complex. The replica control is expected to be functionally identical to the real control which will be installed in the real system. It will be brought in the KEPS lab. Then, it will be interconnected with the upgraded RTDS in a way very close to that of a real control system. Then, the combination between the upgraded RTDS system and the controller would be able to provide simulation results which would carry more authenticity than the simulation results only from software models. Furthermore, such setting would be able to check the control hardware to make sure that the part of hardware can be freely exchangeable between the real system and the replica system. The same idea would extend a new control algorithm. If a certain enhancement regarding the control algorithm to be applied, such algorithm can be evaluated first at the lab with the setting before being applied to the real system. In order to facilitate the necessary preparation, 12 sets of voltage/current amplifiers (from a manufacturer named Doble) were included in the scope of the upgrade project as well. Those amplifiers are expected to the same level of voltage and current signals as required by external replica controllers. Those amplifiers are to be housed in their cubicles, raising the level of security and safety. The cubicles would also provide the necessary connection points in the formality of connection blocks and the RTDS I/O cards for the purpose of simplifying the necessary work to be done once the replica control hardware is brought in the lab and connected with the amplifiers and RTDS. In order to ensure the enough space is reserved for the replica control, the lab layout was totally revamped. Fig. 3. presents the new layout of the lab.

Fig. 4, shows the amplifier cubicle prepared for the external

Fig. 5. Upgraded RTDS in KEPS lab.

hardware interconnection such as between RTDS and a replica control of an HVDC system.

Because of the extensiveness of the upgrade project, the installation of the new hardware and refurbishment of the existing facility at the lab was conducted in two stages. The first stage, which was mainly regarding the processor card replacement was completed in August 2016. Then, the second stage was completed in October 2016. During the installation works, many different large scale AC and DC simulation cases were constructed and tried with the new hardware. One purpose of such attempt was to make sure that all the hardware change and addition would work in an expected way. As well, during such testing and evaluation, it was verified that the upgraded RTDS at the KEPS lab became able to run the entire KEPCO transmission network with no artificial manipulation such as network equivalencing. At the same time, many enhancement introduced into the user interface software of RTDS, RSCAD, enabled easier and more convenient process in regards to converting a substantial size AC simulation data into an RTDS simulation case. One such enhancement is the inclusion of three phase three winding transformer handling capability in the conversion program. The conversion program can read PSS/e input file(s) such as a RAW file. Then, it translates the input into an RTDS simulation case. Before the enhancement regarding the three phase three winding transformer was introduced in it, every such equipment in the system was converted incorrectly. Therefore, the simulation engineer at the lab had to manually modify such errors. If the number of such equipment in the simulation case is small, then probably the time and effort necessary for such change might have been negligible. However, if the number is large, which is the case with many of the KEPCO transmission network data, then the attempt to change becomes time-consuming. Besides, always such change by hand is prone to introducing unwanted human error. In parallel with the RTDS hardware upgrade, the software development work has been conducted by the KEPS simulation engineers to make the large-scale simulation case preparation more accurate and less time consuming. Frequently, the PSS/e input data which is supposed to become an RTDS simulation case has certain peculiarities. One such odd point which needs to be addressed is the multiple step-up transformers connected to a single generator. Most of the times, those step up transformers can be reduced into a single unit. Such reduction can contribute the better utilization of the simulation hardware. Another instance of the peculiarity is the dummy buses. From time to time, dummy buses are added to a PSS/e network data for the sake of convenience in the simulation result analysis. Such buses need to be eliminated in order to make the RTDS simulation case more compact. The software developed in KEPS lab is expected to handle those undesirable points in the input data. Then, the result of the further processing of the input data by the software is expected to achieve better utilization of the simulation hardware as well as more accurate simulation results. Fig. 5 shows the upgraded RTDS in the KEPS lab.

III. CONCLUSION

A comprehensive and substantial upgrade of the large scale RTDS system in KEPS lab was successfully completed in the year 2016. Many testing and evaluation conducted with the upgraded simulation hardware during the project confirmed that KEPCO transmission network system could be simulated and analyzed in real time with no extra manipulation of the network data. The capability would offer the necessary foundation for more complex studies expected from the wider application of high power power electronics applications. One such concern is the deployment of LCC-HVDC systems in KEPCO network. The upgraded RTDS system is expected to make the due contributions to the various technical issues around the company, including those HVDC systems either already under construction or in planning stage.

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