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Techniques for Assessment Inter-Area Power Transfer Capacity for Large Power Systems to Improve System Stability

Chaisit Wannoi[1,*], Narumon Wannoi[2]

[1]Computer Technology Department, Faculty of Agricultural and Industrial Technology, Phetchabun Rajabhat University, Phetchabun, 67000 Thailand

[2]Electrical Industrial Technology Department, Faculty of Agricultural and Industrial Technology, Phetchabun Rajabhat University, Phetchabun, 67000 Thailand

[*]**Corresponding Author**: chaisit.w@pcru.ac.th

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Abstract

This research presents a technique for assessing the power transfer capacity inter-areas of large power systems for improving system stability. In this study, an assessment of the inter-area power transfer capacity was determined by the maximum capacity of an inter-area bus under the thermal limits of all transmission lines connected to the bus. The results of this research were to compare the power transfer capability of each inter-area bus under normal conditions and compare the capability of the transmission lines to connect between areas under the system of loss of 1 device (Contingency n-1), which consisted of 2 cases. The first case is that the system causes the loss of the generators with the highest capacity in each area and the second case is the loss of the transmission line between the areas. In addition, the severity of the area-to-system interconnect transmission line will be compared if disconnected by considering the number of buses and devices that violate the control parameters of the power system, which in this study used the Thailand power system as a system that based on the study and analysis by using the Powerworld simulator program. The results showed that this technique could indicate the power transfer capacity between each area and the capacity of each transmission line connected between the areas, both the system under normal conditions and the loss of 1 device (Contingency n-1), including the ability to sequence the severity of the transmission line affecting the system, which this information can be used to plan the power flow control for the purpose of improving the stability of the power system.

Keywords: Power transfer; Inter-areas; Contingency n-1; Large power systems; System stability

1. Introduction

When considering power transfer in a power system, it is found that the power flow congestion problem in the system is one that affects the stability of the power system [1]. If it happens with equipment that is critical to transfer power in a system, it can have a serious impact on the power grid, especially the inter-area power transfer equipment. Therefore, when considering a large power system, the control area of the power system is divided into sub-control areas to make it easier to plan the control where the various sub-control areas are connected and then transferred to each other due to some sub-regulated areas are very capable of power generators due to their proximity to the fuel source. However, some areas are not suitable for different generating capacity. The devices that connect between areas use transmission lines that are connected between these sub-control areas, called Inter-Tied Lines [2], which can be an important transmission line. This is especially true in inter-area power transfers. If these transmission lines are damaged or disconnected, it can cause insufficient power transfers to other subsystems, which directly affects the stability of the power grid. The power system in Thailand is the same Therefore, in this article, a technique for assessing inter-area power transfer capacity for large power systems is presented in order to improve system stability by using the Thailand power system as the base system for the study, with a capacity of 27443.75 MW. When considering the Thailand power system, it will be found that the Thailand power system has divided sub-controlled areas into 7 control areas. Each sub-control area has a different capacity and load, so it is necessary to connect the transmission lines to transfer power to maintain a balance between capacity and load through the interconnection transmission line. In the assessment of the power transfer capacity between areas, the transmission line's power transmission capacity is assessed by analyzing the overall power transmission capacity under consideration of the transmission line thermal limit [3], which compares the overall capacity of the bus and transmission lines between each area under the system under normal conditions and under a single device loss (Contingency n-1). The loss of one device consists of the largest loss of the generator in each area and the loss of transmission lines connecting between areas.

2. Materials and methods

A research procedure for assessing the power transfer capacity between areas of a large power system can be schematically illustrated in Fig. 1.

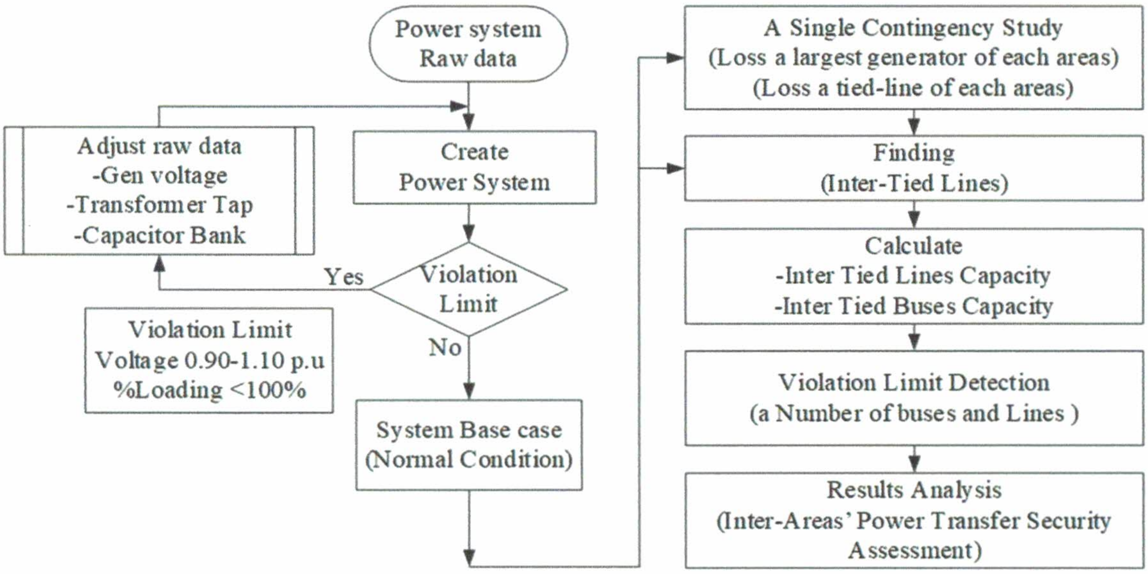


Fig.1 Procedure diagram for the assessment of inter-area power transfer capability.

Fig. 1 shows the procedure for assessing inter-area power transfer capacity. Studies have been initiated by constructing a power system used in the study to present a technique for assessing transfer capability between sub-control areas. In this research study, the Thailand power system was used as the base system and the power system construction process was investigated for violations of the system control. The voltage regulation was set at 0.90 – 1.10 p.u. and the load percentage control of the power transfer device is 100 percent. If the system still has a bus or the device in the system violates, the control is adjusted the generator voltage, the tap of the transformer and the capacitor in the system until the voltage and load percentage of power transfer device do not violate the control values. Then, the base system is obtained in the study and can be regarded as a system under normal conditions.

In the capacity assessment, a system under normal conditions was compared with a system under a single device loss system, consisting of 2 cases. The first case was the largest loss of the generator in each area. The second case is the loss of a single transmission lines between areas. The inter-area interconnection bus and transmission line will then be studied and searched to calculate the power transfer capacity of each inter-area bus and transmission line capacity between the areas under consideration of the transmission line's thermal limit. This study has focused to study the quantity or number of buses and transmission lines that violate control values in order to determine the severity of transmission lines affecting the system. The final step is to analyze the research results and draw conclusions. For the calculating transmission line capacity and inter-area bus capacity, it can be described as below.

Calculation of the capacity of transmission lines connected between areas

The North American Electric Reliability Council (NERC) [4, 5] has determined the overall transmission capacity of the transmission line in the system can be expressed as equation (1). In this study, it was not considered in terms of the TRM and CBM. Therefore, from the NERC ATC terminology, the committed uses are defined power to the users. So, the committed uses are equal to the real power flowing. Therefore, available transfer capability of transmission line can be expressed as an equation (2).

$$\mathrm{TTC} = \mathrm{ATC} + \mathrm{TRM} + (\mathrm{ETC} + \mathrm{CBM}) \tag{1}$$

$$\mathrm{ATC}_{Line} = \mathrm{TTC}_{Line} - \mathrm{Real\_powerflow}_{Line} \tag{2}$$

Where TTC is Total Transfer Capability, ATC is Available Transfer Capability, TRM is Transfer Reliability Margin, ETC is Existing Transfer Capability, CBM is Capability Benefit Margin, $\mathrm{Real\_powerflow}_{Line}$ is real power flow on transmission line

Calculation of the overall available capacity of the interconnected bus between areas

The overall available capacity of the inter-area bus can be calculated from the result of the overall available capacity of all transmission lines connected to the inter-area bus as shown in equations (3). So, the inter-area power is the capacity of each bus in each area combined, as shown in equation (4).

$$\mathrm{ATC}_{Bus} = \sum_{Line\_1}^{Line\_n} \left[\left(\frac{Limit_{Amp}\sqrt{3}VN}{10^6} \right)_{Line} - \left(\sqrt{(MW)^2 + (MVAR)^2} \right)_{Line} \right] \tag{3}$$

$$\mathrm{ATC}_{Area} = \mathrm{ATC}_{Bus\_1} + \mathrm{ATC}_{Bus\_2} + \ldots + \mathrm{ATC}_{Bus\_n} \tag{4}$$

Where TTC_{Line} is total transfer capability of transmission line, ATC_{Area} is available transfer capability of area, ATC_{Bus} is available transfer capability of bus, ATC_{Line} is available transfer capability of transmission line, $Limit_{Amp}$ is Ampere Limit (A), VN is Nominal Voltage (V)

3. Results and Discussion

The results of the study were used to compare the power transfer capacity of each area by calculating the readiness capacity of each bus and each transmission line between the areas. The results were also used to obtain the sequence of transmission line severity affecting the entire system in the normal state and a system under one device loss [6], defined in two cases: the first case, the system lost the highest generators in each area by the name and capacity of each generator in each area is shown in Table 1.

Table 1 The largest generators in each area.

Area	No.	Name	Gen MW	Gen MVAR	Max MW	Max MVAR
1	1013	SB-T3	310	155	310	155
2	2011	LTK-H1	250	125	250	125
3	3011	KN-C11	112	11	112	56
4	4048	MM3-T8	295	140	300	150
5	5043	GULF-C10	265	19	265	133
6	6003	BPK-T3	600	151	600	300
7	7061	TECO-C10	240	39	240	137

In Table 1, it was found that area 6 has the highest generators compared to other areas. The second case is the loss of inter-tied lines. The study results can be shown as follows:

Results of available power transfer capability between areas

Results of available power transfer capability between areas in the normal state system can be shown in Table 2.

Table 2 Inter-area transfer capacity in a normal state system.

Inter-Tied Line Records					Inter-Tied Lines' ATC Assessment (MVA)			
No	Area	From Number	To Number	Area	TTC	Real Power flow	ATC (Line)	ATC (Area)
1		1808	5802		476.90	48.50	428.40	
2		1809	5808	5	953.70	315	638.70	7080.30
3		1908	5906		6228.40	215.20	6013.20	
4		1809	6808		953.70	462.70	491	
5	1	1810	6891	6	858.90	421.20	437.70	1612.20
6		1804	6891		1907.40	1352.80	554.60	
7		1804	6801		953.70	824.80	128.90	
8		1806	7816		953.70	172.60	781.10	
9		1807	7816	7	953.70	200.50	753.20	5295.80
10		1908	7902		4146.50	385	3761.50	
11		2802	4804	4	476.90	179	297.90	1069.30
12		2803	4807		953.80	182.40	771.40	
13	2	2701	5708		117.50	98.10	19.40	
14		2702	5708	5	117.50	77.30	40.20	746.70
15		2807	5803		834.50	147.40	687.10	
16	3	3807	7829	7	953.80	168.80	785	2468
17		3809	7829		1907.40	224.40	1683	
18		4441	5906		6228.40	232.40	5996	
19	4	4751	5720	5	129.70	6.60	123.10	9573.20
20		4803	5802		953.80	101.80	852	

Table 2 (cont.)

Inter-Tied Line Records					Inter-Tied Lines' ATC Assessment (MVA)			
No	**Area**	**From Number**	**To Number**	**Area**	**TTC**	**Real Power flow**	**ATC (Line)**	**ATC (Area)**
21		4804	5807		953.70	131.30	822.40	
22		4804	5805		953.70	94.80	858.90	
23		4804	5801		953.80	33	920.80	
24		4441	6661	6	3114.20	103.70	3010.50	3010.50
25		5906	6911	6	3114.20	744.40	2369.80	8217
26	5	5906	6661		6228.40	381.20	5847.20	
27		5906	7902	7	4146.50	242.50	3904	3904

In Table 2, it was found that the base Thailand power system has 27 transmission lines connecting all areas at the voltage level of 115 kV, 230 kV and 500kV, with the ability to transfer power between areas 2 and 5 and have the lowest available transfer capability at 746.70 MVA and the available transfer capability between area 4 and 5 has the highest available transfer capability of 9573.20 MVA. When considering the assessment of available transfer capability of the transmission line that connected between areas in the normal state system, it was found that there is a transmission line between area No. 2701-5708 (PCH-SR2) connecting area 2 and area 5 that have available transfer capability to support the lowest power transfer between areas, with the available transfer capability of this transmission line at 19.40 MVA. From the results of the study, it was found that the transmission line between Area No. 1908 – 5906 (SNO-WN), the transmission line between Area 1 and Area 5, had the highest remaining available transfer capability to support the power transfer with residual available transfer capability of 6013.20 MVA.

Results of available transfer capability of the transmission line that connected between areas in case losing generator with the highest capacity in each area.

Available transfer capability of transmission line that connected between areas in losing system case of the generator with the highest capacity in each area as shown in Table 1, the results of the study can be shown in Table 3.

Table 3 Capabilities of transmission lines between areas in a losing generator with the highest capacity in each area.

No.	Inter-Tied Lines		Base	Inter-Tied Lines' ATC						
				Area1	**Area2**	**Area3**	**Area4**	**Area5**	**Area6**	**Area7**
1	1808	5802	428.40	437.30	417.90	429	424.70	417	431.40	429.70
2	1809	5808	638.70	623.90	638.90	637.80	639.60	639	625.20	633.90
3	1908	5906	3006	2975.50	2999.80	2982	3005	2999	2971	2964
4	1809	6808	491	490.30	487.10	488.40	486.90	487	502.90	483.70
5	1810	6891	437.70	436.30	433	435.80	432.10	433	523.70	434.10
6	1804	6891	277.30	242.30	268.60	272.60	269	268	371.70	265.70
7	1804	6801	128.90	108.60	125.20	128	125.10	125	115.50	128.60
8	1806	7816	781.10	806.50	779.80	778.90	779.90	780	790.80	773.10
9	1807	7816	753.20	745.70	755.30	751.80	754.70	755	751.40	745.10
10	1908	7902	3762	3762	3759	3784	3759	3759	3764	3795

Table 3 (cont.)

No.	Inter-Tied Lines		Base	Inter-Tied Lines' ATC						
				Area1	Area2	Area3	Area4	Area5	Area6	Area7
1	1808	5802	428.40	437.30	417.90	429	424.70	417	431.40	429.70
2	1809	5808	638.70	623.90	638.90	637.80	639.60	639	625.20	633.90
3	1908	5906	3006	2975.50	2999.80	2982	3005	2999	2971	2964
4	1809	6808	491	490.30	487.10	488.40	486.90	487	502.90	483.70
5	1810	6891	437.70	436.30	433	435.80	432.10	433	523.70	434.10
6	1804	6891	277.30	242.30	268.60	272.60	269	268	371.70	265.70
7	1804	6801	128.90	108.60	125.20	128	125.10	125	115.50	128.60
8	1806	7816	781.10	806.50	779.80	778.90	779.90	780	790.80	773.10
9	1807	7816	753.20	745.70	755.30	751.80	754.70	755	751.40	745.10
10	1908	7902	3762	3762	3759	3784	3759	3759	3764	3795
11	2802	4804	297.90	297.90	277.30	297.90	297.80	292	297.90	297.90
12	2803	4807	385.70	385.50	372.50	385.60	389.70	382	385.50	385.60
13	2701	5708	19.40	19.50	13.50	19.40	18.60	21	19.50	19.50
14	2702	5708	40.20	40.30	35	40.20	39.50	42	40.30	40.20
15	2807	5803	687.10	687.30	602.90	687.10	683.80	696	687.20	687.20
16	3807	7829	392.50	392.60	392.60	369	392.60	393	392.60	392.50
17	3809	7829	841.50	841.50	841.50	808.50	841.50	842	841.50	841.50
18	4441	5906	2998	2997	2962	2999	2918	2970	2996	3000
19	4751	5720	123.10	122.80	120.90	123.10	125	119	122.90	123
20	4803	5802	426	422.70	427.10	425.70	432.80	423	423.80	425.10
21	4804	5807	822.40	821.80	815.50	822.40	828.60	808	822.50	822.30
22	4804	5805	858.90	859	855.30	859.10	863.80	848	859.80	859.10
23	4804	5801	460.40	460.60	458.90	460.50	464.60	456	461	461
24	4441	6661	3011	2999	2974	3006	2941	2977	3002	3001
25	5906	6911	2370	2249	2257	2319	2244	2256	2169	2269
26	5906	6661	2924	2907	2909	2918	2910	2909	2902	2910
27	5906	7902	3904	3908	3901.60	3921.50	3899	3902	3908	3929

The results reveal the residual capacity of each inter-area transmission line and the power change rate when compared with normal conditions, which gives an idea of the transmission line group between the areas that are important to support power transfer. When there is a loss of generators with the highest capacity in each area, the power system stability was analyzed from the results of the normal system study in Table 3, it was found that the transmission line with the lowest total capacity to support cross-area transfer was transmission line number 2701 – 5708 (PCH-SR2) with a total capacity of 19.40 MVA. If the generator with the highest capacity in area 2 is disconnected., the transmission line availability is reduced to 13.50 MVA as shown in Table 3 and the transmission line groups that are important for cross-area transfer support. The priorities can be obtained from the rated power change on the transmission line, as shown in Fig. 2.

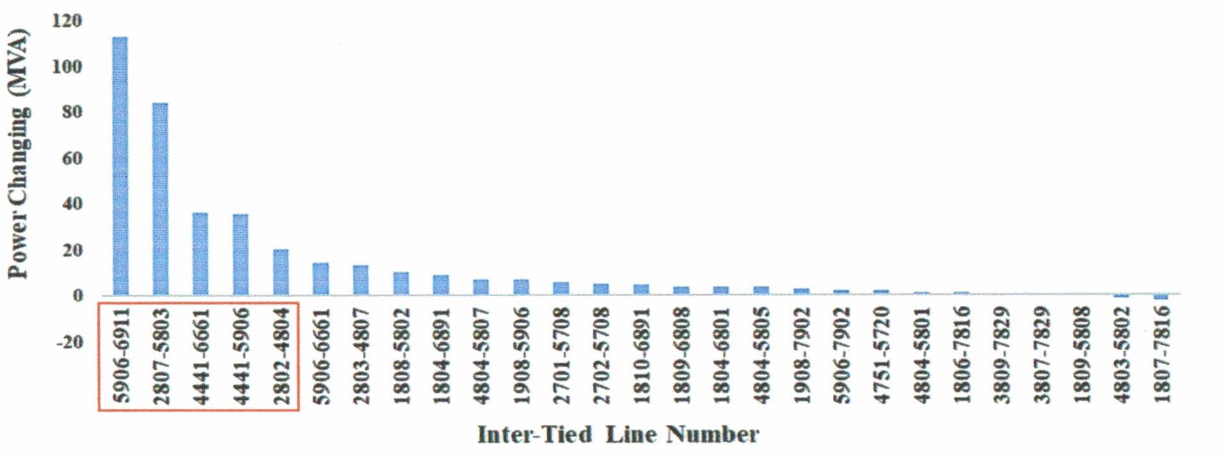


Fig. 2 Transmission line sequence that is important in power transfer in case of the generator with the maximum capacity in area 2 is disconnected.

The Fig. 2 shows an important transmission line rating in the case that the generator with the highest capacity in area 2 is disconnected. In this specific sequence of inter-area transmission lines, it was found that the group of transmission lines were important in supporting power transfer across the five areas with the transmission lines 5906 – 6911, 2807 – 5803, 4441 – 6661, 4441 – 5906 and 2802 – 4804.

Results of assessment available transfer capability of transmission line that connected between areas in case losing a single transmission line that connected between areas

The evaluation results can be shown in Fig. 3, which illustrates available transfer capability of transmission line that connected areas by considering the load percentage of the transmission line in case of loss of each inter-tied line. It was found that when the transmission lines between the 4th and 5t^{h} areas were connected, if it was disconnected, it would result in the transmission line between the 7th and 6th areas being overloaded, respectively. It was also found that whether the 11th or 15th transmission line was disconnected, it would result in the transmission line between the 13th area being overloaded as well. As a result of power changes under the loss of 1 inter-area transmission line, it can make the transmission line sequence important to support the power transfer between areas from the power change rate on the transmission line or the load on the transmission line. When compared with the load in normal conditions, it was found that in the case of the fifth transmission line being disconnected, the 6th transmission line (1804 – 6891) was subject to the maximum load. This means that it is an important transmission line in the supporting for power transfer instead. In this case, the priority of inter-area transmission lines can be obtained as shown in Fig. 4.

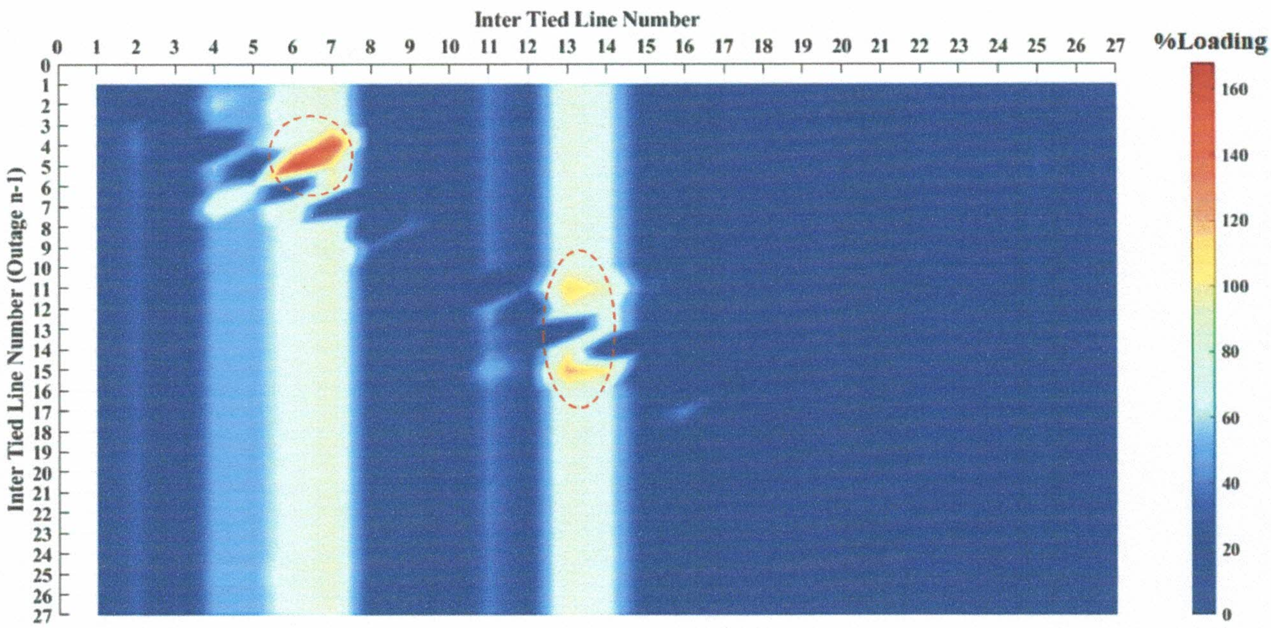


Fig. 3 Inter-tied lines' load percentage assessment in case of loss of each inter-tied line.

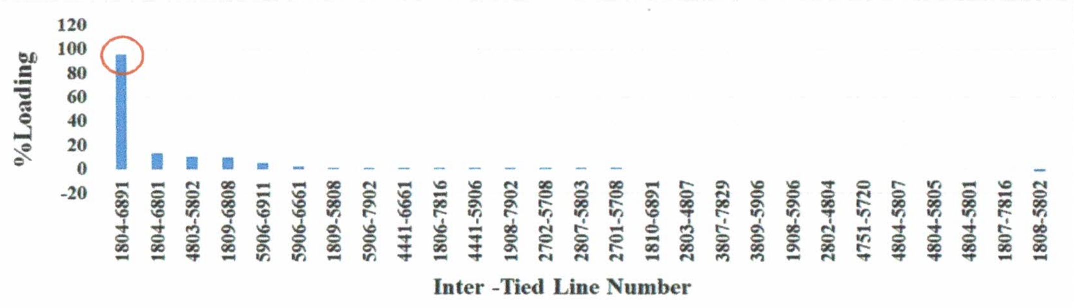
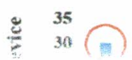


Fig. 4 Priority transmission line sequence in the case of the fifth line (1810 – 6891) is disconnected.

The study results of the severity of the area-to-system transmission line if disconnected

The study results of the severity of the area-to-system transmission line as shown in Fig. 5, in which the severity of this research article is determined by the number of violations of control values. In measuring both the voltage regulation and the load percentage of the transmission line, it was found that the transmission line number 2802 – 4804, if disconnected, will have the most severe impact by the number of violation devices for 30 devices.



4. Conclusion

Research studies assessing power transfer capability between areas are important if transmission lines cannot support the power transfer. They may be disconnected because of overload and possibly cause system instability. Therefore, this research presents techniques for assessing the power transfer capacity between areas of large power systems, and for improving the stability of the system by considering the thermal limit of the transmission line. The thermal limit represents the maximum power transfer capacity of the transmission line. This technique is not only used in the study of the Thailand power system, but also for other power systems. The proposed techniques reveal the maximum and residual capacity of each control area, as well as each transmission line among areas. This includes the priority of transmission lines that support power transfer in both cases. When there is a generator with the highest capacity in each area being disconnected and the transmission line between the areas is disconnected. It can also indicate the severity of the inter-area transmission line if it is disconnected, considering the number of devices that violate both voltage regulation and load percentage values. These data are important information that can be used for planning to improve power system stability.

5. Suggestions

The studies in this research focus on the inter-area power transfer capability based on thermal limit, which is the highest capability of the transmission line. The proposed techniques can be used to assess the capabilities of the transmission lines in a system, not just the inter-area transmission line. The study results of the transmission lines that are important to support the power transfer of each transmission line can be used to manage the power system control to prevent power flow congestion in the system.

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