A study on the power system restoration simulator

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Abstract: This paper presents an operator training simulator for power system restoration against massive blackouts. The system is designed especially focused on the generality and convenient setting up for initial condition of simulation. The former is accomplished by using power flow calculation methodology, and PSS/E data is used to set up the initial state for easy setting. The proposed simulator consists of three major components - a power flow(PF), a data conversion(CONV), and a GUI module. The PF module calculates power flow, and then checks overvoltages of buses and overloads of lines. The CONV module composes a Y-Bus array and a database at each restoration action. The initial Y-Bus array is composed from PSS/E data. A user friendly GUI module is developed including a graphic editor and a built-in operation manual. The maximum processing time for one step operation is 15 seconds, which is adequate for training purpose. Comparison with PSS/E simulation proves accuracy and reliability of the training system.

Key-Words: operator training, simulator, blackout

1 Introduction

Due to a continued improvement of reliability, total blackouts occur less frequently in a modern power system. But the breakdowns tend to be very large once they occur although the reliability might be good[1-2]. After the massive blackout, power system restoration has been achieved by the operator's expert knowledge and experience. Huge disturbances as well as damages to equipments under the restoration process can be caused if the blackout situation is not properly diagnosed by the operator or if there are some mistakes in the restoration process. Therefore, quick and reliable diagnosis and restoration for the blackout are required. Power systems of radial structure have higher possibility of the massive blackout than meshed structure. Operators in these systems have enough experience to restore blackout power systems. But as the massive blackout has not been occurred yet in Korea because Korean power systems are strongly coupled, so far Korean operators have not faced the total or massive blackout, and opportunities to improve ability handling emergency are decreasing gradually.

Therefore, it is necessary to develop a restoration training simulator which can provide operators effective restoration training opportunity for the total or massive blackout, and aid them to restore the blackout power system quickly and accurately[3-7]. This simulator can improve their ability to cope with the emergency. In general, widely used commercial power system analysis packages are used based on some scenario, so it is hard for the trainees to control the simulator arbitrarily under the simulation process.

In this paper, a restoration training simulator is presented. This system does not operate on the scenario base, but offer the operators discretionary control action starting from the arbitrary initial condition. Each restoration step and its results can be shown in reasonable time. Also, changes of voltage profile can be analyzed when terminal voltages of generators are regulated or reactive power is inserted to buses. Therefore, static based analysis about network’s voltage can be done if a voltage/Var controller is added to this system.

2 Functions of the Restoration System

Lots of data are generally required to set up the initial state of power restoration systems. PSS/E raw data is used as the initial input of this simulator to raise reliability of the training system using accurate input data and to set up the initial state conveniently.

This system consists of the PF module which calculates power flow, and checks overloads and overvoltages, the CONV module which makes Y bus and compiles a DB using PSS/E raw data, and the GUI

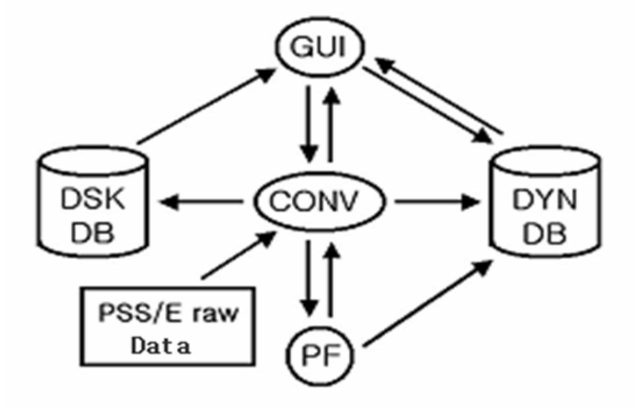

Fig. 1 Configuration of the simulator

module which offers graphic environment to users for convenience. Configuration of the modules are shown in fig. 1. The DB and the GUI display can be modified based on PSS/E data when the power system configuration is changed. As illustrated fig. 1, the system database consists of the DSK DB which is managed in file form and the DYN DB which is managed in memory for fast accessing and writing.

Table 1 Functions of the simulator

Icon	Function explanation
	Open a file in graphic folder(*.kmd)
⇦ ⇨	Change display
	Run simulation
	Load a PSS/E raw file
	Save the present state to *.saf file
	Save the present state to *.cas file
	Load *.saf file
	Load *.cas file
	Undo
✕	Open all the CB(whole blackout)
	Run Mode
	Display system information after power flow calculation
	Set overvoltage level of buses

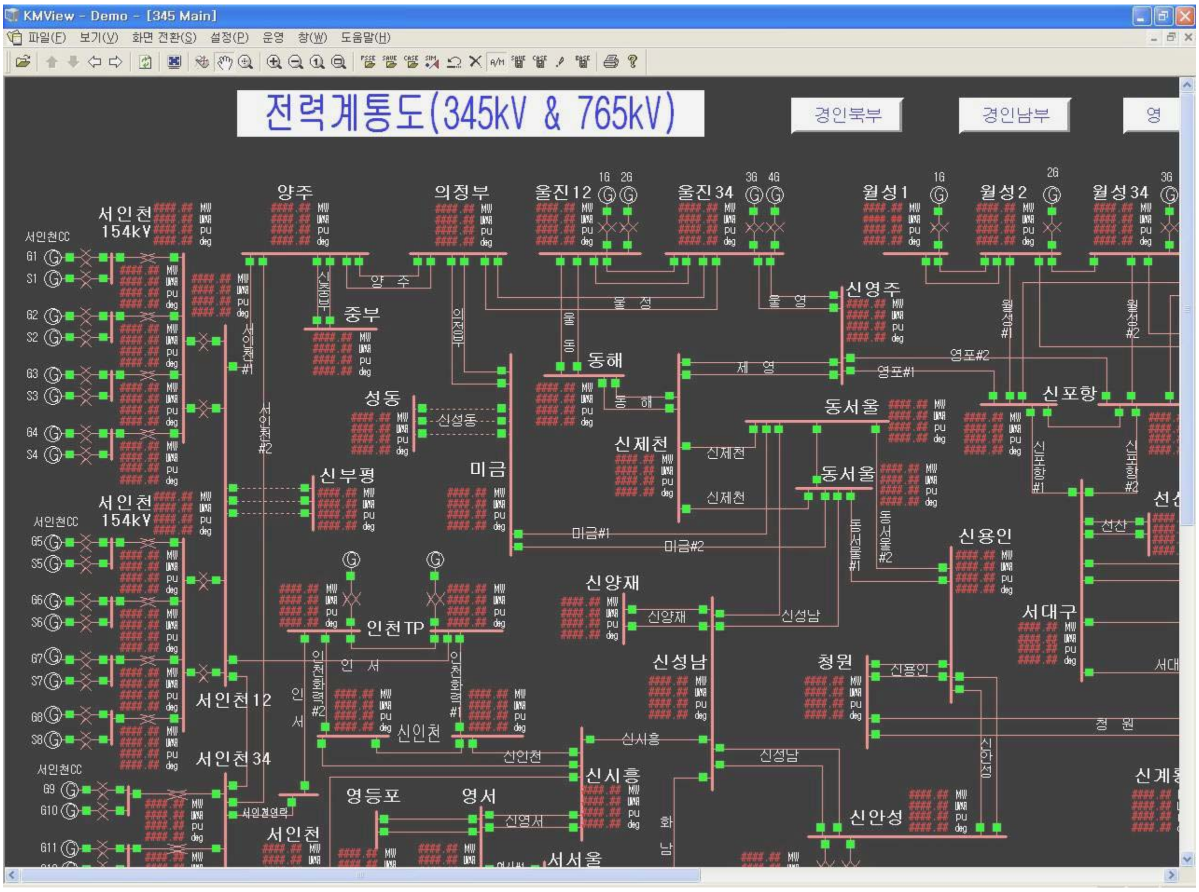

Fig. 2 Initial display of the simulator

Table 2 Advantages and disadvantages depending on restoration methods

	Decentralized	Centralized
Method	▪ Open all CBs in the blackout area	▪ Open CBs which are need for restoration
Advantage	▪ Restore the system simply and securely as CBs only for restoration are closed ▪ Restoration time can be shorten	▪ Less energy for CB tripping than decentralize method
Disadvantage	▪ Lots of energy for CB tripping	▪ Operators should monitor both of restored and dead systems
Object	▪ Greece, Israel, Italy, Korea, USA	▪ None

Three major functions of the training system are as follows. First, Korean 345kV and 765kV networks are shown at a window named KMView as a main display when the simulator starts up at first. These main and PRSs(Primary Restorative Systems) are displayed separately but they are linked with each other. Each display is based on the KMD files which present power systems' graphic information, and share the DB. Displays can be changed as clicking icons. One is the second icon of table 1, and it changes displays sequentially between the main system and PRSs. Other icons are put on top right of the initial display shown in fig. 2, and they present the main system and the PRSs each. Second, visual alarm can be displayed after simulating the results of various CB switching and control action. Overvoltages and overloads can be caused, and line charging capacity can exceed generators' reactive power capability when lines are energized to restore the power system. At this situation, the system can warn the operator using a visual alarm function and a pop-up window. Finally, reconnecting the restored subsystems with each other can be simulated.

Restoration methods are largely two types which are centralized downward and decentralized upward. The former requires lots of time for service restoration, and it is not suitable in case of wide area outage because economic loss and social confusion are increasing over-proportionally with the time of outage, so the latter is commonly adopted[8-11]. Decentralized method is reconnecting the subsystems after restoring them each. Advantage and disadvantage of restoration methods are shown in table 2. Proposed training system can also simulate decentralized method, and reconnecting function can be used as loading *.cas files after saving restored subsystems' information to them.

Fig. 3 Simulation results(overvoltage/overload)

2.1 PF module

The PF module solves power flow based on Y bus which the CONV module makes, and saves the results to the shared DB, so active/reactive power of each bus and overvoltage buses(yellow)/overload lines(purple) can be displayed on the screen. A simulation result is shown in fig. 3. This system is a PRS of Korean power system. The blackstart generator is started up setting the terminal voltage about 1[PU]. Both of an overvoltage and an overload occur, and the overvoltage is caused by Ferranti effect. This situation is not realistic, and the lower terminal voltage is used to consider Ferranti effect under the actual restoration procedure.

Gauss Seidel and Newton Raphson are numerical analysis methods to solve power flow. Gauss method has better robustness to the initial condition but slower convergence speed compared with Newton Raphson. On the other hand, Newton Raphson method has faster convergence speed, but easily diverges depending on the initial condition or power system states. Gauss Seidel and Newton Raphson are used together in this system considering that simulation can be diverged easily because states of power system are bad under restoration procedure. Gauss Seidel is used to select the approximate initial value at first before Newton Raphson's iteration. The system converges well, and its results are good even though power system’s states have big R-X ratio which is hard to be converged by Newton Raphson alone.

2.2 CONV module

The CONV module reads PSS/E raw data, and makes it DB form which is used in this training system. It exchanges data with the GUI and the PF modules, extracts necessary data from PSS/E raw data, and saves them to the DB splitting them into two kinds.
Data for solving power flow and results from it are accessed and modified frequently. Active/reactive power, voltage, angle, on/off state, bus types(load, generator, slack), and components of Y bus belong to this data, and they are saved in the memory(DYN DB) for rapid access. Lasts of PSS/E raw data except them are related to power system configuration, and saved in the disk(DSK DB). The CONV module makes Y bus data referring to the shared memory(DYN DB related to buses and lines), then transfers simulation starting command to the PF process.

2.3 GUI module

The GUI module includes an editor which can modify the graphic information easily to provide users with convenience. Trainees can switch on/off lines, and regulate loads and generating power, then over-voltages and overloads can be displayed using power flow results of the PF module to make the system suitable for training environment. Some functions are provided for user convenience, and they work with icon clicking. Table 1 shows the icons and the functions. Undo is for going to previous step for searching new solution when overloads or over-voltages occur, and Run Mode is for calculating power flow manually or automatically when a state of CB is changed. Fig. 2 shows the initial display of the simulator based on PSS/E raw data, and it is constructed using the built-in graphic editor. The initial display shows only the 345/765kV system and the 154kV system in PRS because of resolution limit. But whole 154kV systems can be added to this simulator using built-in graphic editor. Initializing of this system can be conducted as loading PSS/E data.
The DB is consists of analog and digital data. The analog DB is used for tap values of transformers, bus types(slack, generator, and load), and power flow results(active/reactive power, voltage, phase angle, overvoltage, and over reactive power capability of generators) and, the digital DB is for on/off state of each device.

Fig. 4 The PRS of Area 1

Table 3 Restorative scenario

System	Restorative scenario
Area 1 (PRS)	SRJ P/P #1 (V=0.95 PU, state=on, type=slack)
	Energize SRJ P/P~US C/C
Area 1	Energize BBS~SUS~UJ~SGS
	Energize SGS~GR (overvoltage at UJ, SGS, GR)
	↶ clicking (return to one step before)
	100[MW], lagging 50[MVAR] at SUS
	Energize SGS~GR~SDG
Area 2 (PRS)	MJ P/P #1 (V=1.0 PU, state=on, type=slack)
	Energize MJ P/P~BR C/C (overvoltage at all bus)
	MJ P/P #1 (V=0.9 PU)
Area 2	Energize SOC~CW~SYI (overvoltage)
	↶ clicking (return to one step before)
	50[MW], lagging 40[MVAR] at SOC
	Energize CW~SYI
	BR G/T #2 (V=1.0 PU, state=on)
	100[MW], lagging 70[MVAR] at CY
	Energize SYI~SAS~SSN (overvoltage)
	↶ clicking (return to one step before)
	100[MW], lagging 70[MVAR] at SYI
	MJ P/P #1 (P=200[MW])
	Energize SAS~SSN~HS
	BR G/T #1,2 (V=0.9 PU) BR G/T #2 (P=50[MW])
	Energize HS~SSU
	50[MW], lagging 30[MVAR] at SSU
	Energize SSU~CY
Linking	Load *.cas files of Area 1 and Area 2
	Energize MJ P/P~SDG (tie line between Area 1 and Area 2)

3 Restoration Case Study

Accuracy of training system's algorithm is verified as comparing with the PSS/E simulation result for the 39 bus IEEE system[12].

In this case study, total blackout of the domestic system is supposed. The brief restoration process is as follows.

(1) Energize the PRS of Area 1 and Area 2 each.
(2) Restore Area 1 and Area 2 based on each PRS.
(3) Reconnect Area 1 and Area 2 with each other.

Table 3 shows restorative scenario. SRJ P/P is a blackstart generator of the PRS in area 1, and its terminal voltage is set to 0.95[PU] to prevent overvoltages by Ferranti effect from occurring. There is no problem energizing transmission lines from SRJ P/P to US C/C, and restoration of the PRS is complete. US C/C is a primary restorative generator which needs cranking power and has big capacity. Based on the PRS, area 1 is energized step by step. Undo is used when overvoltages occur. Loads(100[MW]) and shunt reactor(50[MVar]) are inserted to supply power to the load center and to compensate Ferranti effect. Fig. 4 shows that the PRS of Area 1 has been restored. MJ P/P is a blackstart generator of the PRS in area 2, and area 2 is similar to area 1 at the restoration procedure. Area 1 and area 2 can be reconnected with each other after restoration of them is complete, and the result of (3) is shown in fig. 5, and the pop-up window shows gross generation and load.

4 Conclusion

In this paper, an operator training simulator for power system restoration is presented. Commercial programs are hard for the trainees to control the situation arbitrarily under restoration procedure because they follow preset scenario, but arbitrary control is possible for the developed system in real time, so the system can improve the operator's ability of handling blackout situations. The GUI and the DB can be modified easily using built-in graphic editor when configuration of the system is changed, and whole 154kV systems can be added to this simulator, then operator training effect can be improved. Voltage profiles of the power system can be analyzed based on static characteristic if a voltage/Var controller is added to this simulator. This system can be used for operator training, also aiding operator's decision making under blackouts.

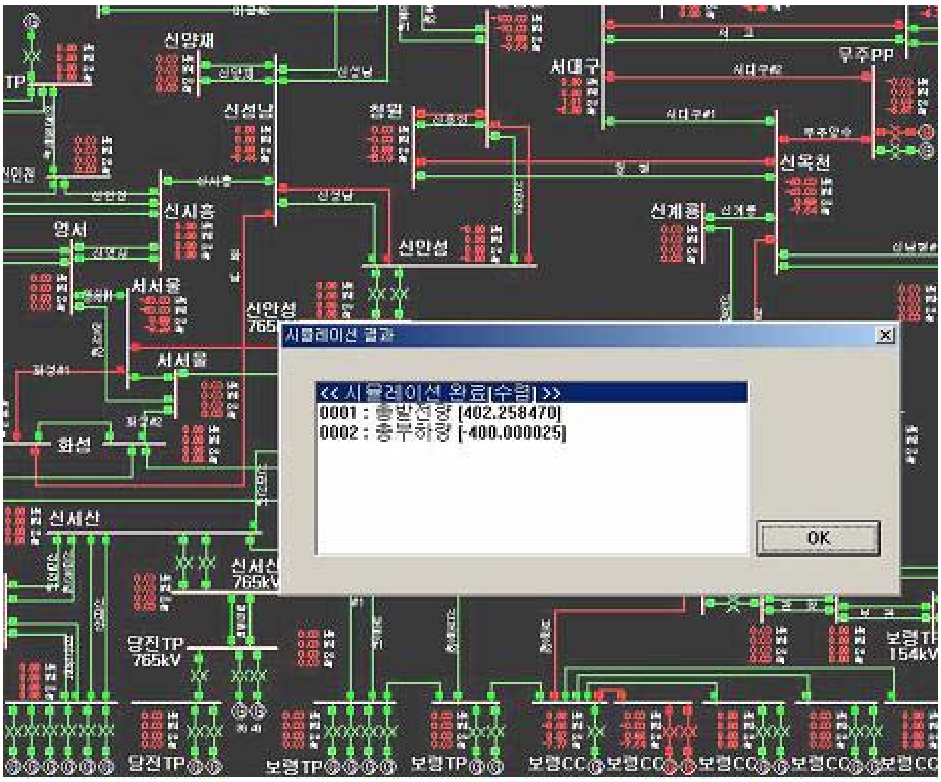

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Fig. 5 Reconnecting of Area1 and Area 2

Acknowledgement

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