Development of Advanced Restoration Expert System for 154kV Distribution Substation

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Abstract: This paper presents an advanced restoration expert system for Korean 154kV distribution substations. The proposed expert system has a topology based general structure and it utilizes basic rules including heuristic rules, topology identification rules and searching rules to generate switching sequence for adequate restoration process. Also, the rule-base of the proposed expert system comprises searching rules to use the bus-tie which is between the 22.9kV buses connected to one transformer. The proposed expert system displays the restoration process with a text window and the switching sequence of restoration with a graphic window. User friendly graphic user interface is developed using visual programming in the windows XP environment. The proposed expert system showed the promising performance through the several case studies.

Key-Words: Distribution Substation, Heuristic Rules, Enhanced Restoration Expert System

1 Introduction

The power system automation, especially the substation automation is one of major issues in power systems research. As the distribution substation is closely connected with end users, it is important to restore the system or to minimize the black-out region if complete restoration is not possible as quickly as possible. Therefore, if a fault occurs in distribution substation, the fault device is isolated from power system and the black-out regions are restored.

Regarding the substation restoration issue, many interesting basic study has been presented. Topology based interlocking[4] has been proposed, which can be easily realized using expert system. Switching sequence generation expert system[6, 7] deals with feasible or optimal switching sequence when a desired task is given. Japanese system[1, 2] looks like to have this function by guess. But clear comments are not found in the paper. Korean restoration expert system[3] has a topology based structure and has been tested in a practical sub-control center. Saudi system[5] deals with restoration procedure in Saudi electric company.

This paper presents an advanced restoration expert system for Korean 154kV distribution substations. The rule-base of this restoration expert system comprises basic rules suggested by Korea electric power company including heuristic rules, topology identification rules and searching rules to generate switching sequence for adequate restoration process. Also, the rule-base of this expert system comprises the heuristic rules to use bus-tie which is between the 22.9kV buses connected to the one transformer. The proposed expert system displays the restoration process with a text window and the switching sequence of restoration with a graphic window. User friendly G.U.I. is developed using visual programming in the windows XP environment. The proposed expert system showed the enhanced performance through the several case studies.

2 Data Structure of Devices

Data representations are closely related with system efficiency as well as that of rules and reasoning method. In this paper, compact representations of topology and devices are introduced. The general structure of 154kV distribution substations shows in fig. 1. As shown in fig. 1, distribution substation is composed of devices such as a transmission lines(TLs), 154kV double buses(HBUSes), 154kV/22.9kV main transformers (MTRs), 22.9kV double structured distribution bus (LBUSes), distribution lines(DLs), and switching devices like circuit breakers(CBs), and line switches(LSs).

In this paper, each unit device is described. And data which is required to represent the topology of substation is described as follows.

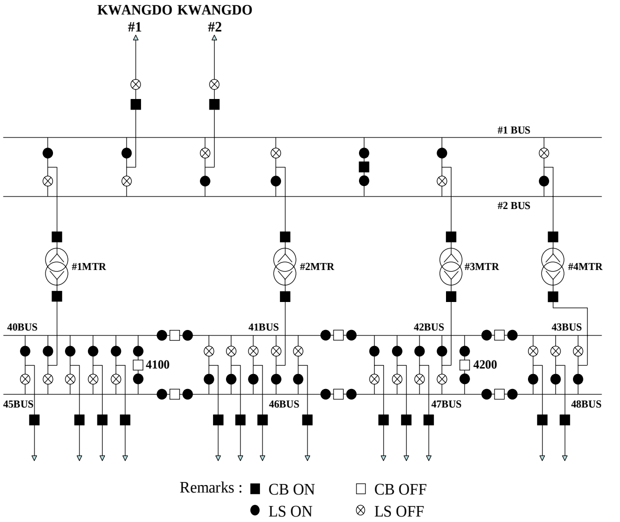

Fig. 1 Basic structure of 154kV distribution substation

Fig. 2 Display of restoration result

tl-hbus(tl_name, ls_no, cb_no, ls_no_list)
hbus-tr(tr_name, cb_no, ls_no_list)
tr-lbus(tr_name, cb_no, ls_no_list)
hbus-tie(cb_no, ls_no_list)
lbus-tie(lbus_name_list, cb_no, ls_no_list)

Herein, 'lbus_name_lsit' is set of 22.9kV bus which connected to lbus-tie.
In this representation, topological structure of the distribution substation is determined by reasoning using the status of CBs and LSs and it is utilized restoration process. Each generated physical connection is described as follows.

tl(name, status, availability).
hbus(name, status, tl_name_list, tr_name_list).
mtr(name, capacity, status, lbus_name_list).
lbus(name, status, dl_name_list).
dl(name, status, priority)

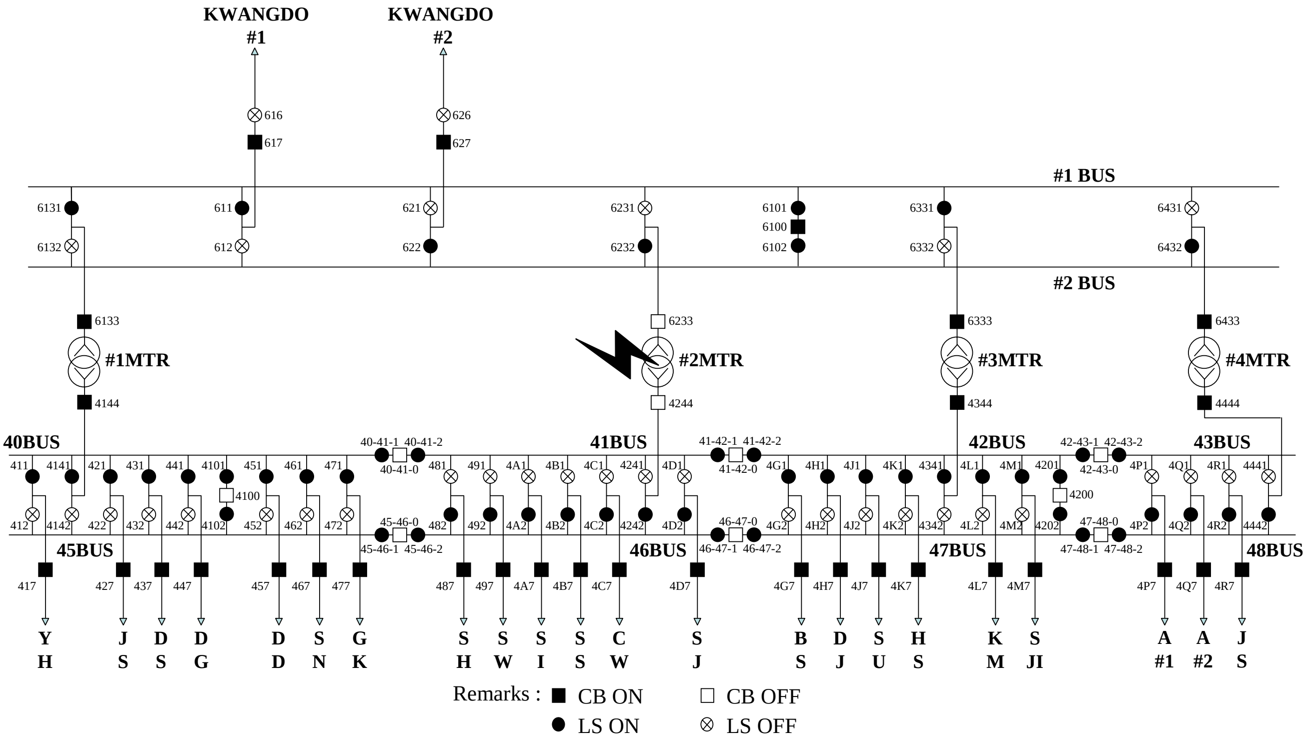

Fig. 3 Configuration before restoration

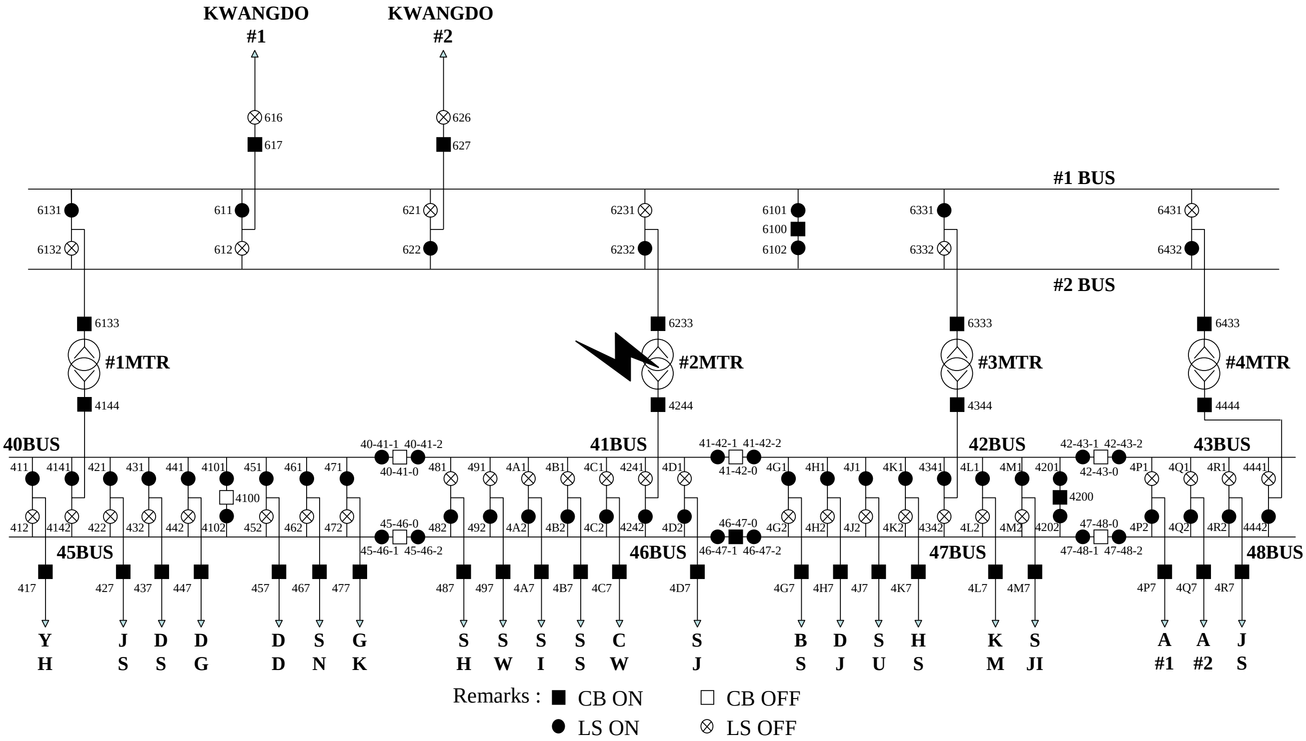

Fig. 4 Configuration after restoration(scenario #1)

Herein, 'name' describes name of each substation device, 'capacity' describes capacity of each device. 'tl_name_list', ‘tr_name_list’, ‘lbus_name_list’, and 'dl_name_list' is set of devices which connected to the each unit device. 'priority' means the degree of importance the distribution line. ‘status’ describes energized or de-energized of each device.

3 Inference and GUI

As shown in fig. 1, this substation has the bus-tie which is between the 22.9kV buses connected to the one transformer.(ex: 4100, 4200) The rule-base comprises heuristic rules to use the bus-tie.

When fault occurs at the transformer, black-out LBUS and D/Ls are transferred to other transformer. In this process, at first, the proposed restoration system searches the transformer which has full margin to restore total black-out load. And then, restoration process is performed by using selected transformer. If there are no enough margins in energized transformers, restoration process is performed by using two transformers.

Some major linguistic rules to solve the restoration problems are as follows.

In case of transformer selection, at first, select the transformer that has a minimum switching number in a restoration path, and at second, select the transformer that has the largest margin.

In case of black-out D/Ls restoration, they must be restored by the sequence of priority which is pre-assigned to each D/L.

In case of load transfer, up to 95% of maximum capacity of transformer is allowed and the load balance of energized transformers is not considered.

User friendly multi-window environment is developed. A screen dump of restoration result is given in fig. 2. The background in the figure shows the topological structure of substation.

4 Case Study

The fault is supposed to occur at the #2 main transformer of the substation and the fault section is just estimated by operator or the fault diagnosis system. Fig. 3 shows the states of the substation before restoration.

<u>Restoration Scenario #1</u> : The fault occurs at the #2 MTR of the substation. The total load of black-out is 13.94MW and margin of #1 MTR, #3 MTR, #4 MTR is 22.96MW, 30.53MW, 27.54MW individually. In this case, the three transformers have enough margins to restore black-out load. In this scenario, #3 MTR that has the largest margin is selected. Fig. 4 shows the

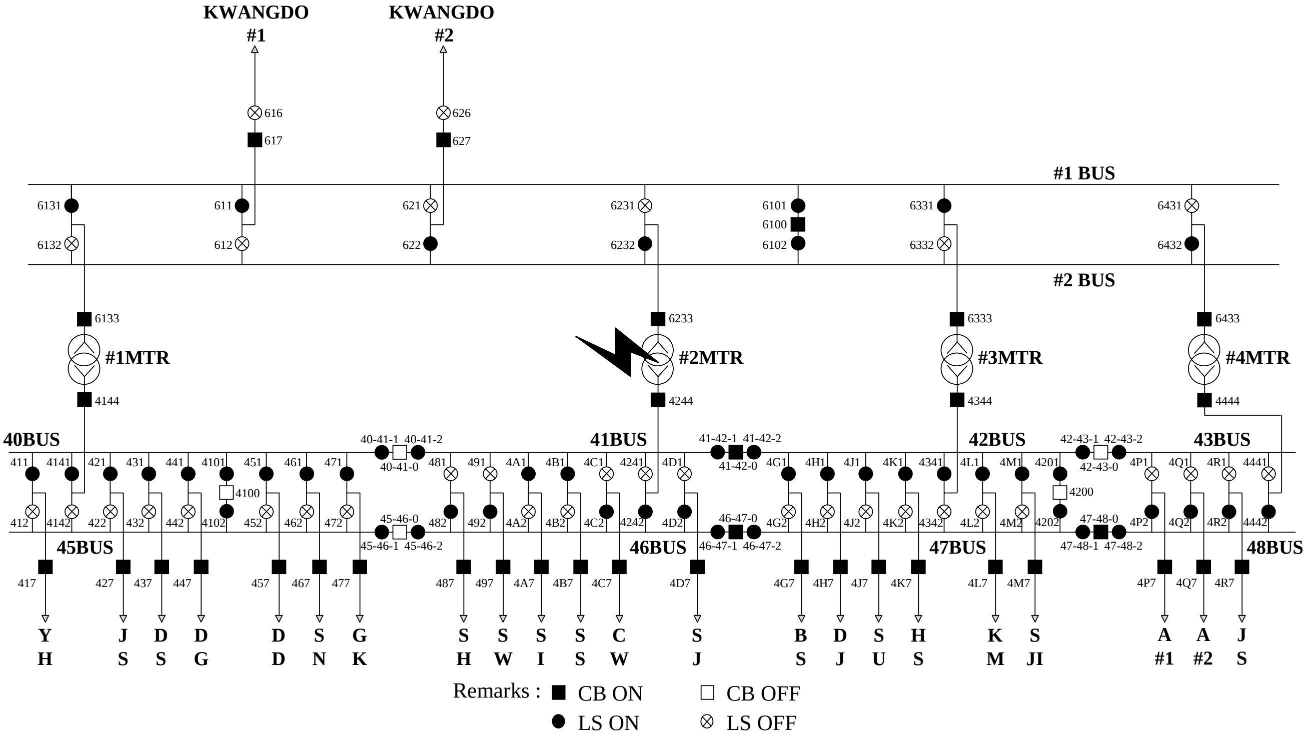

Fig. 5 Configuration after restoration(scenario #2)

expected state of the system after restoration.
The text output is as follows.

◙ Fault Substation : ddukdo

◙ Fault Device Input : #2 MTR

◈ TO ISOLATE THE BLACK-OUT D/Ls
: Turn off CB : 487, 497, 4A7, 4B7, 4C7, 4D7

◈ LBUS CONNECTION
- #46, #47 and #42 22.9kV bus connection
: Turn on CB : 46-47-0
: Turn on CB : 4200

◈ D/Ls RESTORATION
- SH D/L restoration
: Turn on CB : 487
- SW D/L restoration
: Turn on CB : 497
- SI D/L restoration
: Turn on CB : 4A7
- SS D/L restoration
: Turn on CB : 4B7
- CW D/L restoration
: Turn on CB : 4C7
- SJ D/L restoration
: Turn on CB : 4D7

◈ TO ISOLATE THE FAULT SECTION
: Turn off LS : 6232
: Turn off LS : 4242

<u>Restoration Scenario #2</u> : The fault occurs at the #2 MTR of the substation. The total load of black-out is 13.94MW and margin of #1 MTR, #3 MTR, #4 MTR is 2.96MW, 9.53MW, 10.54MW individually. In this case, restoration process is performed by using #3 MTR and #4 MTR. Fig. 5 shows the expected state of the system after restoration.
The text output is as follows.

◙ Fault Substation : ddukdo

◙ Fault Device Input : #2 MTR

◈ TO ISOLATE THE BLACK-OUT D/Ls
: Turn off CBs: 487, 497, 4A7, 4B7, 4C7, 4D7

◈ LBUS CONNECTION
- #41 and #42 22.9kV bus connection
: Turn on CB : 41-42-0

- #46, #47 and #48 22.9kV bus connection
: Turn on CB : 46-47-0
: Turn on CB : 47-48-0

◈ D/Ls RESTORATION
- SH D/L restoration
: Turn on CB : 487
- SW D/L restoration
: Turn on CB : 497

- SI D/L restoration
: Turn off LS : 4A2
: Turn on CB : 4A1
: Turn on CB : 4A7
- SS D/L restoration
: Turn off LS : 4B2
: Turn on LS : 4B1
: Turn on CB : 4B7
- CW D/L restoration
: Turn on CB : 4C7
- SJ D/L restoration
: Turn on CB : 4D7

◈ *TO ISOLATE THE FAULT SECTION*
: Turn off LS : 6232
: Turn off LS : 4242

5 Conclusion

An advanced restoration expert system for 154kV distribution substation is developed. The proposed expert system includes the heuristic rules to utilize bus-tie circuit breakers which are connected between the 22.9kV buses. As a result, the number of switching and processing time are much reduced. The proposed expert system displays the restoration process with a text window and the switching sequence of restoration with a graphic window. User friendly GUI is developed using visual programming in the windows XP environment.

Acknowledgement

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