CHAPTER 2

Principle and Methodology

This chapter introduces the principle and methodology of generation planning for reliability improving of the power system in northern and central 1 region of Lao PDR. This study is used the power flow analysis theory and calculated the reliability indices such as System average Interruption Frequency Index (SAIFI), System Averages Interruption Duration Index (SAIDI), and Energy Not Supplied Index (ENS). The analyze use the network system and technical information of EDL.

2.1 Principle and Theory

2.1.1 Power flow analysis

The analysis of power flow is important for the planning and designing the power system in the future. The analysis of power flow is important for the planning and designing the power system in the future. The load flow analysis is an important tool to process the planning, designing and power system operation under several operating conditions and configuration of equipment. The differences of power flow calculation can be used to predict the value of line loss, transformer loading, power exchange between two or more grid, and required voltage control range of transformer and generator [10], [11].

In power flow calculation, an electric network is presumed to be operated under the symmetrical condition, and represented with a single-phase model. Three bus types in the system are specified; PQ Buses (the active and reactive demand of every load bus; MW and MVar, respectively), voltage-controlled buses (the injected active power and the set magnitude voltage of every generator bus; MW and pu, respectively), and slack buses (the set of the phase angle and magnitude voltage of every slack generator bus; degree and pu, respectively).

To solving a power flow problem is to determine a phase voltage (both angle and magnitude) of every bus, injected reactive power from every generator, and injected power from every slack generator.

The figure 12 is shown the relation between bus voltages and active/reactive powers at each bus. Which the load flow can be calculated criteria below.

The bus-admittance equation is

$$Y_{ij} = |Y_{ij}|\angle\theta_{ij} = |Y_{ij}|\cos\theta_{ij} + j|Y_{ij}|\sin\theta_{ij} = G_{ij} + jB_{ij} \tag{2.1}$$

Where:

G_{ij} = Bus Conductance, and

B_{ij} = Bus Susceptance;

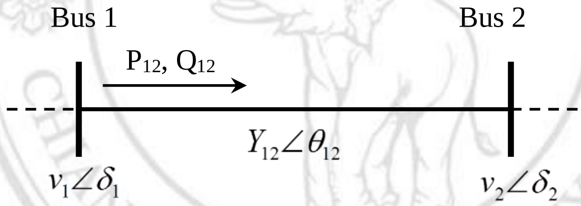


Figure 2.1 The relation between bus voltages and active/reactive powers at each bus.

The voltage at the i^{th} bus of the system is given by

$$V_i = |V_i|\angle\delta_i = |V_i|(\cos\delta_i + j\sin\delta_i) \tag{2.2}$$

Where:

δ_i = the phase angle of the voltage at the i^{th} bus.

The active (Pi) and reactive (Qi) powers injected from the bus in term of the element Yij are

$$P_i = |V_i|^2 \times G_{ii} + \sum_{n=1, n\neq i}^{N} |V_i V_n Y_{in}| \times \cos(\theta_{in} + \delta_n - \delta_i) \tag{2.3}$$

$$Q_i = -|V_i|^2 \times B_{ii} - \sum_{n=1, n\neq i}^{N} |V_i V_n Y_{in}| \times \sin\left(\theta_{in} + \delta_n - \delta_i\right) \tag{2.4}$$

The numerical method applied to find the solutions of the above power flow equations is the Newton-Raphson techniques.

2.1.2 System Reliability Assessments

The system reliability assessments is study very important. It can be used to show the numerical understanding and led to the decision to choose for a system or equipment system to changes and other components. Reliability analysis of an electrical system is considered as a tool for the planning engineer to ensure an appropriate quality of service. It allows a choice between different system expansion plans that cost intelligent are comparative when considering system investment and cost of losses. The details are used methods for analyzing the reliability of power system is below [12], [13].

2.1.2.1 System average Interruption Frequency Index (SAIFI)

SAIFI is indicates how often the average customer experiences a sustained interruption during the period specified in the calculation, and its units is 1 per customer per annual [1/C/a]. Consequently, SAIFI calculation refers to the equation (2.5).

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruption}{Total\ Number\ of\ Customer} = \frac{\sum N_i}{\sum N_T} \tag{2.5}$$

Where:

N_i = Number of interrupted customers for each sustained interruption even during the reporting.

N_T = Total number of customers served of the areas.

2.1.2.2 System Averages Interruption Duration Index (SAIDI)

SAIDI is indicates the total duration of interruption for the average customer during the period in the calculation. It is commonly measured in customer minutes or customer hours of interruption, and its units is the hours per customer per annual [h/C/a]. The calculation is refers to the equation (2.6).

$$SAIDI = \frac{Sum\,of\ Customer\ Interruption\,Duration}{Total\ Number\ of\ Customer\ Served} = \frac{\sum r_i N_i}{\sum N_T} \qquad (2.6)$$

Where:

r_i = Restoration time for each interruption event.

N_i = Number of interrupted customers for each sustained interruption even during the reporting.

N_T = Total number of customers served of the areas.

2.1.2.3 Energy Not Supplied Index (ENS)

ENS is the total amount of energy on average not delivered to the system load, and its units is the Megawatt hours per annual [h/C/a]. The calculation is refers to the equation (2.7).

$$ENS = \sum L_{a(i)} U_i . \quad \text{[kWh/year]} \qquad (2.7)$$

Where:

$L_{a(i)}$ = the average load (kW) not supplied if tripping the transmission line i,

= the average load (kW) connected to load point i.

Ui = is the annual outage time.

2.2. The method of study

The method of study is used the technical data of EDL. The analysis is studied in several cases to select the suitable case for the best generation planning in the future, the load data, generation data, and transmission data should be considered. DIgSILENT software is used in this study for analyzing the load flow and reliability assessment of the system. The result of this study can help to choose the best case, which is under fundamental technical criteria of EDL below:

1) The overloading should be ≤ 85 % of the rated transmission line.

2) The bus voltages must be in the range ± 5 % of the nominal voltage.

3) The system power loss must be decreased.

The Figure 2.1 shows the procedure of generation planning and improving the reliability of power system, which has the operation step as bellowing.

- Step 1: The load demand forecast, generation, and transmission line data of EDL is used for the analysis in this research.

- Step 2: To create the simulation modeling in DIgSILENT software. Run program to analyze the power flow (Overloading, voltage and power loss).

- Step 3: addition the hydropower plant will be to connect with the grid of EDL. Selection the result under the fundamental technical criteria of EDL.

- Step 4: Calculation reliability indices such as SAIFI, SAIDI, and ENS to find the sustainable case.

- Step 5: Compare reliability between the base case and select case.

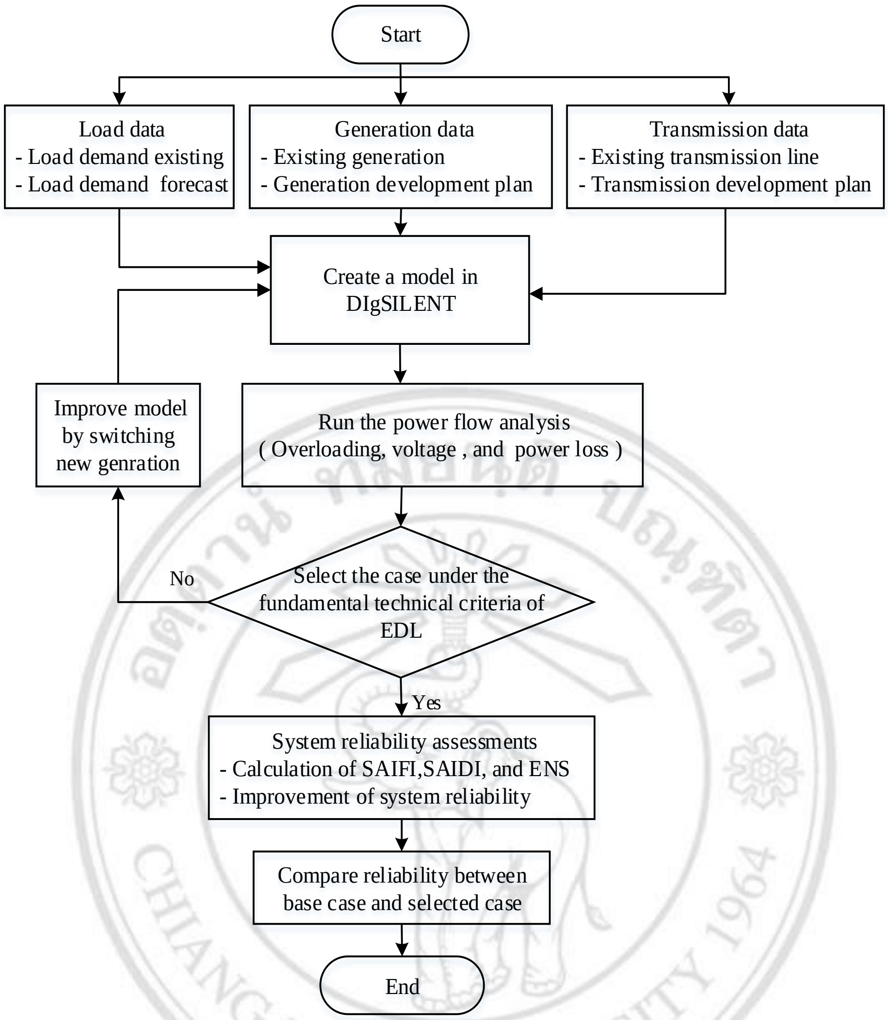


Figure 2. 1 The procedure of generation planning and improving reliability of power system.

2.3. Power flow Calculation

This research calculated the power flow by DIgSILENT Programming Language (DPL) is used to create script writing for analyzing all of the power system parameters. Figure. 2.2 is shown flowchart the power flow analysis of DPL function, which has the operation step as bellowing [10].

- Step 1: is used the power system and the generation development plan of EDL.
- Step 2: initial the script writing to analyze the overloading, voltage, and power loss of each project.
- Step 3: run the program and save the result.

- Step 4: addition the generation until 12 projects.

- Step 5: The resulting analysis of the run program and the selected minimum value.

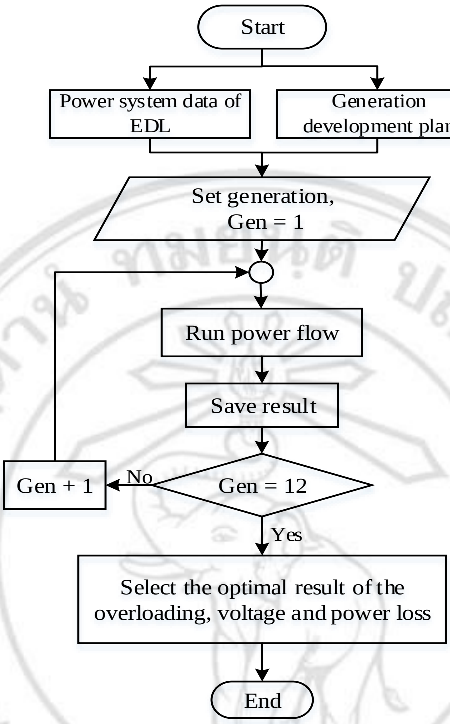
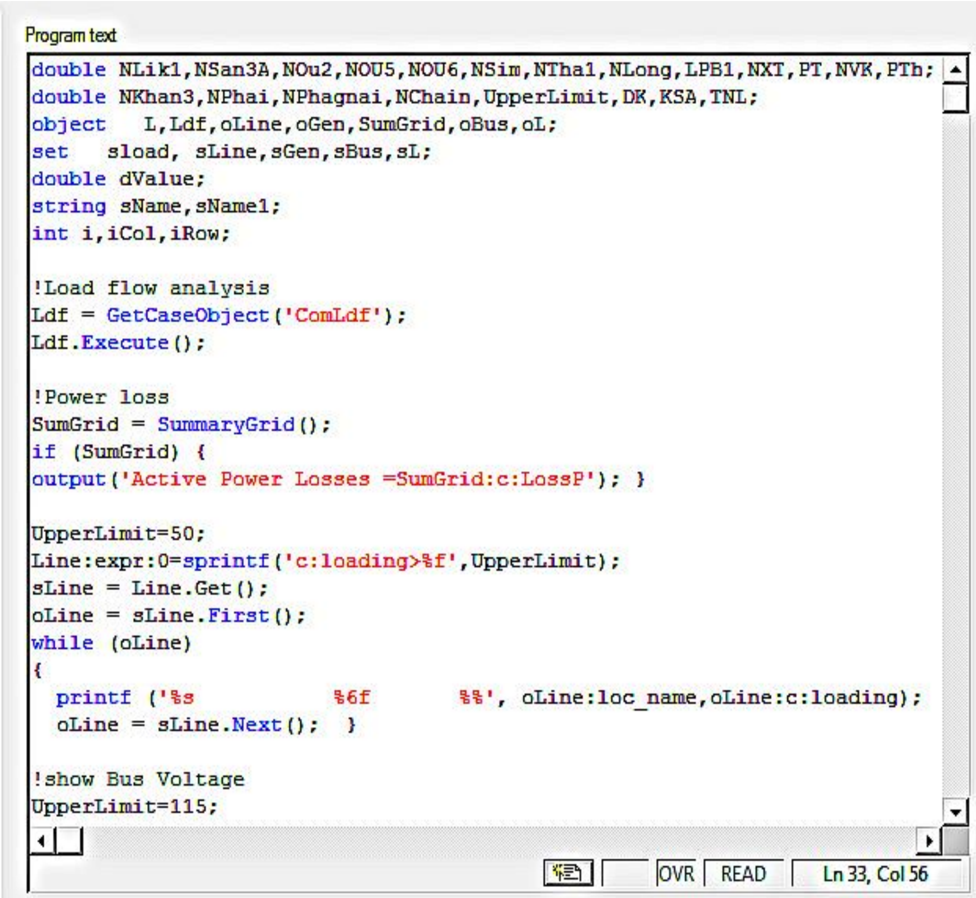


Figure 2. 2 The flowchart of the power flow analysis by DPL.

The writing of the DPL script in DIgsILENT software is a method to analyze the overloading, voltage, and power loss. The analysis process is connected by adding one hydropower plant until all new hydropower plants. Figure 2.4 is shown the partial writing DPL function script, as shown following.



```
Program text
double NLik1,NSan3A,NOu2,NOU5,NOU6,NSim,NTha1,NLong,LPB1,NXT,PT,NVK,PTh;
double NKhan3,NPhai,NPhagnai,NChain,UpperLimit,DK,KSA,TNL;
object   L,Ldf,oLine,oGen,SumGrid,oBus,oL;
set   sload, sLine,sGen,sBus,sL;
double dValue;
string sName,sName1;
int i,iCol,iRow;

!Load flow analysis
Ldf = GetCaseObject('ComLdf');
Ldf.Execute();

!Power loss
SumGrid = SummaryGrid();
if (SumGrid) {
output('Active Power Losses =SumGrid:c:LossP'); }

UpperLimit=50;
Line:expr:0=sprintf('c:loading>%f',UpperLimit);
sLine = Line.Get();
oLine = sLine.First();
while (oLine)
{
  printf ('%s          %6f        %%', oLine:loc_name,oLine:c:loading);
  oLine = sLine.Next();  }

!show Bus Voltage
UpperLimit=115;
```


Figure 2. 3 The partial script writing for analyzing the power flow in DPL function.

Example 2.1, Assume the transmission line connecting bus 1 to 2 has the impedance 100∠60° Ω and the bus voltage is 73,034.8∠30° and 66,395.3∠20° V per phase, respectively. Calculate the active power per phase, the reactive power per phase, and the power loss of bus 1 to 2.

From the equation (2.3) and (2.4) can could calculation the active power and reactive power of the network power system as following:

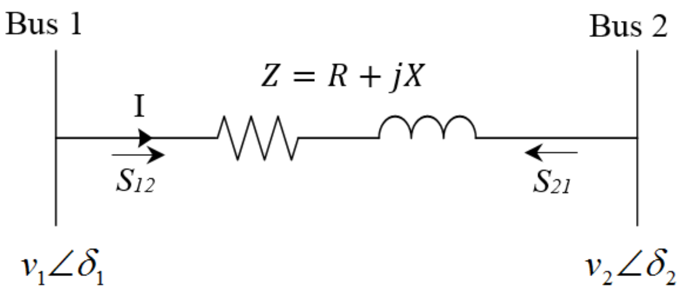


Figure 2. 4 The relation between voltage bus and active/reactive power at each bus.

Solution

$$S_{12} = P_{12} + Q_{12} = V_1(-I)^*$$

Since $I = \dfrac{V_1 - V_2}{Z}$

$$S_{12} = \frac{V_1^* - V_2^*}{Z}$$

$$S_{12} = (36517.4\angle 30°)\frac{36517.4\angle -30° - 33197.6\angle -20°}{50\angle 60}$$

$$= 5052403.14\angle 3.54°$$

$$= 5042762.82 + j311962.42$$

So

$$P_{12} = 5052403.14W$$

$$Q_{12} = 311962.42\,\text{var}$$

And

$$P_{Loss} = I^2 xR$$

From

$$I = \frac{P}{UCos\varphi} \quad / \; Cos\varphi = \frac{P}{S} = \frac{5042762.82}{5052403.14} = 0.99PF$$

$$I = \frac{5042762.82}{36517.4x0.99} = 139.48A$$

Therefor

$$P_{Loss} = (139.48)^2 x43.3$$

$$P_{Loss} = 848406.68W$$

2.4. Reliability Calculation

From the equation (2.5), (2.6) and (2.7) can could the reliability indices such as SAIFI, SAIDI and ENS to find sustainable case.

Example 2.2, the reliability index calculates the power system. The data details of the number customers and the average load connected to bus bar as shown in Table 2.1 and 2.2.

Table 2. 1 Data of number customer and average load connected.

Load point	Number customer	Average load connected
L1	800	3600
L2	1000	5000
L3	500	2400
L4	600	2800
L5	300	1800
L6	500	2400
Total	40,00	19,000

Table 2. 2 Data of interruption effected.

Interruption case	Load point effected	Duration interruption
1	1 3	2 3
2	2 4	2 2.5
3	3	2
4	5 6	2 3

- System Average Interruption Frequency Index (SAFI)

From

$$SAFI = \frac{\sum N_i}{N_T} = \frac{N_1 + N_2 + N_3 + N_4}{N_T}$$

$$= \frac{(800 + 500) + (10{,}00 + 600) + (500) + (300 + 500)}{400}$$

$= 0.33$ Times/customer/year.

- System Average Interruption Frequency Index (SAFI)

From

$$SADI = \frac{\sum N_i * d_i}{N_T} = \frac{N_1 d_1 + N_2 d_2 + N_3 d_3 + N_4 d_4}{N_T}$$

$$= \frac{(800 \times 2 + 500 \times 3) + (10{,}00 \times 2 + 6002.5) + (500 \times 2) + (300 \times 2 + 500 \times 3)}{40{,}00}$$

$= 0.6925$ Hour/customer/year.

- Energy Not Supply (ENS)

From

$$ENS = \sum L_i d_i = L_1 d_1 + L_2 d_2 + L_3 d_3 + L_4 d_4$$

$$= (800 \times 2 + 500 \times 3) + (10{,}00 \times 2 + 6002.5) + (500 \times 2) + (300 \times 2 + 500 \times 3)$$

$= 27{,}700$ KW/hour/year.

2.5. Case study

This case study has analyzed the suitable generation planning that has the analysis process is switching respectively the different hydropower plant into the existing system of EDL. The analysis is based on the base case of EDL, which has 12 hydropower plant with the total of installed capacity is 1,095 MW and they will be connected to the existing system of EDL as shown Table 2.3.

Table 2. 3 The 12 hydropower project connect to grid of EDL.

Projects No.	**Name of project**	**Location**	**Installed Capacity (MW)**	**Owner-ships**
1	Nam Khan3 (N.Kan3)	Luangprabang	60	EDL
2	Nam Long 2 (N.Long2	Luangnamtha	13	IPP.D
3	Nam Ou 2 (N.Ou2)	Luangprabang	120	IPP.D
4	Nam Ou 6 (N.Ou2)	Phongsaly	180	IPP.D
5	Nam Ou 5 (N.Ou2)	Phongsaly	240	IPP.D
6	Nam Sim (N.Sim)	Houaphanh	9	IPP.D
7	Nam Phagnai (N.Phagnai)	Saysomboun	15	IPP.D
8	Nam Chien (N.Chien)	Saysomboun	104	EDL
9	Nam San 3A (N.San 3A	Saysomboun	23	IPP.D
10	Nam Lik 1 (N.Lik1)	Vientiane Pro	64	IPP.D
11	Nam Tha 1 (N.Tha1)	Borkeo	168	IPP.D
12	Nam Pai (N.Phai)	Saysomboun	88	IPP.D
	Total		**1,095**	

In studying the generation planning for reliability improving the power system by analyzing the each project hydropower plant connects to the grid of EDL. After that will examine the result of run program which considered under fundamental technical criteria of EDL.

When to select the suitable case from the power flow analysis result. After that calculated the reliability indices such as SAIFI, SAIDI, and ENS to improve the reliability of power system.