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. DlgsILENT 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, DlgsILENT 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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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.

![Flowchart of procedure for power system restoration planning.](image)

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.](image)

**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-
The 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 case 1.

Fig. 5. Behavior of bus voltages during the power system restoration for case 1.

Fig. 6. Grid power during the power system restoration for case 1.
- 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.
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.
Table IX illustrates the analysis results of the three case studies. The analysis result of case 3 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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