P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol.28 No.2 April - June 2023
Page: [164-173]
Original research article

Severity Heat Mapping for Power System Security Assessment with N-2 Contingency Analysis

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Received 14 December 2022; Received in revised form 20 January 2023
Accepted 20 January 2023; Available online 14 June 2023

ABSTRACT

This research presents severity heat mapping for a power system security assessment with N-2 contingency analysis. The severity heat map considered the number of devices that exceeded the violation limit for power systems. This study used Thailand's power system in 2019 as the research base, while the Powerworld program was used to simulate and analyze the results. The study considered four cases. The first was the number of devices that exceeded the violation limit, while the second case was the percentage of the maximum branch. The third case was the voltage drops below the controlled value and the last case was the voltage greater than the controlled value. This research focused on studying the stability of the power system in the central region of Thailand, which has the largest difference in load and generation capacity. The results of the N-2 contingency analysis considered the cases of two generators that experienced outages in the system. The results showed that a severity heat map could indicate the devices that could cause an impact or severity on power system stability in each case. Power flow congestion management may then be used to enhance power system stability.

Keywords: N-2 contingency; Power flow congestion; Power system security; Severity heat map

1. Introduction

A study of the impact on the stability of a power system [1, 2] is very important for planning, protecting and enhancement of system stability. The problem of the system that occurs by the loss of power transmission

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doi: 10.14456/scitechasia.2023.35

devices [3, 4] is one of the problems which can affect the stability of the power system. Impact assessment, especially on power flow congestion in a power system, [5, 6] is important in order to understand the significant devices for power transmission and severity level, which can be used for planning power systems control, or even planning device maintenance systems [7, 8]. This research also studied the impact of a protection plan on power system stability.

The objectives of the study were to present a severity heat map in order to assess power system stability by N-2 contingency to indicate the important devices in power transmission and to manage the prevention of power flow congestion management problems. Thailand's power system was used to improve the peak load period in 2019 [9, 10] as a research base, which is divided into 7 areas (Subsystems). This study focused on the impact of a power system in Area 1 with the highest difference in load capacity and generation capacity when compared to other subsystems and needs power requirements from other subsystems via inter-tied lines [8]. A case study has been considered in case a power system loses two generators to create a severity heat map via 4 cases used in the impact analysis. The severity heat map will consider the number of devices that exceeded the violation limit. The second case is a percentage of the maximum branch. The third case is the voltage drops below the control value and the last case is the voltage is greater than the control value.

The results of this study also ranked the dual generators as being highly affected by power flow congestion in each case. In addition, the results of this study provided a system bus frequently affected by a loss of power in the generator situation. It can be used for information power flow congestion management and planning protection to enhance the stability of the power system.

2. Materials and Methods

2.1 Preparation of power system base case

This research used the modified Thailand power systems during the peak load period in 2019 as a research base system. The modified Thailand power systems and generation capacity data [9, 10] (Fig. 1) and (Table 1) are below.

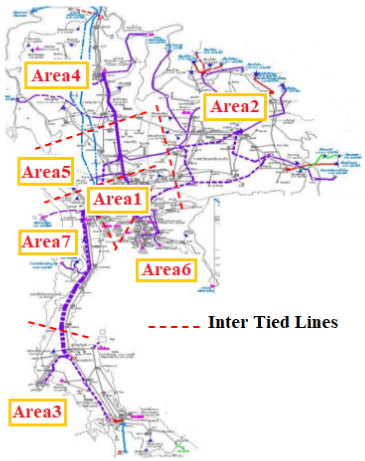

Fig. 1. Overview of a modified Thailand power system base case in 2019.

Table 1. Generation and load capacity in a modified Thailand power system base case.

Area	Generation (MW)	Loads (MW)	Losses (MW)
1	2,379.03	10,849.60	96.98
2	2,858.23	3,229.92	134.08
3	2,088.02	2,668.39	70.15
4	3,517.51	3,010.42	133.81
5	3,972.12	3,161.60	84.74
6	10,133.06	4,061.96	54.76
7	5,333.73	2,675.60	49.69
Total	3,0281.70	29,657.49	624.21

The results in Table 1 show that Thailand's power systems are divided into 7 areas, with each area having a different generation capacity and number of loads. The active power balance in the power system, therefore each area is connected by an inter-tied line. There are 30,281.70 MW of generation capacity, 29,657.49 MW of loads, and 624.21 MW of power losses in the power system. The number of devices in each area is given in Table 2.

Table 2. Number of devices in each area.

Area	Gen.	Transformer	Transmission Line
1	14	162	148
2	92	167	192
3	23	150	141
4	37	177	122
5	25	108	123
6	109	215	150
7	30	142	120
Total	330	1121	996

In this study, the Powerworld program [11] was used to simulate and analyze the results. This research focused on an impact study of the central region of Thailand's power system (Area 1) under a loss of dual generators because it has the highest power difference during load and generation capacity at 8,470.57 MW. Area 1 has 2,379.03 MW of generation capacity and 10,849.60 MW of load. The names of the generators in Area 1 can be seen in Table 3, comprising 14 generators.

Table 3. Name of generators in Area 1.

No.	Number	Name	Gen MW	Gen MVAR	Min MW	Max MW	Min MVAR	Max MVAR
1	1011	SB-T1	200	100	80	200	-50	100
2	1012	SB-T2	200	100	80	200	-50	100
3	1013	SB-T3	310	155	124	310	-77.50	155
4	1014	SB-T4	310	155	124	310	-77.50	155
5	1015	SB-T5	310	155	124	310	-77.50	155
6	1021	SB-C11	110	55	44	110	-27.50	55
7	1022	SB-C12	110	55	44	110	-27.50	55
8	1023	SB-C10	115	57.50	46	115	-28.75	57.50
9	1031	SB-C21	202	101	80.80	202	-50.50	101
10	1032	SB-C22	202	101	80.80	202	-50.50	101
11	1033	SB-C20	220	100	80	220	-50	100
12	11004	SMC-C10	30	9.53	10	30	-21.30	21.30
13	11005	SMC-C11	30	9.6	10	30	-14.70	14.70
14	11006	SMC-C12	30	9.6	10	30	-14.70	14.70

2.2 Violation limits of power system control

Power system control in the study involved setting the operating limits of devices to control the power system to a steady state. Basic power system control values consist of two limit values including voltage limit [12] and percentage of the load limit. Both of these values were used to detect the devices that violated the control limits of the power system (Table 4). In Table 4, the power system base case creation and severity assessment have set three violation limits. The first limit is the percentage of device loading set at 100%. The second limit is high bus voltage set at 1.05 p.u. and the third limit is low bus voltage set at 0.95 p.u.

2.3 Study method

The severity heat mapping study process starts by using a contingency n-1 analysis (Fig. 2). The first step of the research was to create a power system. This study used the Newton-Raphson method. The power system control setting for violation limits can be seen in Table 3. If there was a violation, it would adjust data as generator voltage, transformer tap or capacitor bank step until there was no violation of the system control values, then select an area or subsystem for study. This study focused on the central region of Thailand's power system (Area1) under contingency N-2 analysis considering the loss of two generators. The effect in each case would be checked by setting the violation limits as shown in Table 4 for severity heat mapping. After that, a severity heat map was created from all of the devices that violated power system control data.

Table 4. Power system control values.

Case	Violation limit	Control Values	Unit
Power system base case & Severity assessment	Loading of device	100	%
	High bus voltage	1.05	p.u.
	Low bus voltage	0.95	p.u.

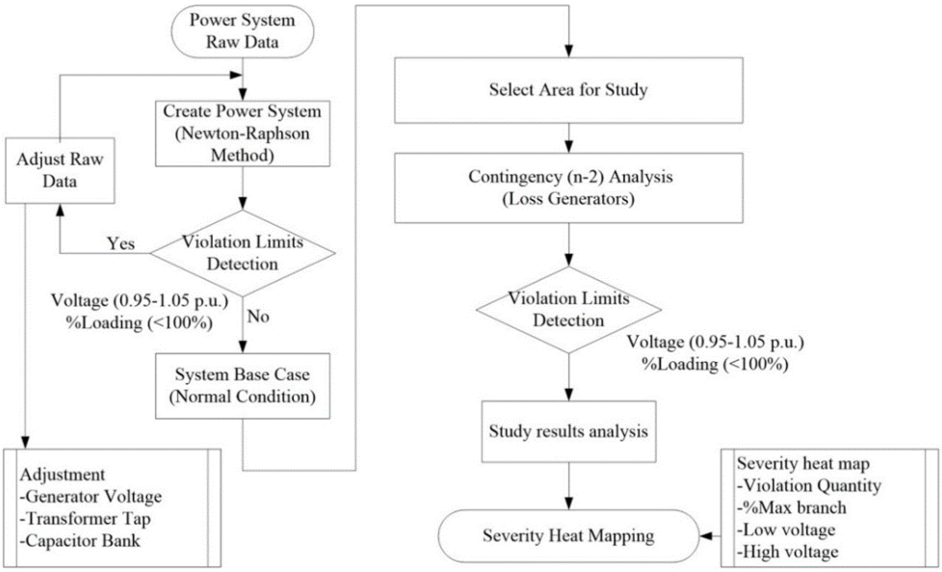

Fig. 2. The severity heat mapping study process by using a contingency n-1 analysis.

3. Results and Discussion

This research presents a severity heat map for power system security assessment under N-2 Contingency Analysis [13, 14]. This study focused on the impact of studying the stability of a power system in the central region of Thailand's Power Systems or Area 1. The results of the severity heat map were divided into 4 cases and also presented affected areas and devices, as shown below.

3.1 The study results for severity heat map under loss of two generators

The results of the severity heat map under the loss of two generators were divided into 4 cases (Figs. 3-6). For a severity heat map under the loss of two generators, sequence generators are shown in Table 3. The level of severity was considered by the number of devices that exceeded the violation limit, for which the system control setting values are shown in Table 4.

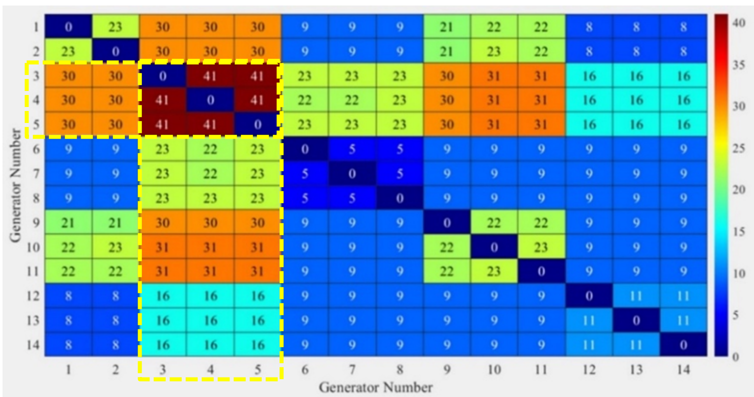

Fig. 3. Severity heat map under loss of two generators by considering the number of devices exceeding violation limits.

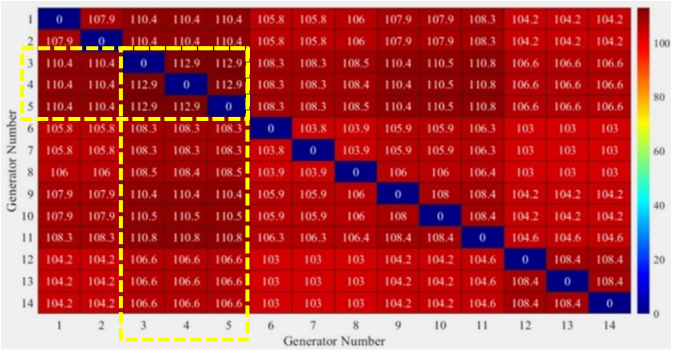

Fig. 4. Severity heat map under loss of two generators by considering the percentage of the branch that exceeded %loading violation limit.

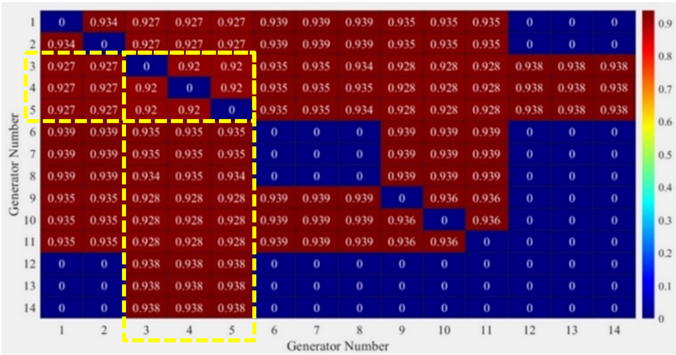

Fig. 5. Severity heat map under loss of two generators by considering bus voltage below the low voltage violation limit.

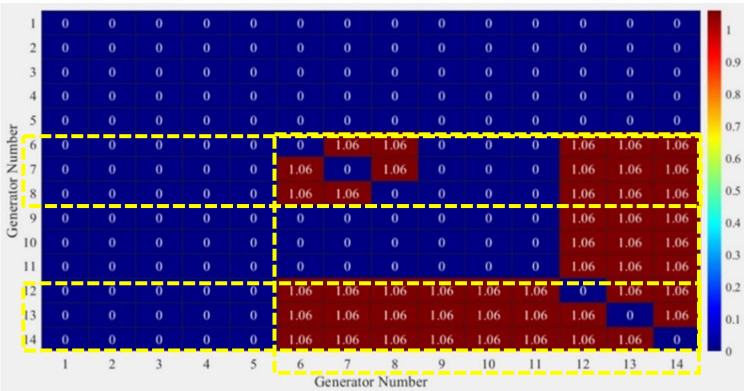

Fig. 6. Severity heat map under loss of two generators by considering bus voltage exceeding high voltage violation limits.

Heat map severity assessments are divided by shade. Red represents the highest severity, while blue represents the lowest severity.

Fig. 3 shows the severity heat map under the loss of two generators considering the number of devices in violation of the power system limit; the levels of severity are divided by shade. The study results show that the generator pairs that caused the highest control value violation were generator pair numbers 3-4, 3-5 and 4-5. If either pair of generators is disconnected from the system, it will cause devices in the system to be in maximum violation of the system control limits, where the number of devices in the system that are violated is 41 devices. Therefore, these 3 pairs of generators are very important in maintenance or operation planning and must avoid simultaneous shutdown or simultaneous disengagement protection. If considering pairs of generators that cause the equipment in the system to minimally violate the system control limits, they are generator pair numbers 6-7, 6-8 and 7-8, where the number of devices in the system that violates are 5 devices.

Fig. 4 shows the severity heat map under losses of two generators based on the percentage load of the power transmission equipment in the system; the severity levels are divided by shade. The study results show that the generator pair losses that cause the equipment in the system to experience the highest load are generator pair numbers 3-4, 3-5 and 4-5. If either pair of generators is disconnected from the system, it will cause the equipment in the system to receive a maximum load of 112.9 percent. Therefore, these 3 pairs of generators are very important in planning maintenance and operation as well.

Fig. 5 shows the severity heat map under the loss of 2 generators considering the power system's low-voltage limits, in which the severity levels are divided by shade. The study results show that the generator pairs that caused the system the greatest low voltage impact were generator pair numbers 3-4, 3-5 and 4-5. If any of the generator pairs are disconnected from the system, the system will suffer a low voltage effect with a minimum voltage of 0.92 p.u., and it can be considered that these 3 pairs of generators are very important for maintenance and operation planning of the power system.

Fig. 6 shows the severity heat map under two generator losses based on the high voltage limit, in which the severity levels are divided by shade. The study results found that the generator pairs cause the system to be affected by high voltage by causing the system to have a high voltage impact of 1.06 p.u., and it can be considered that these generator pairs are very important in planning the maintenance and operation of the power system as well.

3.2 Study results of the dual generators ranked with high impact on power flow congestion

The results of the dual generators ranked with a high impact on power flow congestion were divided into 4 cases (Figs. 7-10). Figs. 7-9 illustrate the ranking of the dual generators by considering the number of devices that exceeded violation limits, exceeded the % loading violation limit, and were below the low voltage violation limit. The results show the first 30 pairs of high-impacted generators. The results found that, if dual generator numbers 1013-1014, 1013-1015 and 1014-1015 were lost, it would have a high impact on power flow congestion.

For the dual generators ranked by considering the bus voltage that exceeded the high voltage violation limit, the results showed the first 30 pairs of high-impacted generators and found that the maximum bus voltage variation was 1.065 p.u. (Fig. 10).

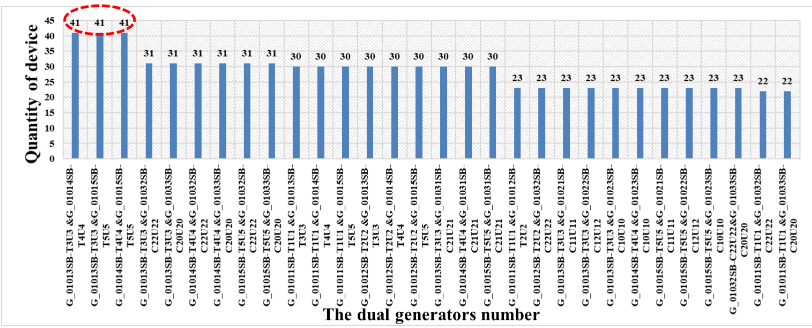

Fig. 7. Dual generators ranked by considering the number of devices that exceeded violation limits.

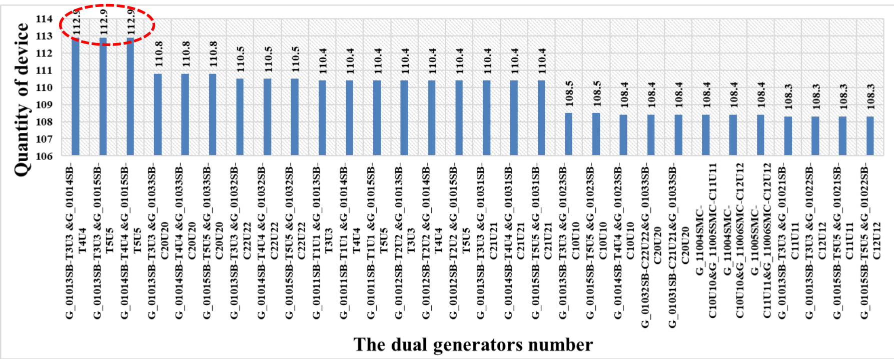

Fig. 8. Dual generators ranked by considering a percentage of the branch that exceeded % the loading violation limit.

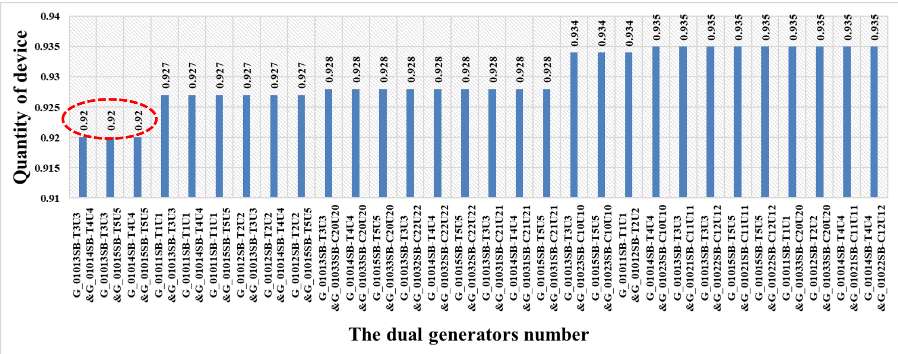

Fig. 9. Dual generators ranked by considering bus voltage below the low voltage violation limit.

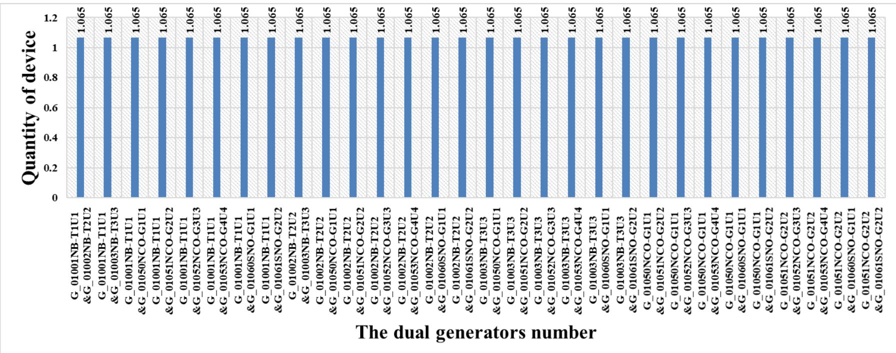

Fig. 10. Dual generators ranked by considering bus voltage that exceeded the high voltage violation limit.

3.3 The study results of high frequency impacted device ranking

The study results of finding highly impacted devices or often affected devices were considered by impact under the loss of two generators (Figs. 11-12).

Fig. 11 shows that there are 27 high frequency impacted buses. The highest frequency impacted bus is RPS-2J at 159 times. Fig. 12 shows that for power transmission device sequencing with high frequency impact, there are 13 devices. 6661NCO-NCO_2J is the highest impacted power transmission device at 217 times. Thus, these are important areas and devices to transfer power in case of a loss of two generators.

The study results demonstrate the creation of a severity heat map under the loss of two generators. The results of the study are divided into 4 cases, consisting of the consideration of the number of devices that violate the power system control values, consideration of equipment load percentage, and considering low voltage effects as well as the effects of high voltage. The correlation of the results of the four studies found that the study results under consideration the number of devices that violate the power system control values will indicate the severity of the power flow congestion in the system under dual generators losses. This disconnected dual generator can also point out the effects of equipment load and system voltage stability. In addition, the study results suggest the generator pair rankings that have the greatest impact on the system for application in power system control planning, whether for the maintenance of equipment or the operation plan of the power system to avoid or maintain the system so that the aforementioned generator pairs are shut down. Moreover, the results of the study also point out areas or equipment that are frequently affected; the information can be used to plan improvements to power system stability. Therefore, the creation of a severity heat map is an important tool for estimating the severity that will occur under the loss of two devices in order to apply for power system control planning.

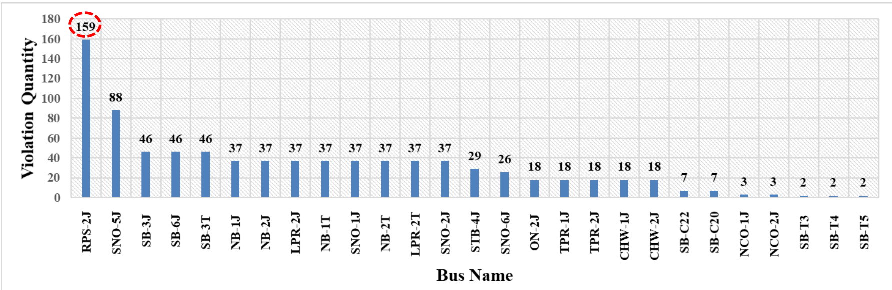

Fig. 11. High frequency impacted bus ranking.

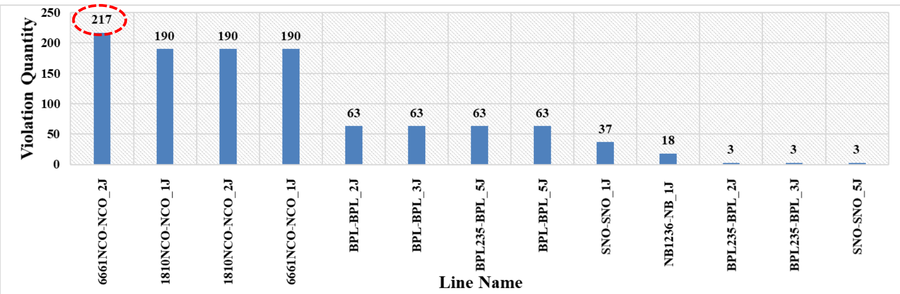

Fig. 12. High frequency impacted power transmission device ranking.

4. Conclusion

This research studied severity heat mapping for a power system security assessment with N-2 contingency analysis. This severity heat map considered the number of devices that exceeded the violation limits for power systems. The violation limits consist of a percentage of the loading limit for the power transfer device and the bus voltage control limit. This research focused on creating a severity heat map in the case of the loss of two generators for use as a guideline in other cases such as the loss of two transformers, the loss of two transmission lines, loss of transformer and transmission line, loss of transmission line and generator, and loss of generator and transformer. The study results emphasized Area 1, which has a load capacity greater than the generation capacity and requires power from other subsystems via inter-tied lines. Therefore, power system control should have tools for the assessment of disturbances in certain situations and the risk to lose devices or even to plan maintenance. Consequently, creating a severity heat map is very useful. It will help to understand important devices in the system that can affect system stability. In addition, the power system security assessment with N-2 contingency analysis indicated important buses and devices to support power transmission. The results and data could be used for power flow congestion management and improvement of the stability of the power system.

Acknowledgements

The authors would like to express their sincere thanks to the Faculty of Agriculture and Industrial Technology, the Research and Development Institute, Phetchabun Rajabhat University (PCRU) and King Mongkut's Institute of Technology Ladkrabang (KMITL) for the advice and research experience provided, including the tools that were used in the research. The authors are also thankful for all the advice and suggestions received by this research for its successful completion.

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