Identification of Acceptable Restoration Strategies

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Abstract

In recent years, we have seen several catastrophic & cascading failures of power systems throughout the world. Power system breakup and blackouts are rare events. However, when they occur, the effects on utilities & general population can be quite severe. To prevent or reduce cascading sequences of events caused by the various reasons, KEPRI is researching ways to revolutionize innovative strategies that will significantly reduce the vulnerability of the power system and will ensure successful restoration of service to customers. This paper describes a restoration guidelines / recommendations for the KEPS simulator, which allows power system operator and planner to simulate and plan restoration events in an interactive mode. The KEPS simulator provides a list of restoration events according to the priority based on some restoration rules and list of priority loads. Further, the paper will draw on research using information from a Jeju case study.

Keywords

Restoration, Blackouts, Cascading Failures, Real-Time Digital Simulator, Decision Support Tool

1. INTRODUCTION

It is clear that the power systems of today are not what they were before open access and deregulation were introduced in many countries. Over the past few years, we have seen several catastrophic failures of power systems. Moreover, we are witnessing unusual generation and power flow patterns, unplanned congestion, and the introduction of renewable (wind, photovoltaic, fuel cell, etc) generation with its associated uncertainties. A major blackout in power system is usually caused by a consequence of cascading contingencies. The usual scenario of such events is that the power system is in a stressed state, followed by faults on critical facilities, followed by unanticipated tripping of other facilities, finally leading to system blackouts. System restoration following a blackout is one of the most important tasks of the operators. However, few computer tools have been developed and implemented for the real-time operational environment. Indeed, most power systems rely on non real-time restoration plans that are developed for selected scenarios of contingencies, and equipment outages. All power system operators strive to operate their systems with a high degree of reliability. In view of this, operators need to be aware of the situation & adapt to the changing system conditions during system restoration. Most operating companies maintain restoration plans based on their restoration objectives, operating philosophies and practices with the characteristics of their power plant restart capabilities and power system reintegration peculiarities. While these plans have successfully restored power systems in the past, they can be improved significantly by simulating transient and dynamic behavior of the power system under various restoration operating conditions and by real-time digital simulator reflecting many factors not readily modeled. It is therefore necessary to identify a general procedure or guidelines, and the available black start capabilities / the optimal sequence of switching and must be tested by real-time simulation to enhance rapid restoration.

2. REAL TIME DIGITAL SIMULATOR(KEPS) & DATA CONVERSION S/W

2.1 KEPCO's Enhanced Power system Simulator

The KEPS is a parallel processing based power system simulator capable of continuous real-time simulation of both power systems and control systems. The power system network is modeled using the well known Dommel algorithm first incorporated into the EMTP. The availability of a substantial number of both analogue and digital input/output ports on the KEPS, coupled with operation in real-time permits interconnection of physical control and protection equipment to the simulation. It is thus possible for the user to study the performance of the external control and protection equipment under test in a closed loop manner. If the user does not have access to the physical control and protection equipment, that equipment can be modeled using the KEPS. This KEPS unit represents the world's largest and most advanced real-time digital simulator. It consists of 26 racks of modified RTDS hardware, each containing 1 GPC, 13 Triple Process Cards, 1 Workstation Interface Card, 1

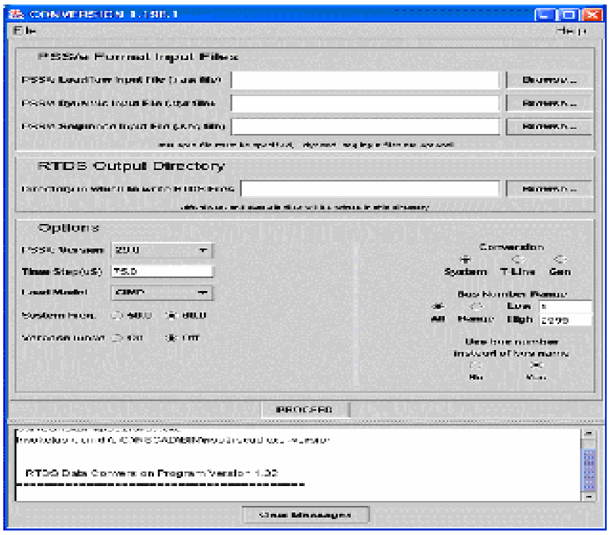
Dual Inter Rack Communication Card and various auxiliary components. In addition, many significant enhancements and improvements were made to KEPS hardware and software. A number of application software developments were undertaken and many are also part of on-going projects. Data Conversion S/W converts existing PSS/E files to KEPS/Draft file including initial system conditions. System Reduction S/W, evaluate existing and create custom techniques used to reduce large systems, but maintain system dynamics. 3-Dimensional Visualization S/W helps display results from large simulations. It is also expected that KEPS facility will serve as a training and education tool for KEPCO/KEPRI engineers and operators.

Fig.1 An overview of KEPS Simulator

The Data Conversion Software has been developed by KEPRI, LS & RTI engineers to facilitate the set-up and data specification for KEPS simulation cases. Another words, the data conversion software automatically converts existing PSS/E data–files of a particular format to the KEPS Graphical Draft file. This automatic data conversion process results in fewer human errors. The software is reliable and allows the parameters that are required as input to the KEPS power system component models and the efficient operation of the KEPS.

2.2 Data Conversion S/W

In general, PSS/E type programs require less detailed data than EMTP programs. Therefore, these would have to be added manually or automatically. The structure of RSCAD Draft is such that the graphical image assembled by the user is converted to a data file before being passed to the RTDS compiler. Hence, there is a possible way to interface at the data level instead of at the Draft level. Currently, KEPRI/KEPCO use PSS/E programs widely and therefore have much of the system data in a format acceptable by PSS/E. With relatively large power systems being a primary focus and an automatic conversion process was desirable, we are now making good use of the PSS/E to RTDS format conversion facility. This feature allows the users to convert systems already available in PSS/E and run them on the RTDS.



PSS/E Version 29.0
Time Step(uS) 75.0
System Freq. ○ 50.0 ● 60.0
Conversion
System T-Line Gen
Bus Number Range
All Range Low High 2299

RTDS Data Conversion Program Version 1.32

Fig.2 Data file conversion s/w

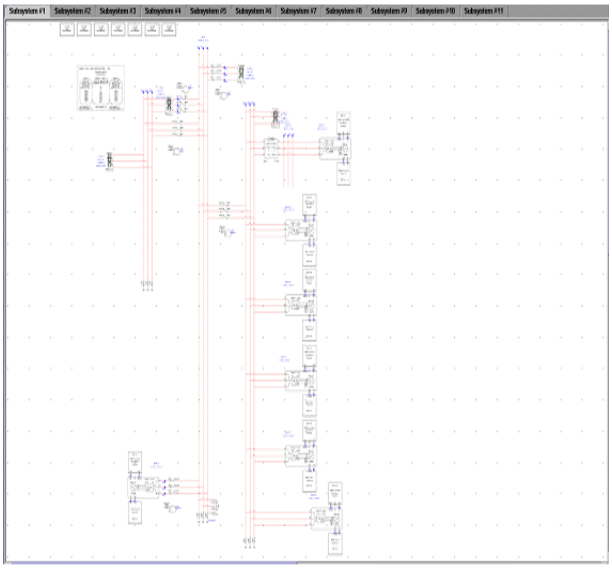


Fig.3 Partial Draft of Jeju system

3. SIMULATION STUDY

3.1 Review of Jeju Power System

While in some severe situations, it is difficult to determine the disturbance source correctly because of the difficulty in collecting reliable information about the disturbance. Experience based methods usually adopted will suffer a great difficulty and sometimes lead to a delay for the restoration process. Therefore, special concerns have been given to the development of system restoration scheme done by electric utilities in advance. IEEE working group also gave a special report about power system restoration. Due to different properties and different requirements for each power system, it is necessary for us to study this problem at individual system and to develop a suitable restoration scheme for each particular system to direct the operations of the system operators accordingly. Jeju power network is isolated from the main land and interconnected by HVDC lines from Haenam S/S to Jeju S/S. This 12-pulse bipolar system normally conveys 150MW, which corresponds to 60% of the total load demand in Jeju island. There are 3 large thermal power plants, 5 diesel power plants and 4 gas turbines in various sizes. Total generating capacity of this network is about 530MW by the end of 2007. Peak load during the summer 2005 was 490MW. Approximately one half of the production is directly connected to 154kV network and controlled by provincial control center, and the other half comprises gas turbines, diesel generators, small thermal plants by area control centers and partly by district control centers. A RTDS model of the Jeju power system corresponding to the actual summer peak of June 2005 (490MW/214MVar) has been developed. Fig.3. consists of 20 buses, 35 branches, 24 transformers and 16 generators. The total power is mainly provided by 3 thermal plants and other diesel & steam/gas turbine plants. A strong 154kV transmission network of 300km superposed to provide the necessary power flows. System loads are modeled as mixed type constant power/constant admittance.

Summary	Original System
# of generators	14
# of buses	29
# of branches	36
# of loads	9
# of transformers	19
Total generation	495
Total load	490

Table 1 Description of original system

3.2 Jeju Area Power System Restoration Plan

The purpose of the Jeju area power system restoration procedure is to provide guidance to the system operator to manage system restoration events that affect the Jeju area and adjoining control areas. KEPCO and KPX utilize an “all-open” switching strategy following a major system failure. The adapted “build-up” strategy entails the main guidelines described in restoration plans, namely, ;

- Assessment of power system status; faulted area isolation if it is known or search for its identification
- Starting as soon as possible of GT generating stations
- Voltage is supplied to the main switching stations
- Units of power stations are synchronized
- Consumers are reconnected to the network

When Jeju system disturbance results in a complete loss or a partial blackout, the plan is split into four steps. The first is relevant to the detection of the blackout status at the different control levels and to the switching sequences to be performed for network preparation by the ACCs. It is of prime importance the role played by, in starting the plan, by disconnecting loads and most of the lines, or stopping it if necessary. At the end of this step, “early restoration plants” must be started up. The objective of the second phase is to quickly constitute a transmission path between black start units and thermal plants in order to recover them into service as soon as possible. The third phase is entirely by the RCCs. The plant operators resynchronize the thermal units to the path and start the load pick-up. The fourth phase is managed by the RCC. As the thermal units have reached their lower capability limit, connection between independent paths is performed. At the end of this phase, the network will have sufficient power and stability to withstand the transients related to further load reconnection and recovery of other generating units. Table 2 below summarizes, at a very high level, the restoration plans of Jeju area.

Type of restoration plan	Primary priority	Secondary priority
In the event of a complete system shutdown the plan defines a specific switching sequence along with general guidelines to restore the system	To start an early restoration plants and to establish a cranking path to provide start up power to all other plants & connect them together.	Restore ac supply to critical loads AC & DC station service for switch-yards, substations, generating station, control centers & interdependent infrastructure

Table 2 A quick reference of area restoration plan

- Black start unit : Unit 3 at the gas turbine power plant of Jeju
- Supply no load branch : Jeju TP Bus
- Circuit Breaker On
- Establish a cranking path
- Provide start up power to early restoration generator, Hanlim GT
- Restore the basic minimum power to generating stations & transmission stations
- Coordinate & direct all transmission connections
- Provide start up power to major generating plants

Similarly, in the event of a partial system shutdown only the applicable guidelines and steps are followed. These plans address the possibility of a complete system blackout by calling for the building of a basic minimum power system from designated key facilities. The ultimate goal of this rebuilding process is to reconnect electrical areas to reestablish a fully interconnected system.

3.3 Typical simulation results

A simulation model of the Jeju power system corresponding to the actual summer of June 2005 has been developed. This restoration test just discussed has been analysed by RTDS. From the whole operative sequence the black start, start-up of early restoration generator, a defined path approach and gradual system reconnection from a complete blackout are here examined in detail, as they collect significant aspects of the restoration process.

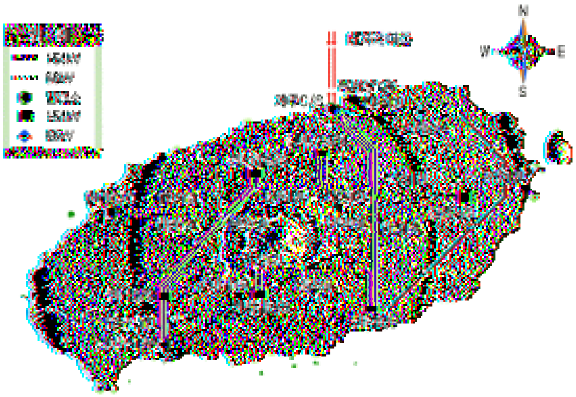


Fig. 4 The Jeju Power System

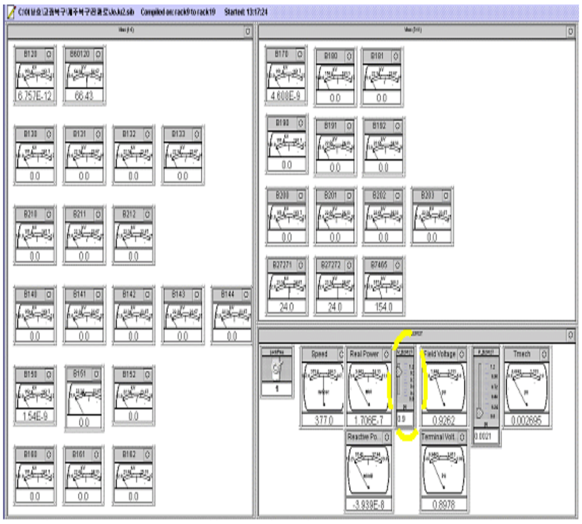


Fig. 5 Terminal voltage for Jeju GT#3

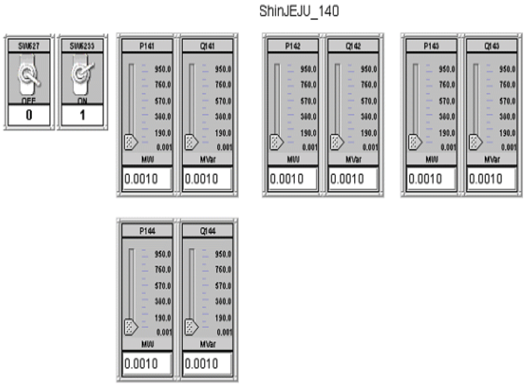


Fig. 6 Sinjeju S/S circuit breaker 6233 ON

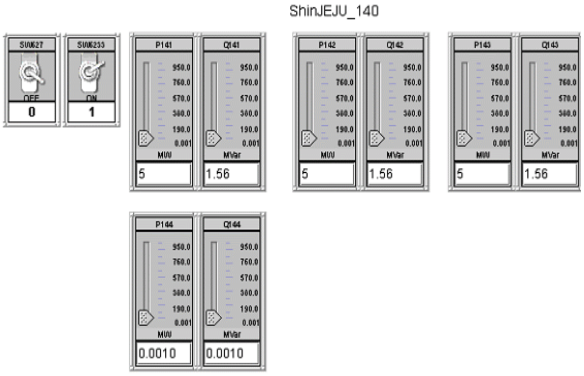


Fig. 7 Sinjeju S/S M.TR #1,#2 reenergized
(5MW, 1.56Mvar)

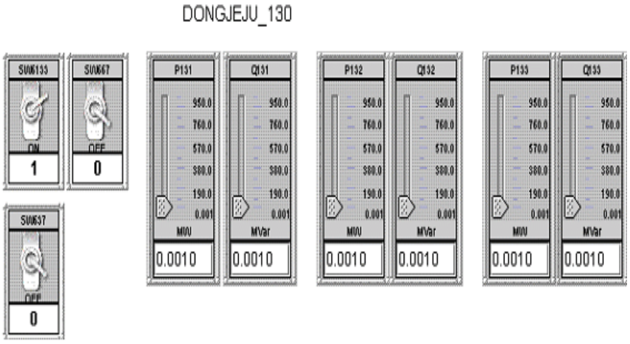


Fig. 8 Dongjeju S/S circuit breaker 6133 ON

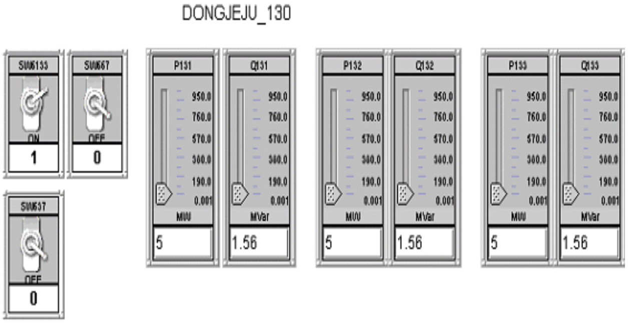


Fig. 9 Dongjeju S/S M.TR #1,#2, #3 (5MW, 1.56Mvar)

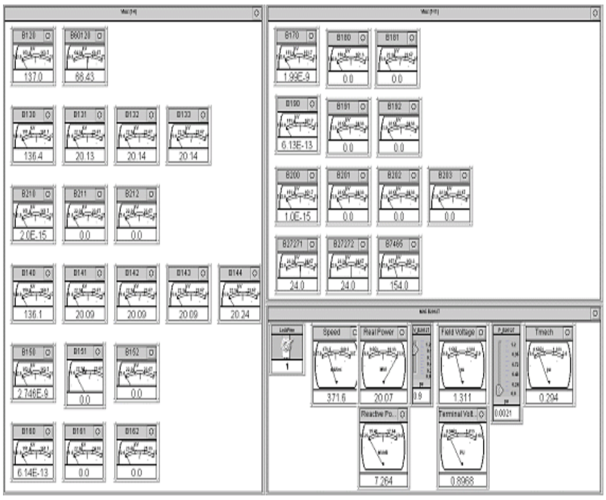


Fig. 10 Terminal voltage for Jeju GT#3

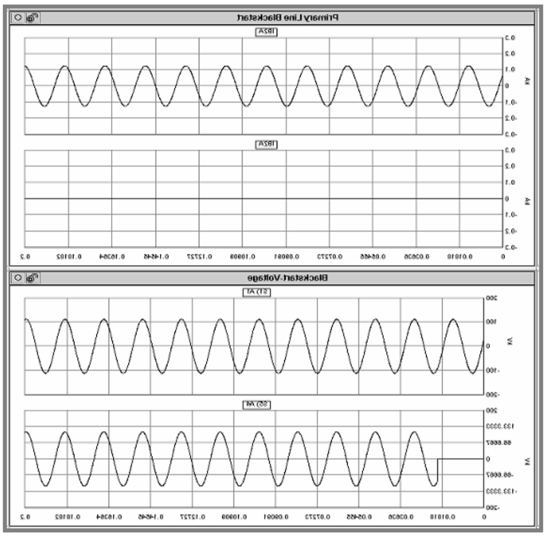


Fig. 11 A phase voltage & current for Jeju TP & Hanlim CC

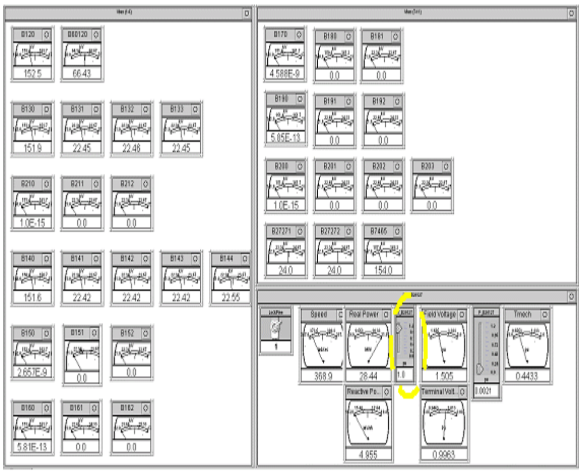


Fig. 12 Raise terminal voltage for Jeju GT#3(0.9 → 1.0pu)

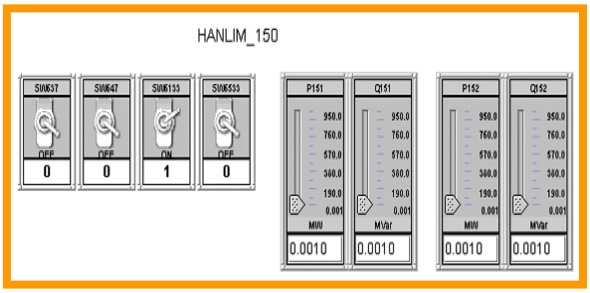


Fig. 13 Hanlim C/C circuit breaker 6133 ON

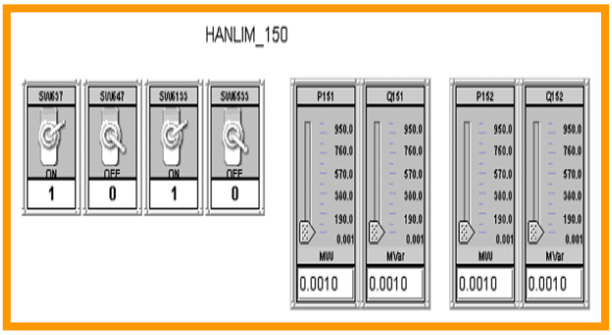


Fig. 14 Hanlim C/C circuit breaker 637 ON

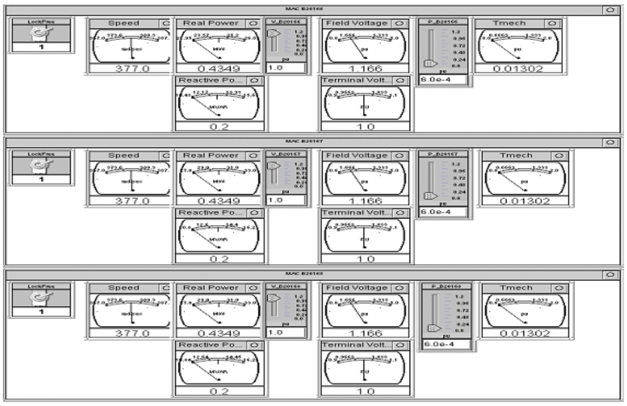


Fig. 15 Synchronize Hanlim units

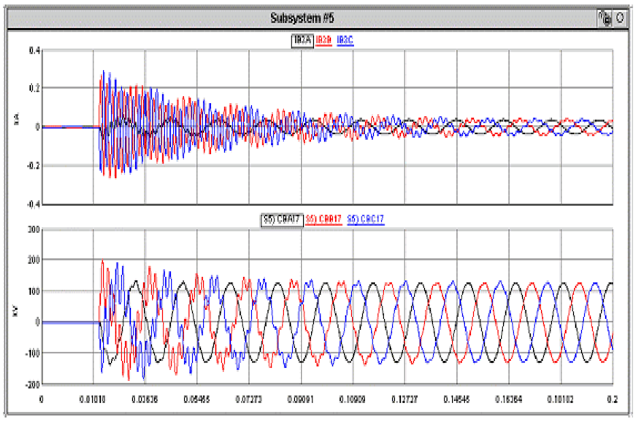


Fig. 16 A phase voltage & current for Hanlim CC

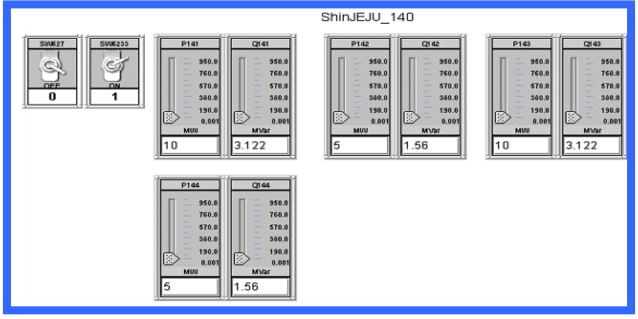


Fig. 17 Sinjeju S/S M.TR #1,#3 (10MW, 3.122Mvar) & M.TR #4 (5MW, 1.56Mvar)

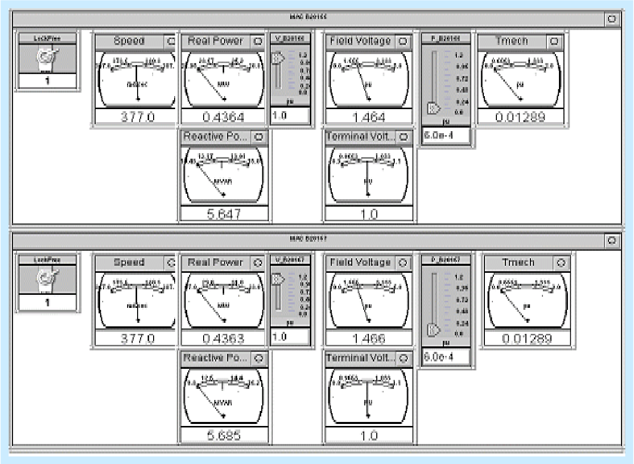


Fig. 18 Hanlim CC output after restoration

4. CONCLUSION

In this paper, the application of real time digital simulator for power system restoration studies is presented. The KEPS is specially adapted to simulate the behavior of a Jeju electric power system experiencing a restoration plan / procedures following a blackout condition. It is shown that KEPS can provide an effective means by which the operator can be trained to deal with real restoration situations in a secure, controllable and real time simulation environment and they can be used for effective restoration planning. All the work done at this stage is preliminary to the new formulation of guidelines for an operator decision and training support system, for KEPS. The overall results obtained appear quite satisfactory. Based on these results, the system could modify the suggested sequence of actions to help arrive at an improved restoration. More advanced indices and guidelines would be certainly needed in order to exploit the simulator as an on-line restoration aid to system operators and dispatchers. With some major system modifications (200MW Namjeju thermal units, wind generators, etc) and minor procedural changes, any problems which might occur can be avoided.

5. BIOGRAPHIES

Seung-Tae Cha has a B.S degree in Electrical Engineering from Illinois Institute of Technology, Chicago in 1992, and a M.S degree in Electrical Engineering from Yonsei University, Korea in 1997. Upon graduation, he joined the Korea Electric Power Research Institute where he was actively engaged in the development of KEPS, a fully digital real-time simulator, other various research projects and instruction of utility personnel in technical & software training courses. He is a senior researcher and his present interest includes real-time simulation of power systems, model development, studies involving load flow, system planning & operation.

Nam-Ho Lee received his B.S and M.S degrees in Electrical Engineering from Myongji University, Korea in 1998 and 2001 respectively. He has been a researcher of LS Industrial Systems Co. Ltd since 2004 where he performed several projects related to Real Time Digital Simulation of power systems. His major research topics include real-time power system simulation , power system modeling and restoration.

Eung-Bo Shim was born in Cheonan, Korea in Feb, 1955. He received his B.S, M.S and Ph.D. degrees in Electrical Engineering from Yonsei University, Korea, in 1978, 1980 and 1990 respectively. From 1991 to 1992, he was a visiting researcher at MIT, USA. He is currently a leader of power quality and reliability areas at Power System Laboratory, KEPRI.

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Soo-Chul Nam received his B.S and M.S degree in Electrical Engineering from Korea University, Korea in 2001 and 2006 respectively. He has extensive experience with transient and dynamic stability. He has performed and directed load flow, short circuit, railroad electrical system, and protective relaying studies. Mr. Nam joined KEPRI’s Power System Analysis Center as a researcher in Feb 2006 where he is developing an integrated optimization scheme for reactive power management system for KEPCO and also participating in several transmission power system studies.

Acknowledgements

The work described in this paper was sponsored by the Ministry of Commerce, Industry & Energy (MOCIE). We express our appreciation for the support provided by MOCIE under grant NF-200 received. I would like to thank all corresponding authors for their kind assistance in the preparation of the paper.

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