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Electrical power system restoration planning in southern area of Lao PDR

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Abstract

This paper presents a study for a power system restoration plan for the Electricité Du Laos (EDL) power system in Southern area of Lao's People Democratic Republic (Lao PDR) that utilizes available hydropower generation. Transient analysis is used in studying frequency and voltage fluctuations during the power system restoration process. DIgSILENT PowerFactory software is used as a tool to simulate the power system. Simulation results can be used to formulate guidelines for a safe and efficient restoration procedure of power system. The result of this research can assist the power system operators and planning engineers to set the plans for power system restoration in the case of a blackout.

Keywords: Blackout, DIgSILENT PowerFactory, power system restoration, restoration planning

1. Introduction

The EDL is responsible for operating the electrical power system in the Southern region of Lao PDR. The EDL has a duty to operate the generation, transmission, and distribution system. The system covers four provinces of Southern Lao PDR: Champasak, Saravanh, Sekong, and Attapeu. The generation system utilizes hydropower generation, one of the main sources of energy in this area. The hydropower plants (HPPs) are owned by EDL-Generation Public Company (EDL-Gen), which is a subordinate of the EDL and Independent Power Producer for domestic supply (IPPd) as shown in Table I. The transmission system belongs to EDL, which is operated at a 115 kV voltage level. The distribution system consists of nine substations, all of which have 115/22 kV transformers used to convert the voltage level to 22 kV as shown in Table II. Furthermore, the Southern power system is connected to the Electricity Generating Authority of Thailand's (EGAT) power grid through a single circuit of 115 kV transmission line. This circuit allows for the exchange (import/export) of power between southern Laos and Thailand as shown in Fig. 1[1].

Table 1. The generations in the southern power system [1]

Name of HPP	Owner	Installation capacity (*unit x MW*)
Xeset1 [XS1]	EDL-Gen	2 x 3, 3 x 13
Xeset2 [XS2]	EDL-Gen	2 x 38
Xeset3 [XS3]	EDL-Gen	1 x 5, 1 x 18
H.lamphangnai [HLPG]	EDL-Gen	2 x 44
Xelabam [XLB]	EDL-Gen	3 x 0.7, 1 x 3
Houaypor [HP]	IPPd	2.5 x 2, 2 x 5
Xenamnoy1 [XNN1]	IPPd	2 x 7.5
Xenamnoy6 [XNN6]	IPPd	2 x 2.5

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Xekatam [XKT]	IPPd	3 x 7
Namkong2 [NK2]	IPPd	3 x 22
Total		359

Table 2. The substations in the southern power system [1]

Name of substation	Location	Transformer capacity (*unit x MW*)
Bangyo (BY)	Champasak	2 x 25
Banhat (BH)	Champasak	2 x 20
Saphaothong (SPT)	Attapeu	1 x 20
Banna (BN)	Champasak	2 x 30
Taothan (TT)	Saravanh	1 x 30
Nongbong (NB)	Sekong	1 x 30
Nathone (NT)	Saravanh	2 x 20
Jiangxai (JX)	Champasak	1 x 30
Paksong (PS)	Champasak	1 x 50
Total		350

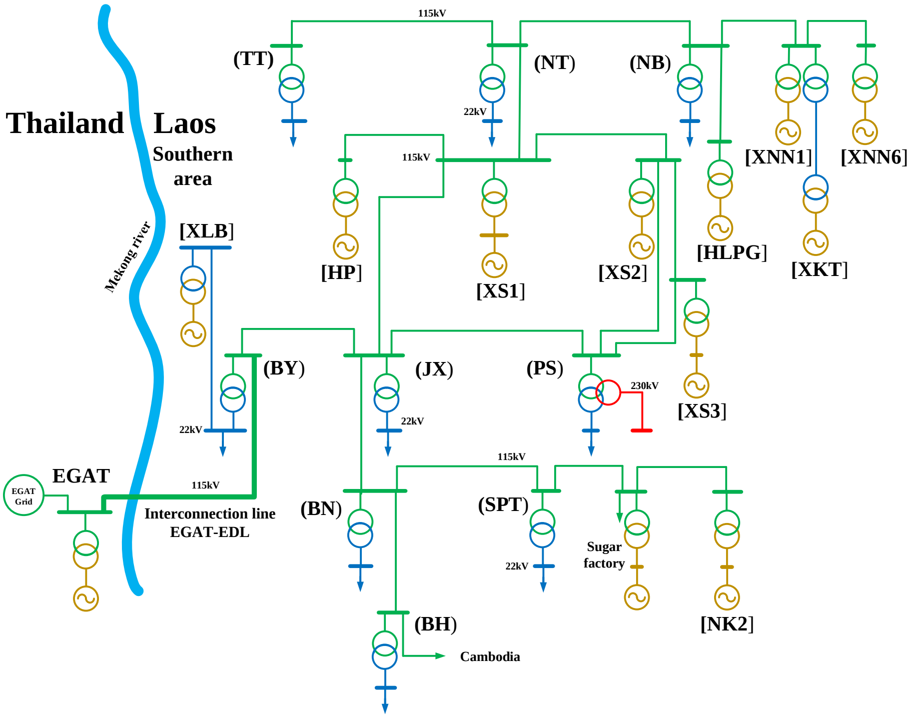

Fig. 1. The southern power system [1].

While the EDL is the power system operator for Southern Lao PDR's power system, the interconnection line is shared with Thailand's EGAT's power system. The EDL does not participate in frequency control of the much larger EGAT power system. An unpredictable event such as the tripping out of an interconnection line with a more powerful transfer, by fault still may occur and cause a blackout in the Southern Lao PDR power system. The power in this area would suffer from the blackout with households, businesses, industries and the power generation of the hydropower plants being impacted [2]. During the blackout, restoration of the power system would be reliant on imported power from the EGAT's power grid to provide electricity. The advanced preparation of a system restoration plan is very important to help the EDL to manage power during such a crisis situation.

The purpose of this paper is to investigate the power system restoration planning in the Southern power system by using the available hydropower generation. This paper focuses on the case of a blackout with all the power plants tripped out of the system. The electricity will be restored from a black-start generation unit rather than being transferred from a nearby system through the interconnection line.

2. Research Methodology

In this study uses DIgSILENT PowerFactory software to execute the power system dynamic simulations and calculate the frequency and voltage fluctuations during the power system restoration process [3]. Fig. 2 shows the flowchart of the simulation model for the power system restoration analysis method starting with input the data for the generation, transmission, substation, and load. Firstly, the generators are hydraulic power plants. The hydraulic turbine governor and excitation systems are selected from the PowerFactory library standard models related to the IEEE models named "gov_HYGOV" and "avr_EXST1" respectively [4], [5], [6]. Next, the transient Simulation will be used in the modified model. This involves switch events used to analyze the process of power system restoration. For example, start-up generator into the system, charging a transmission line and load pick-up. Then the simulation model will use the transient analysis as a tool to calculate frequency and voltage fluctuations following the defined switch events. Finally, the report result will be shown in the virtual instrument panel of PowerFactory. The result of the simulation can help to select the best plan. These following criteria are determined during the system restoration process to improve the opportunity of restoring successfully [7], [8]:

- A frequency fluctuation should be in the range of 50 ±0.5Hz.
- First point A voltage fluctuation should be in the range of -5% to +10% of nominal voltage.
- Energizing transmission line at 115 kV with 1 circuit before.
- Supply load about 20-30% of the total load at any substation in order to control voltage level in range.
- Supply generation to another power plants that cannot black start itself to startup generator.

The Flowchart of the procedure for the power system restoration planning analysis is shown in Fig. 2.

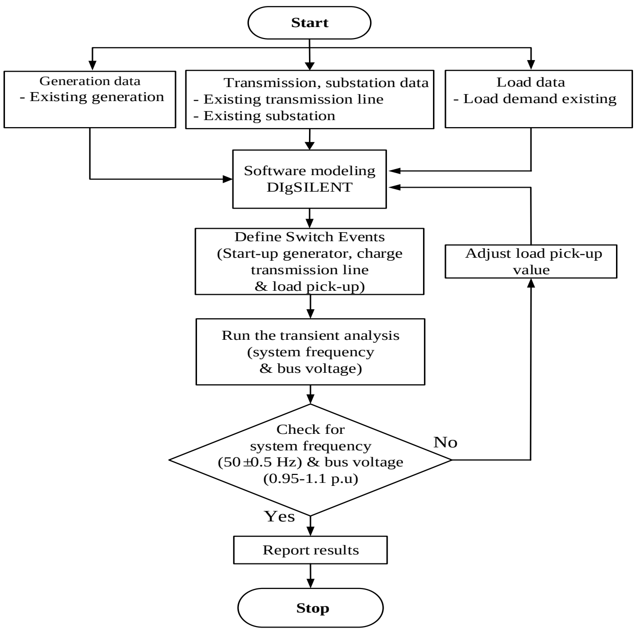

Fig. 2. Flowchart of procedure for power system restoration planning.

3. Case Study and Result

3.1. The case study

The analytical process was applied to this case study to determine the appropriate system restoration planning method. The transient analytical process involved defined switch events such as restarting generation, line charging, and load pick-up for the system restoration process. The power system representing a section of the Southern power system is shown in Fig. 3. The system consists of five generators in four hydropower plants that are built on synchronous generators and a few control units as shown in Table III. The system has 14 circuits of 115 kV transmission lines as shown in Table IV. The system supplies power to nine substations with total peak load demand 111.3 MW (20/04/2018) as shown in table V [9].

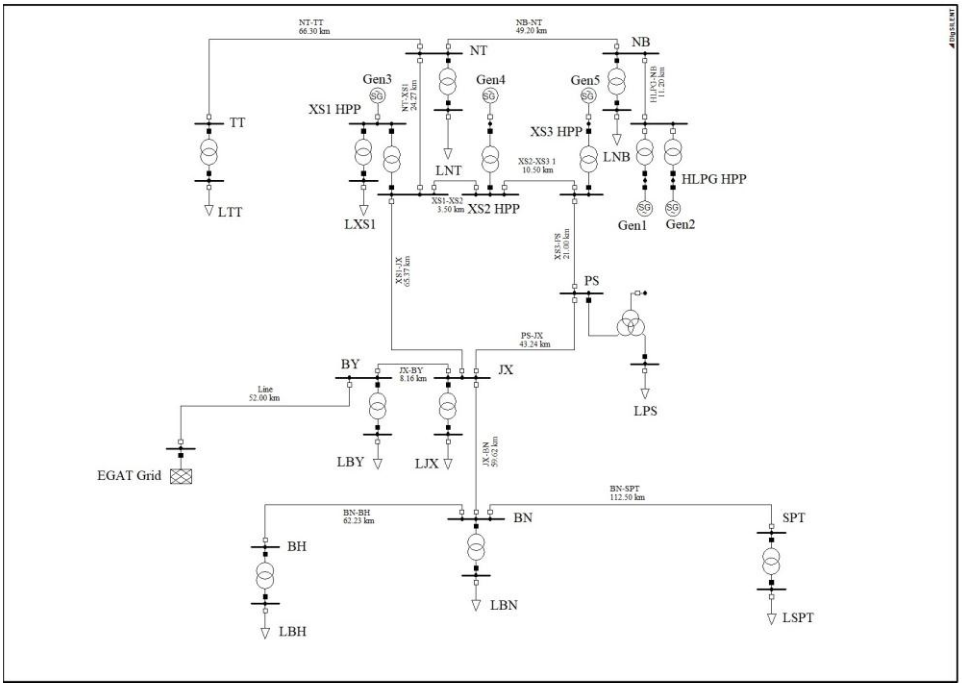

Fig. 3. The simulation model in DIgSILENT PowerFactory.

Table 3. Main characteristics of generators

Name	Unit type	Power plant	S (*MW*)	Voltage regulator	Speed governor
Gen1	Hydro	HLPG	44	avr_EXST1	gov_HYGOV
Gen2	Hydro	HLPG	44	avr_EXST1	gov_HYGOV
Gen3	Hydro	XS1	13	avr_EXST1	gov_HYGOV
Gen4	Hydro	XS2	38	avr_EXST1	gov_HYGOV
Gen5	Hydro	XS3	18	avr_EXST1	gov_HYGOV

Table 4. The details of 14 transmission lines [1]

Line	Type of line	Length (*km*)
HLPG-NB	240 sqmm ACSR	11.2
NB-NT	240 sqmm ACSR	49.2
NT-XS1	240 sqmm ACSR	24.2
XS1-XS2	240 sqmm ACSR	3.5
XS2-XS3	240 sqmm ACSR	10.5
XS3-PS	240 sqmm ACSR	21.0
PS-JX	240 sqmm ACSR	43.2
JX-BY	240 sqmm ACSR	8.1
JX-BN	240 sqmm ACSR	59.6
BN-BH	240 sqmm ACSR	62.2
NT-TT	240 sqmm ACSR	66.3
BN-SPT	240 sqmm ACSR	112.5
XS1-JX	240 sqmm ACSR	65.3
BY-EGAT	240 sqmm ACSR	52.0
Total		588.8

Table 5. Peak load demand in each substation [9]

Substation	Load name	Load (*MW*)
BY	LBY	30.3
BH	LBH	17.8
SPT	LSPT	12.1
BN	LBN	9.1
TT	LTT	5.0
NB	LNB	4.6
NT	LNT	15.4
JX	LJX	10.6
PS	LPS	5.1
XS1	LXS1	1.2
Total		111.3

This research can be used as a guideline for power system restoration planning. The transient analysis used the condition of system restoration planning. The results will be used to improve the power system restoration planning.

3.2. The simulation results of the transient analysis

The purpose of this research is to be able to restore the power system during times of crisis, using available hydropower generation. The procedure of the analysis process is black-starting a power plant, charging and synchronizing with interconnection line. Distribution of a load is not the main objective. However, what is required is the successful transfer of electrical power from a black-start generator to another that results in the electrical power system recovering. There are three case studies for the power system restoration analysis as follow:

- Case1: Power system restoration by Gen1

The power system restoration sequence of events that were identified for case1 are outlined in Table VI.

Table 6. Power system restoration sequence for case1

Time (*s*)	Event	Time (*s*)	Event
0	Close line HLPG-NB	2820	Load Pick-up LBY
300	Start-up Gen1	3000	Load Pick-up LBY
480	Load Pick-up LNB	3180	Close line JX-BN
660	Close line NB-NT	3360	Load Pick-up LBN
840	Load Pick-up LNT	3540	Load Pick-up LBN
1020	Close line NT-XS1	3720	Close line BN-BH
1200	Load Pick-up LXS1	3900	Load Pick-up LBH
1380	Close line XS1-XS2	4080	Load Pick-up LBH
1560	Close line XS1-XS3	4260	Close line NT-TT
1740	Close line XS3-PS	4440	Load Pick-up LTT
1920	Load Pick-up LPS	4620	Load Pick-up LTT
2100	Close line PS-JX	4800	Close line BN-SPT
2280	Load Pick-up LJX	4980	Load Pick-up LSPT
2460	Load Pick-up LJX	5160	Load Pick-up LSPT
2640	Close line JX-BY		

Remark: Start-up time hydropower units: 300 s, grid operations: 180 s

Fig. 4-6 show the simulation results for case1. During the restoration process, the lowest and steady-state frequency of the system is 49.3 Hz and 49.6 Hz respectively as shown in Fig. 4. For the voltage fluctuation result, the lowest and highest are 0.96 p.u. and 1.04 p.u. respectively as shown in Fig. 5. The initial load that can be restored is 31.2 MW (28% of peak load) as shown in Fig. 6.

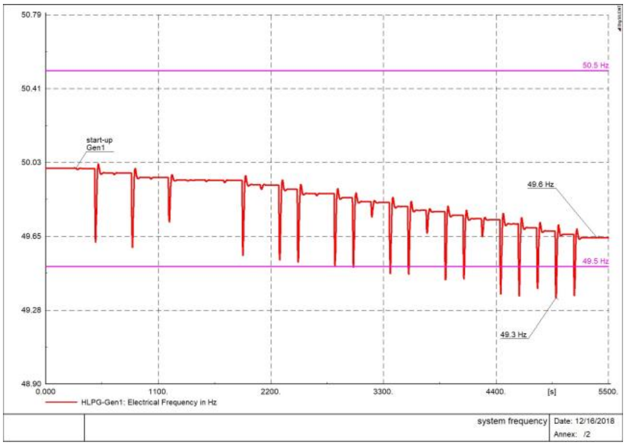

Fig. 4. Behavior of frequency during the power system restoration for case1.

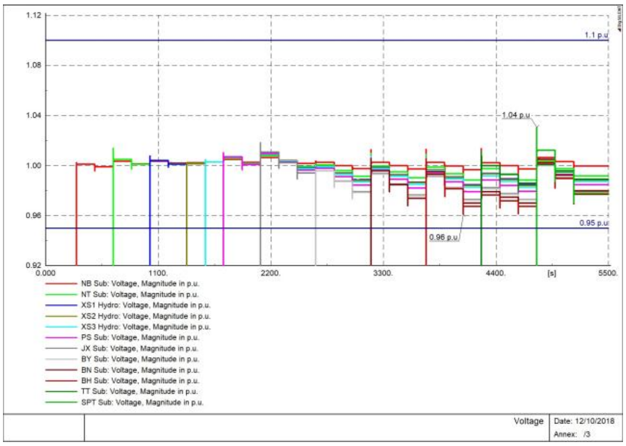

Fig. 5. Behavior of bus voltages during the power system restoration for case1.

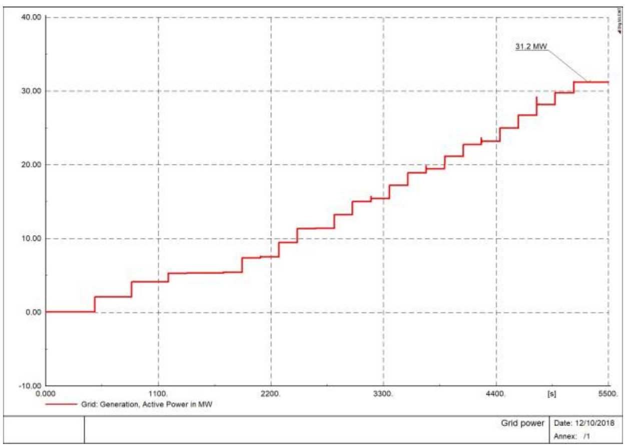

Fig. 6. Grid power during the power system restoration for case1.

- Case2: Power system restoration by 2 generators (Gen1 and Gen2)

  The power system restoration sequence of events that were identified for case2 are shown in Table VII.

Table 7. Power system restoration sequence for case2

Time (*s*)	Event	Time (*s*)	Event
0	Close line HLPG-NB	2280	Close line PS-JX
300	Start-up Gen1	2460	Load Pick-up LJX
480	Load Pick-up LNB	2640	Close line JX-BY
660	Close line NB-NT	2820	Load Pick-up LBY
840	Load Pick-up LNT	3000	Close line JX-BN
1034	Start-up Gen2	3180	Load Pick-up LBN
1200	Close line NT-XS1	3360	Close line BN-BH
1380	Load Pick-up LXS1	3540	Load Pick-up LBH
1560	Close line XS1-XS2	3720	Close line NT-TT
1740	Close line XS1-XS3	3900	Load Pick-up LTT
1920	Close line XS3-PS	4080	Close line BN-SPT
2100	Load Pick-up LPS	4260	Load Pick-up LSPT

Remark: Start-up time hydropower units: 300 s, grid operations: 180 s

Fig. 7-9 show the simulation results for case2. During the restoration process, the lowest and steady-state frequency of the system is 49.5 Hz and 49.8 Hz respectively as shown in Fig. 7. For the voltage fluctuation result, the lowest and highest are 0.96 p.u. and 1.01 p.u. respectively as shown in Fig. 8. The initial load that can be restored is 31.2 MW (28% of peak load) as shown in Fig. 9.

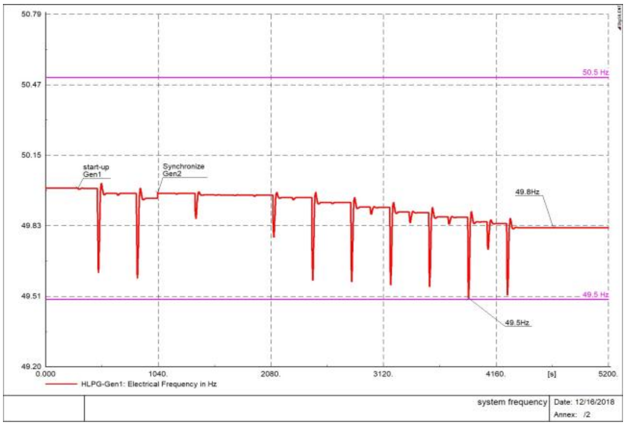

Fig. 7. Behavior of frequency during the power system restoration for case2.

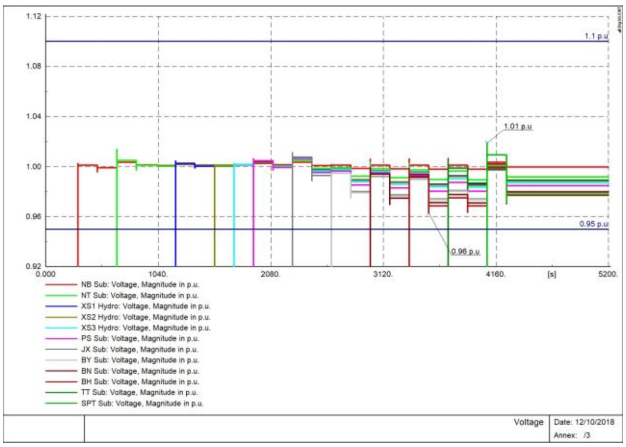

Fig. 8. Behavior of bus voltages during the power system restoration for case2.

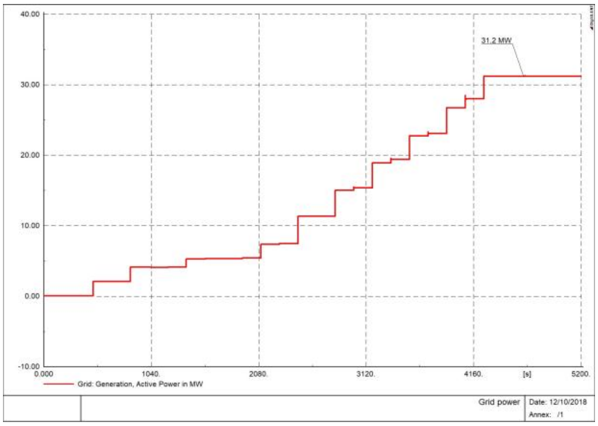

Fig. 9. Grid power during the power system restoration for case2.

- Case3: Power system restoration by 5 generators (Gen1, Gen2, Gen3, Gen4, and Gen5)

The power system restoration sequence of events that were identified for case3 are presented in Table VIII.

Table 8. Power system restoration sequence for case3

Time (*s*)	Event	Time (*s*)	Event
0	Close line HLPG-NB	2640	Close line PS-JX
300	Start-up Gen1	2820	Load Pick-up LJX
480	Load Pick-up LNB	3013.4	Start-up Gen5
660	Close line NB-NT	3180	Close line JX-BY
840	Load Pick-up LNT	3360	Load Pick-up LBY
1034	Start-up Gen2	3540	Close line JX-BN
1200	Close line NT-XS1	3720	Load Pick-up LBN
1380	Load Pick-up LXS1	3900	Close line BN-BH
1560	Close line XS1-XS2	4080	Load Pick-up LBH
1740	Close line XS1-XS3	4260	Close line NT-TT
1934.9	Start-up Gen3	4440	Load Pick-up LTT
2100	Close line XS3-PS	4620	Close line BN-SPT
2280	Load Pick-up LPS	4800	Load Pick-up LSPT
2471.2	Start-up Gen4		

Remark: Start-up time hydropower units: 300 s, grid operations: 180 s

Fig. 10-12 show the simulation results for case3. During the restoration process, the lowest and steady-state frequency of the system is 49.6 Hz and 49.9 Hz respectively as shown in Fig. 10. For the voltage fluctuation result, the lowest and highest are 0.98 p.u. and 1.01 p.u. respectively as shown in Fig. 11. The initial load that can be restored is 31.3 MW (28% of peak load) as shown in Fig. 12.

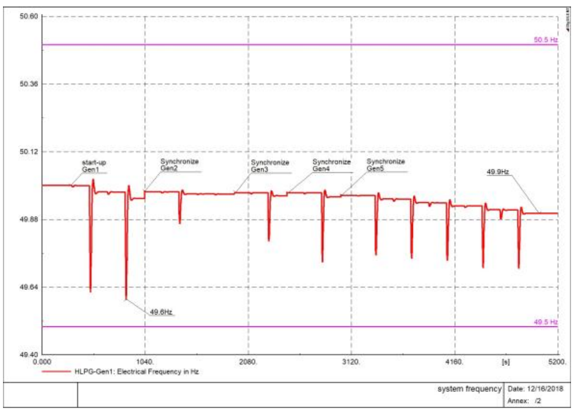

Fig. 10. Behavior of frequency during the power system restoration for case3.

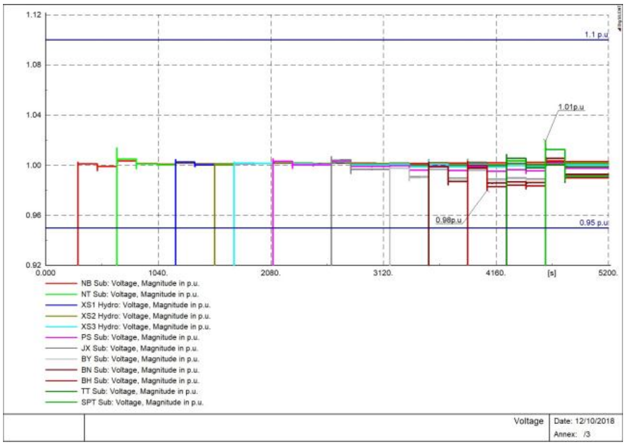

Fig. 11. Behavior of bus voltages during the power system restoration for case3.

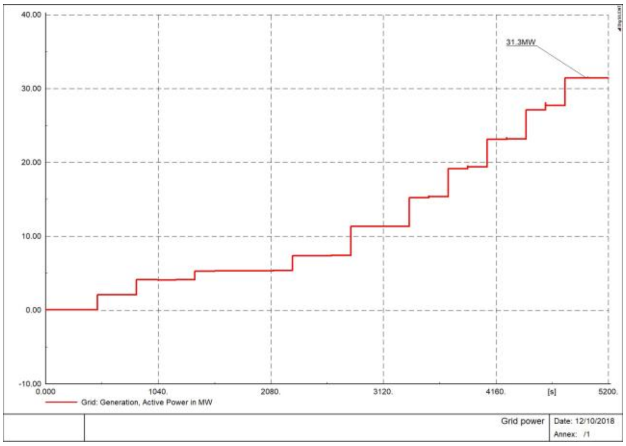

Fig. 12. Grid power during the power system restoration for case3.

Table IX illustrates the analysis results of the three case studies. The analysis result of case3 has shown that the frequency and voltage fluctuations are minimal compared to the other cases. Therefore, it is the most suitable case for the system restoration planning, in consideration of system stability.

Table 9. The analysis results of the three case studies

No.	Frequency fluctuation (*Hz*)	Δf	Voltage fluctuation (*p.u.*)	Δv	Grid power (*MW*)
Case1	50.0-49.3	0.7	1.04-0.96	0.08	31.2
Case2	50.0-49.5	0.5	1.01-0.96	0.05	31.2
Case3	50.0-49.6	0.4	1.01-0.98	0.03	31.3

4. Conclusions

The transient analysis can be a guideline for power system restoration planning. In this case study, the DIgSILENT PowerFactory software is applied for the power system restoration planning. As reported by the analysis result, the frequency and voltage fluctuations during the power system restoration process can be used to define guidelines for power system restoration procedures. The result of this research can help power system operators and planning engineers to plan for a potential blackout through power system restoration plans.

Conflict of Interest

The purpose of power system operation is to control the power system with more reliability and security. The stability has to be operated within the criteria. Thus, power system control strategies are necessary for electrical utility in order to achieve this purpose. Unfortunately, the power system still has a risk to face an unwanted event. Hence, the electrical utility is not only having a plan to protect the power system from an unpredictable event but also have preparation to restore the power system back to normal operation. This paper describes the procedures of the power system restoration plan that utilizes available hydropower generation. The result of this research can assist the power system operators and planning engineers to set the plan in the case of a blackout. Therefore, the author declares that in this paper no conflict of interest.

Author Contributions

In order to qualify for authorship, all authors have engaged in research and preparation as follows. This study was designed, directed, and coordinated as the principal inspectors, providing conceptual and technical advice for all aspects of this project by Assoc. Prof. Dr. Suttichai Premrudeepreechacharn. Performed and supported the experimental data by Electricity Generating Authority of Thailand (EGAT) as Kanchit Ngamsanroaj. Discussed and commented on by Kohji Higuchi. Finally, summary and wrote the paper by Vanhxay Khounnavong.

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