Chapter 3

Proposed Method

As the import and export tariffs are different and depending on time of uses according to demand-supply principle. EDL requires a methodology for generation operation planning optimization taking into consideration generator maintenance scheduling. The methodology must also consider important characteristics of hydro power plant such as variation of capacity, different inflow in each period of year and limitation of energy etc. In this chapter, it is proposed that generator maintenance scheduling is integrated with, and is the first step in, generation operation planning. The chapter firstly describes the generation planning with hydro power plant characteristics. The proposed generation planning is a three process. In the first step, upper and lower storage limits are defined as detailed in section 3.1. After that the whole period will be divided into sub-periods. The result of this step will be different for each reservoir. The final step, described in section 3.2, is a generation planning to maximize system revenue, as a main objective function, and reliability as a main constraint. The detail of maintenance schedule search will be described in section 3.3.

3.1 Reservoir Operation Planning

Reservoir operation planning is water resource management problem such as how the water in reservoir will be used efficiently. Generally, the reservoir operation planners employ rule curves to control the water in reservoir. Many kinds of rule curves will be selected one or more depend upon the purposes of water in reservoir and the reservoir system in the river basin. In some places, the reservoirs are used for irrigation, electricity generation, flood control, transportation or pollution control and may be supported more than one purpose i.e. multipurpose. In some river basins, there is only one reservoir. Other river basins may have reservoirs cascaded on a river or separated to each branch of the river. The area of study in this report will consider only stand alone reservoir in a river basin and only electricity generation is supported due to the nature of Laos region-I reservoir.

The most important input parameter of hydro power plant is water inflow which is seasonal. Effective reservoir operation starts with high storage volume at the beginning of a dry season and the water will be released efficiently during the season. Opposite operation is adopted in rainy season. Consequently, it is energy limited unit for generation. The water level is increased with carefully controlled for avoiding the spill water. Generally the inflow probability of any reservoir will be forecasted, and the inflow volume is specified by inflow probability table that is derived from hydrology statistics. Normally if probability is low, the inflow is high. For prevention of high volume of spilled water and flood in rainy season and water shortage in the next dry season, the upper and lower rule curves of storage will be created and employed as constraints. The upper rule curve is determined from inflow volume based on wet year probability and maximum release passed through turbine. On the other hand, the drought year inflow probability with minimum release, which supports the security of the system or for other propose such as minimum water requirement, will be taken into account in lower rule curve calculation. The upper and lower rule curves will be different in each month due to the difference of the monthly inflow and water requirement.

To minimize the spill water, before starting of high inflow periods the reservoir storage should be at lower level in order to capture the incoming water and provide spill water protection. After the high inflow, the reservoir should be ideally full for serving the demand. The inflow data that used for creating this curve is the maximum inflow, the rule curve is the same concept of flood control rule curve and guarantee no spill water. Practically, if the maximum inflow in the past years is used to define the upper rule curve, the very high water will be released and may bring the reservoir to more shortage risk situation. Therefore, the inflow for the rule curve is selected are acceptable an spill probability such as once in decade, once in five years etc. Concern to the electricity generation reservoir and spill water protection, the water can be released pass turbines at the same time as high inflow coming, if assume that flood problem is not concerned. Normally, the reservoirs will employ this rule curve as maximum limit, called upper rule curve, and can be determine by the following formula.

$$URC_i = V_F - \sum_{j=i+1}^{k-1}\left(I_{\max} - q_{\max}\right) \tag{3.1}$$

Where, URC_i Upper Rule Curve in the month i

- V_F Full reservoir water volume
- j month
- i is the month that is calculating upper rule curve
- k is the month that $\left(I_{\max} - q_{\max}\right) \le 0$
- $I_{\max}$ is maximum inflow in the month j
- $q_{\max}$ is maximum outflow through turbine in the month j

On the other hand, the system requires minimum generation from the hydro power station that implied the system require minimum water storage for electricity generation. For protecting the water shortage, the minimum limit called lower rule curve must be calculated. The release water is easy to calculate from minimum generation but how to predict the inflow is not as easy. If the minimum inflow is used, it will guarantee no water shortage. But if the higher inflow is employed, the system will take higher risk. However, it will give more opportunities to produce the electricity at the most proper time. The proper inflow selected to create the minimum limit depends upon the acceptable water shortage probability, the consequential damage from water shortage and the opportunities to release electricity shortage. If the reservoir is very large when compared with the inflow, with this situation, the minimum inflow should be selected because it guarantees electricity shortage will not occur as the reservoir has large storage capability. The lower rule curve can be calculated by the following formula:

$$LRC_i = V_d - \sum_{j=i+1}^{k-1}\left(I_{\min} - q_{\min}\right) \tag{3.2}$$

Where, LRC_i Lower Rule Curve in the month i

- V_d is reservoir water volume at dead storage

j	month
i	is the month that is calculating lower rule curve
k	is the month that $(I_{\min} - q_{\min}) \geq 0$
$I_{\min}$	is minimum inflow in the month j
$q_{\min}$	is minimum outflow through turbine in the month j

Generally the upper and lower rule curves will decrease from a peak to a bottom in dry season and increase from a bottom to a peak in rainy season. Planning sub-period is defined by the peak and bottom points of upper and lower rule curves. Initial operating curve is calculated from average value of upper and lower rule curves. After that, the curve is divided into sub-period according to minimum and maximum point of the curve based on management of reservoir storage and release seasons, for explanation more detail we can see in figure 3.1. Hence, released water amount for each sub-period can be calculated. This process is start with setting the initial and target storage of each sub-period. The initial storage of the first sub-period and the target storage of the last sub-period are set by assumptions and constraints. The target of each sub-period except the last is derived from the upper and lower rule curves.

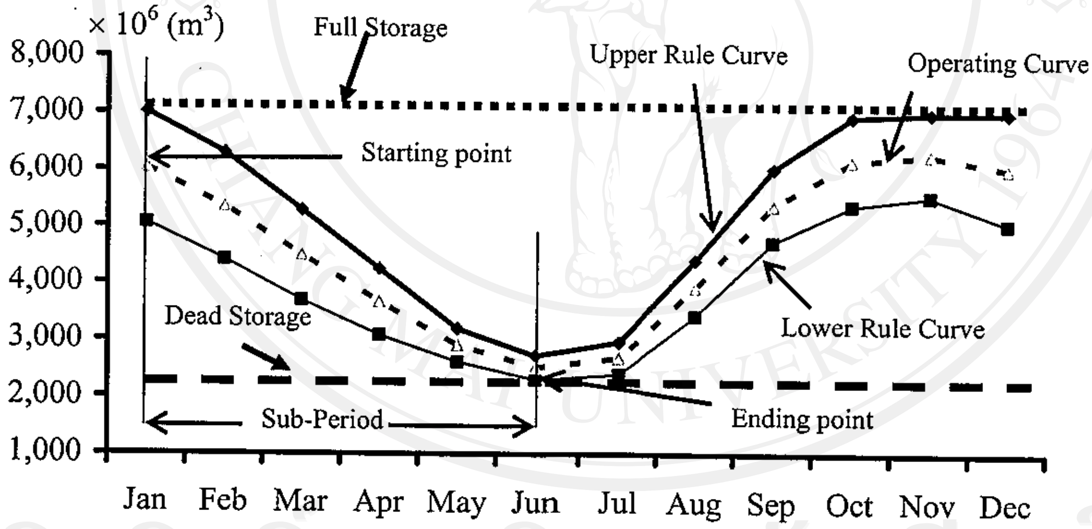

Figure 3.1 Initial Operating Rule Curve

3.2 Generation Planning Methodology

The released water of each sub-period calculated is the constraints in generation planning process as target generation and the upper and lower rule curves are constraints of each reservoir. Target energy generation of each sub-period can be calculated from released water. The equation (3.3), (3.4) and (3.5) are used for calculating the energy generation and the released water.

$$Energy\lim it_P = \frac{Release_P}{Water\,rate_P}\ ; \qquad kwh \tag{3.3}$$

$$Release_P = Start_P - End_P + I_P\ ; \qquad m^3 \tag{3.4}$$

where; $Water\,rate_P = f(head);\ m^3/kWh$

$Head = f(Volume)\ ;\ m$

$$Energy\lim it\ in\ period\ = \sum_{P=1}^{n} Energy\lim it_P \tag{3.5}$$

Where;

$Energy\lim it_P$ is the amount of enrgy that can be produced in sub-period P. (GWh)

$Release_P$ is the amount of water that can be released in sub-period P. (million cubic meters)

$Water\,rate_P$ is the amount of water that will be released for generating electric energy 1 kWh. (cubic meters per kWh)

n is the total number of sub-period.

Generation planning methodology in practical is the use of storage water in the reservoir and water inflow to the reservoir to generate electric energy considering water value. In this thesis, the best generating period is when the water is in high price. The objective is the maximum net revenue that is described in section 2.2.4. and the equation (2.9) is used as the objective function. The generation planning algorithm is shown in figure 3.2, and production planning is divided into three steps.

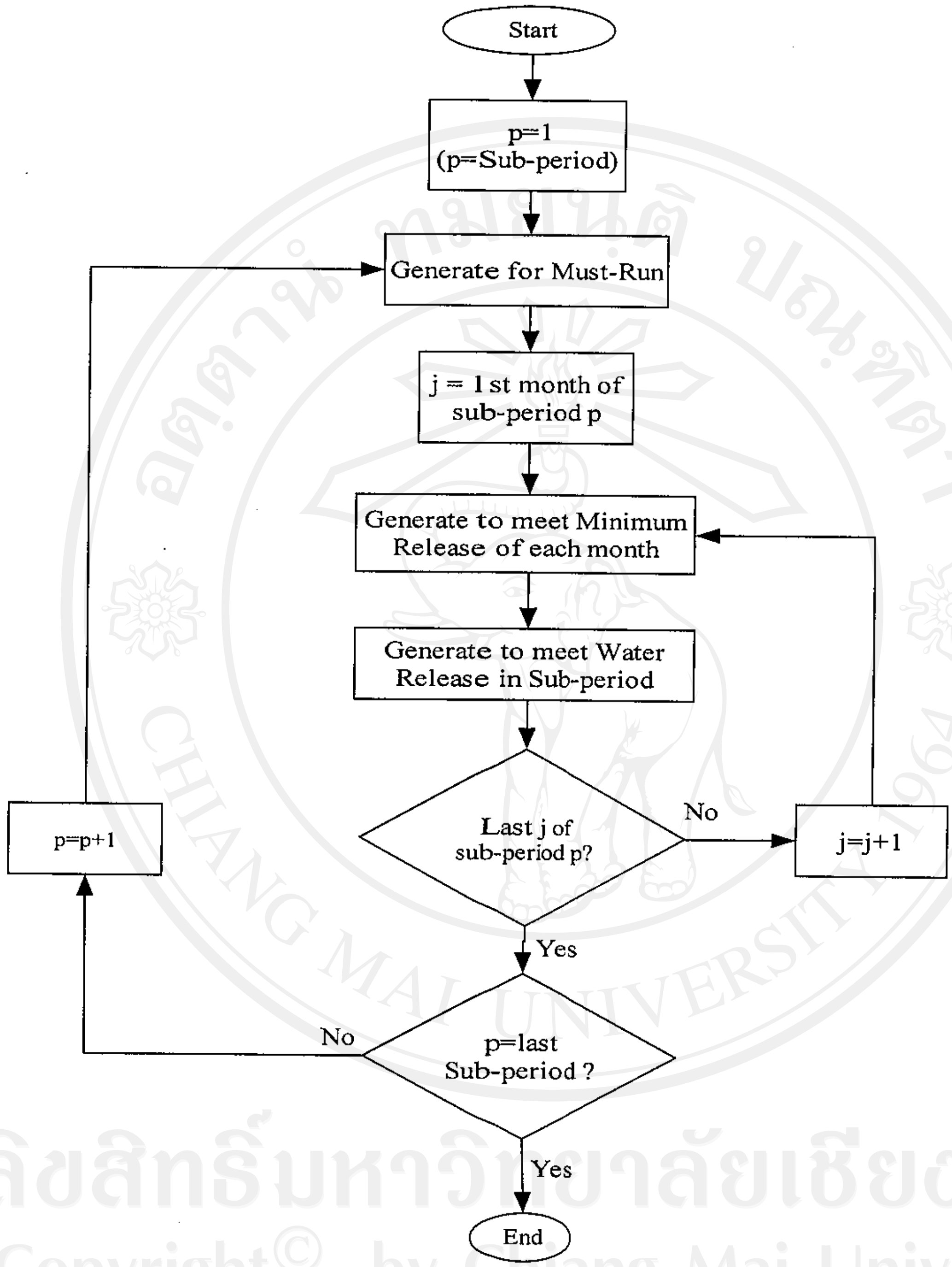

Figure 3.2 Generation planning flow chart for each reservoir

3.2.1. First Step: Generate for must-run

In this step, as shown in figure 3.2, it is explained that generating capacity must be enough for the needs of security constraint. The must-run capacity in hour i must be equal to the load in hour i minus the maximum import which is predetermined based on N-1 criteria. The generation is started from the hour with highest must run capacity. During this hour, the system demand is high and the water value will be maximum similar to the peak shaving concept described in section 2.7. The generator will continue supplying in next priority hour until the released water reaches water limit. Then, the must-run capacity i is continuously reduced depending on generating capacity in that hour. Generation is continued until must-run capacity is equal to zero or generate every hour in the study period.

3.2.2. Second Step: Generate to meet Minimum Release of each month

The excess of generating power equals to the load in hour i minus the sum of generating power ($\sum Gen_{ki}$). The generating power of the first month must be close to the upper limit which uses the equation (3.6). Generating hour must be chosen at the high price of the electricity in the month. It is supposed to check the condition of generating water used for the month, becomes the minimum of water to release (Minimum release). If all conditions are satisfied, check if the generator has been used or not? If it is not, check if the price of the electricity is high (Export Price). In this case, start generating right away, but do not generate over the maximum to export (Maximum Export) limit. If the price is low (Import Tariff), generation is allowed only for the load needed. Flowchart of the second step is shown in figure 3.3

$$Min.\mathrm{Re}lease_j = Start_j - URC_j + Inflow_j \qquad (3.6)$$

Where, $Start_j$ is starting volume in the month j

URC_j is the upper rule curve in the month j

$Inflow_j$ is inflow in the month j

The main objective of the generation to meet minimum release is to keep the water level below the upper rule curve.

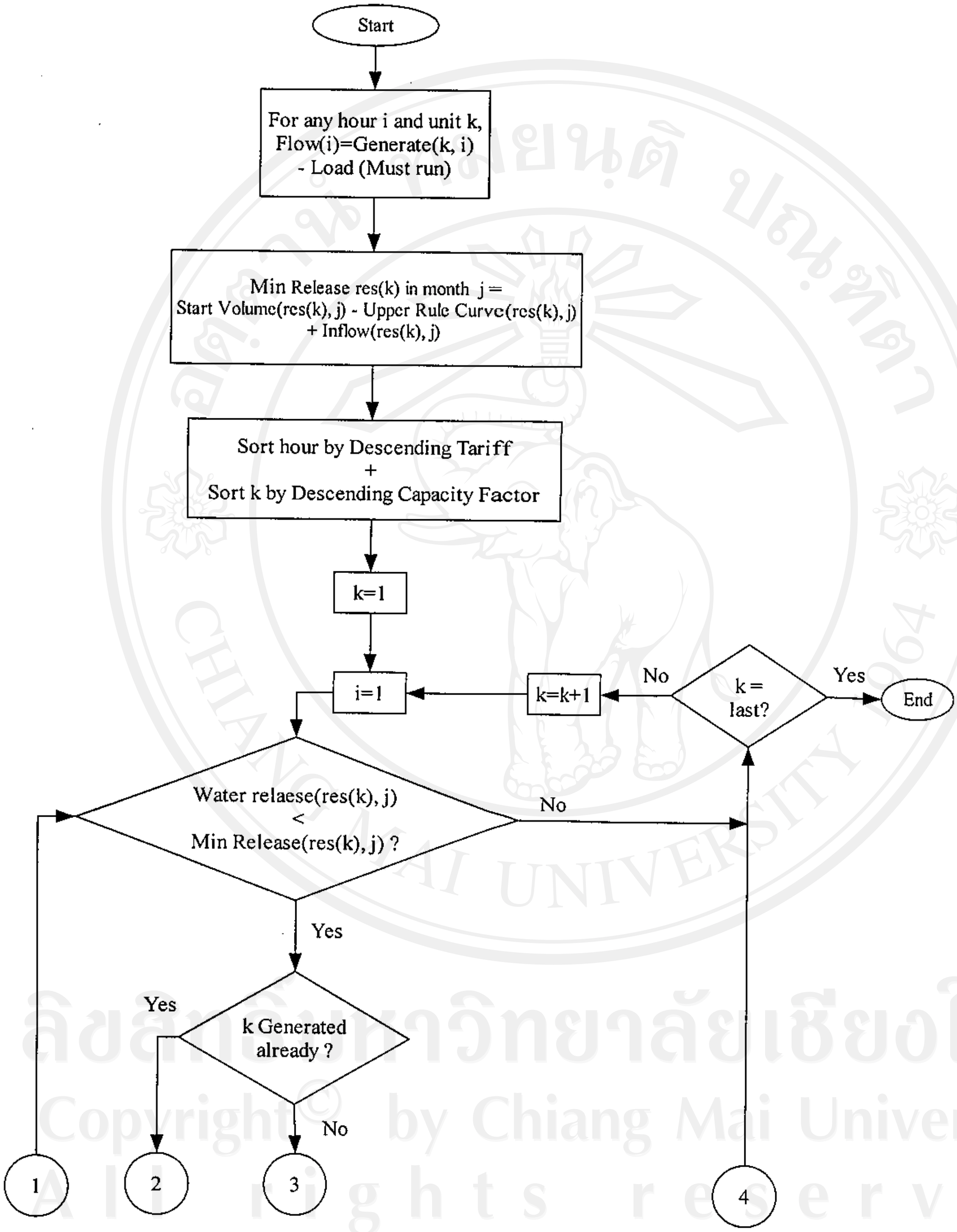

Figure 3.3 Flow chart of Generation to meet Minimum Release of each month

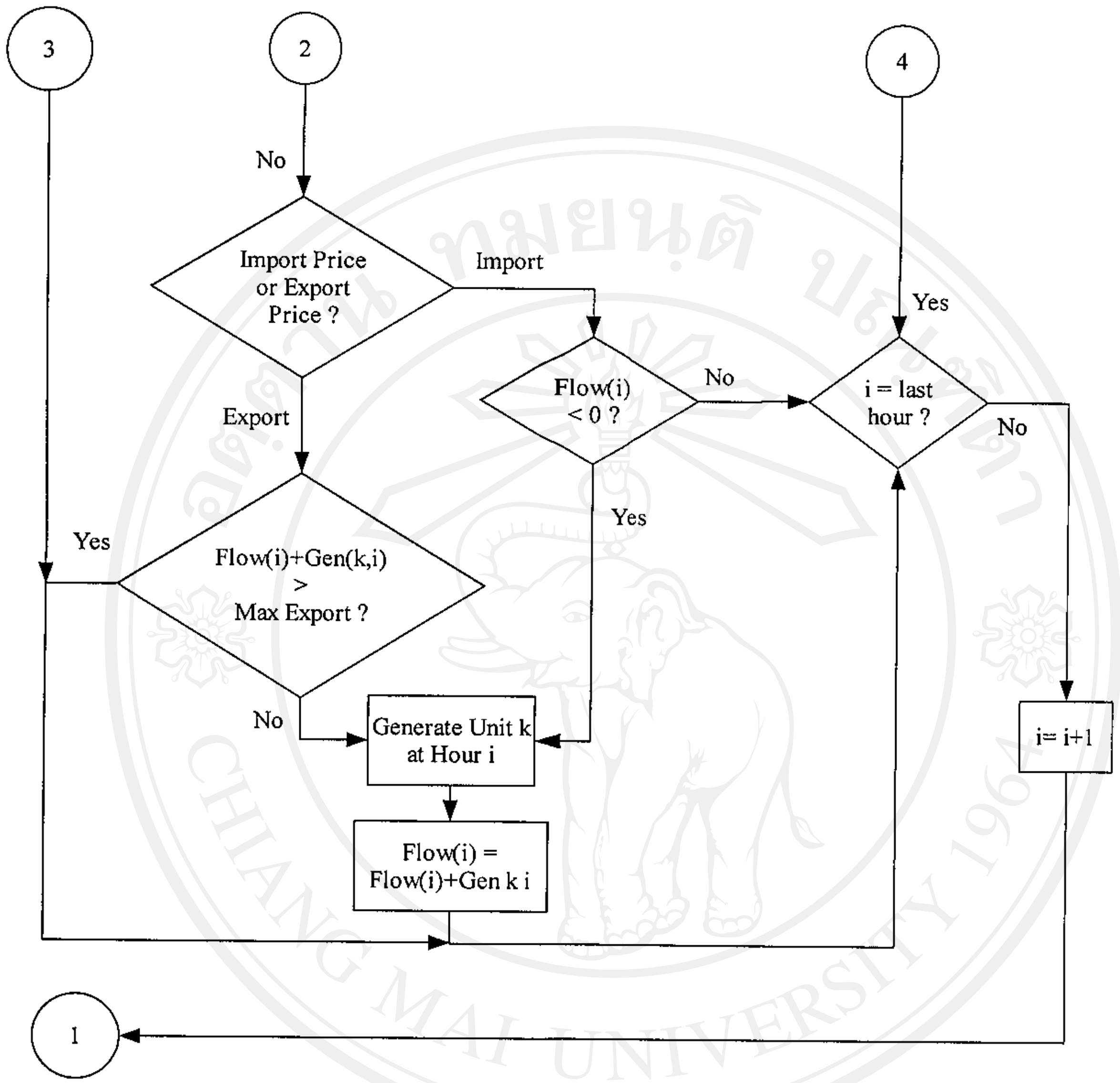

Figure 3.3 Flow chart of Generation to meet Minimum Release of each month (Continue)

3.2.3. Third Step: Generation to meet water release in sub-period

After the generation planning for minimum releasing of the month *j*, any generator will generate to release the water in sub-period based on economic objective. In this step, the water value is the most important variable. Assume the water value is equal the import or export tariff that is related to total generation and load. Then, the generator must generate at the hour that have the most import or export tariff. Figure 3.4 shows the algorithm of this step. The hours in study period will be sorted by descending tariff that is considered both import and export tariff. Then, it is similar that the number of considered hour will increase to double. The generation plan will start with generated by the first unit at the first hour. Because the unit may has been dispatched in the first and second steps already, the unit status must be checked. Moreover, the unit status checking is necessary because the same can be considered twice due to the double number of considered hour related to import and export tariff. If the unit has not been dispatched, the kind of tariff is next considered factor. If the hour considered for high export tariff and the export power is within constraint, the unit will be dispatched. On the other hand, if the hour is selected for high import tariff, the unit will be dispatched if the system is importing the power. The scheduled unit will stop supplying energy if the following condition is met

- The last hour in priority
- The released water in sub-period is more than the released target.
- The water volume at the end of month *j* that is the first month of considered sub-period is below the lower rule curve of month *j*.

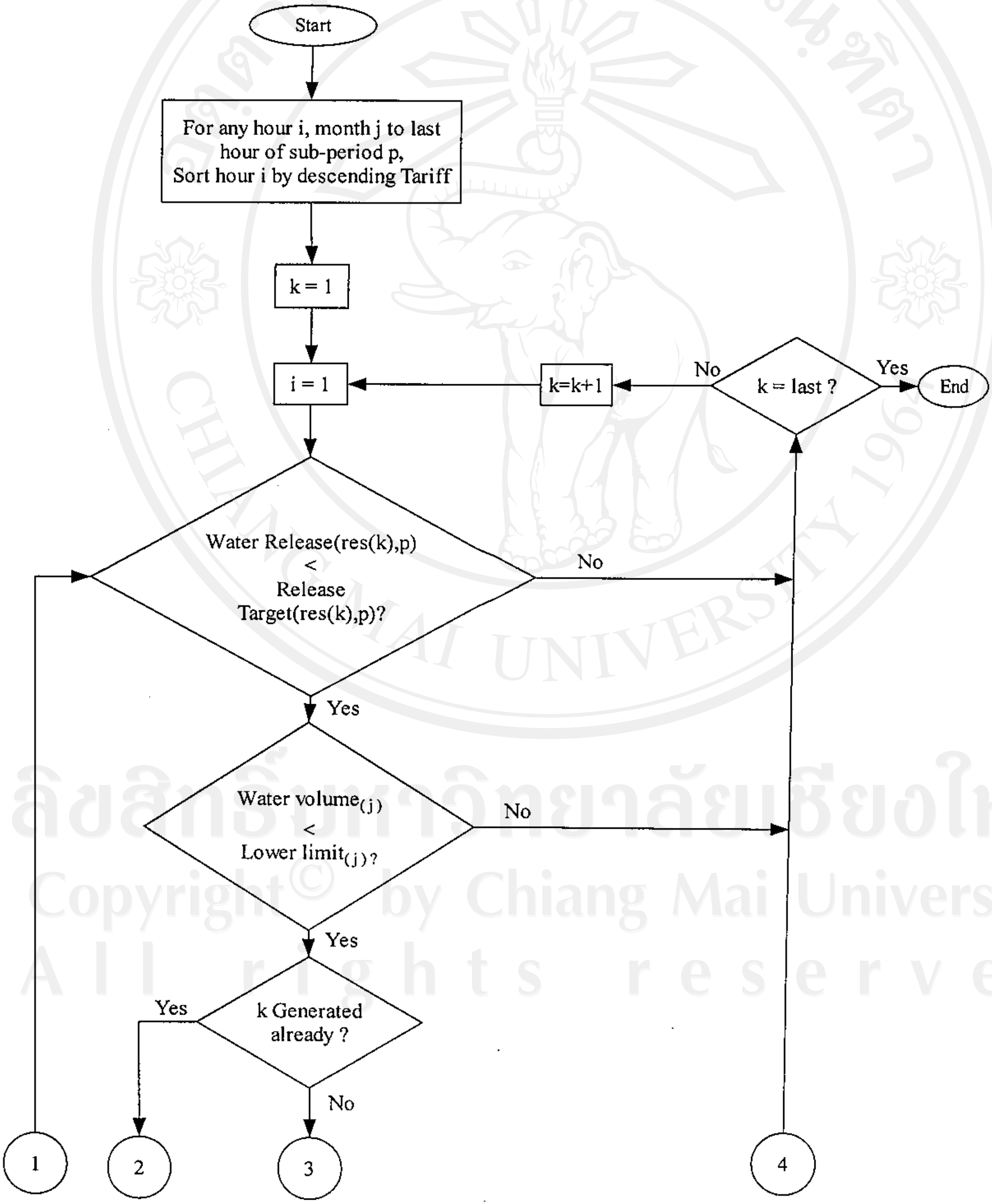

Figure 3.4 Generation to meet Water Release in sub-period flow chart.

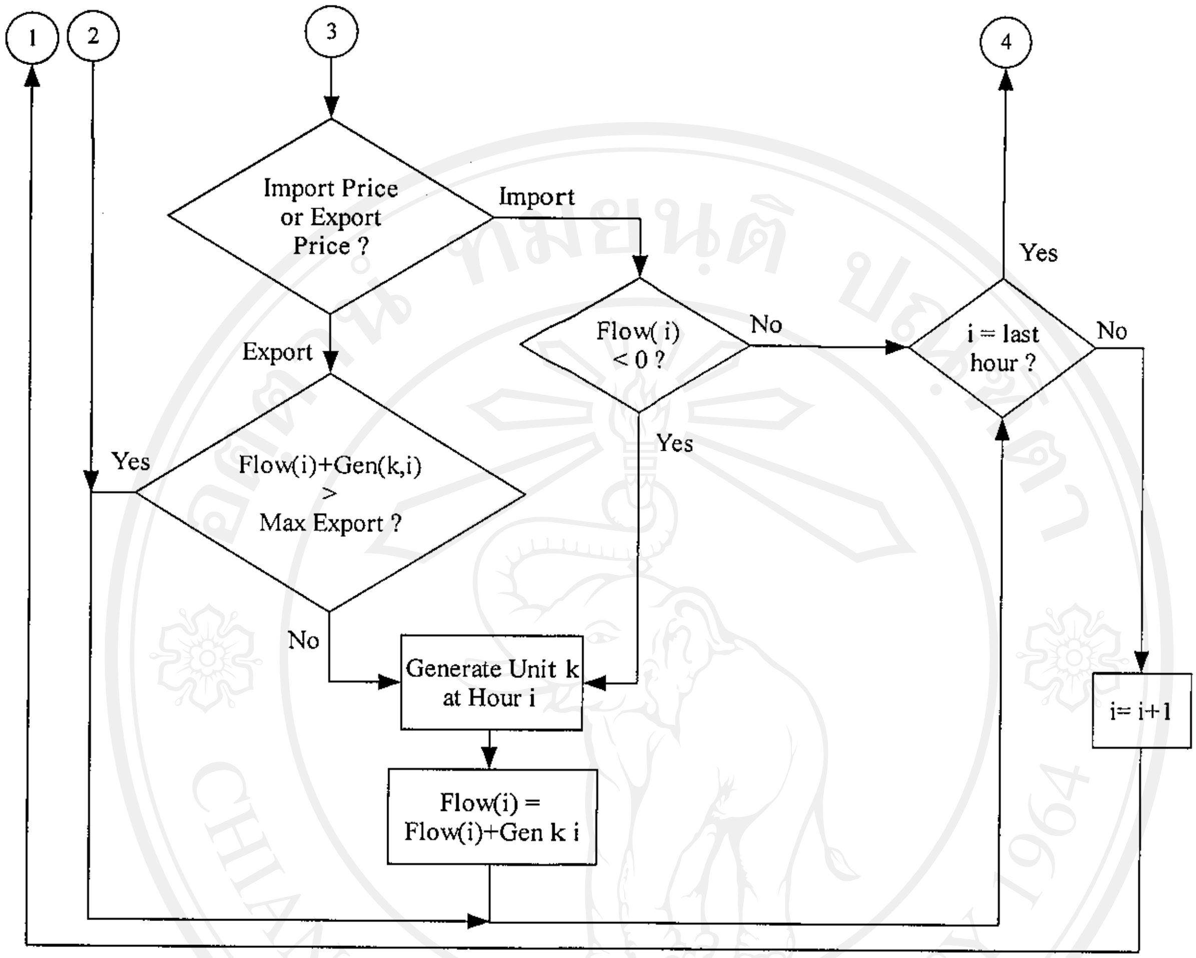

Figure 3.4 Generation to meet Water Release in sub-period flow chart (Continue)

3.3 Search Method for Maintenance Scheduling

As described before, the economic is employed as maintenance scheduling objective. The equation (2.9) in section 2.2.4 is employed as objective function. The proposed search method starts selecting an initial feasible maintenance schedule which satisfies all maintenance and reliability constraints. The continuity of maintenance activity, maintenance must be completed in a continuous time interval once started. Maintenance stage constraint, the maintenance of a named generating unit must be carried out in given time interval. In a case that a unit has two or more maintenance requirements in planning period, the duration of the two maintenance schedule are respectively and the minimum time interval between two maintenance schedules is concerned. And the last of maintenance constraints, maintenance crew constraint, normally two generating units using the common maintenance team cannot be scheduled for maintenance together in the same power plant and at the same time. The detail of maintenance constraints are describe in section 2.3.1, 2.3.2, 2.3.3 and 2.3.4. Moreover, the minimum reserve capacity is employed as reliability constraint (equation (2.16) in section 2.3.6).

With a initial feasible maintenance schedule, a generation schedule is calculated as mentioned in section 3.2. The dynamic programming that explained in section 2.4.2 is employed as searching technique. Searching process starts from the first generator unit by changing to another feasible maintenance scheduling while the maintenance schedule of other units is fixed. The new resulting revenue is compared with that of the initial revenue. If the new revenue is less, the existing scheduling is selected. If the better revenue is found, then the scheduling is updated. When all choices of the unit have been searched for every unit and the result is within the given tolerance, the search process is stopped as shown in flowchart Figure 3.5.

The tolerance used in this thesis is ξ which equals to 0.00001 which is acceptable when compare with many uncertainties. Searching is continuing until y is less than ξ , where y is calculated using the equation below:

$$y = \left| \frac{N_{New} - N_{Old}}{N_{Old}} \right| \tag{3.7}$$

Where,

N_{New} is revenue of the last maintenance scheduling iteration.
N_{Old} is revenue of the previous maintenance scheduling iteration.

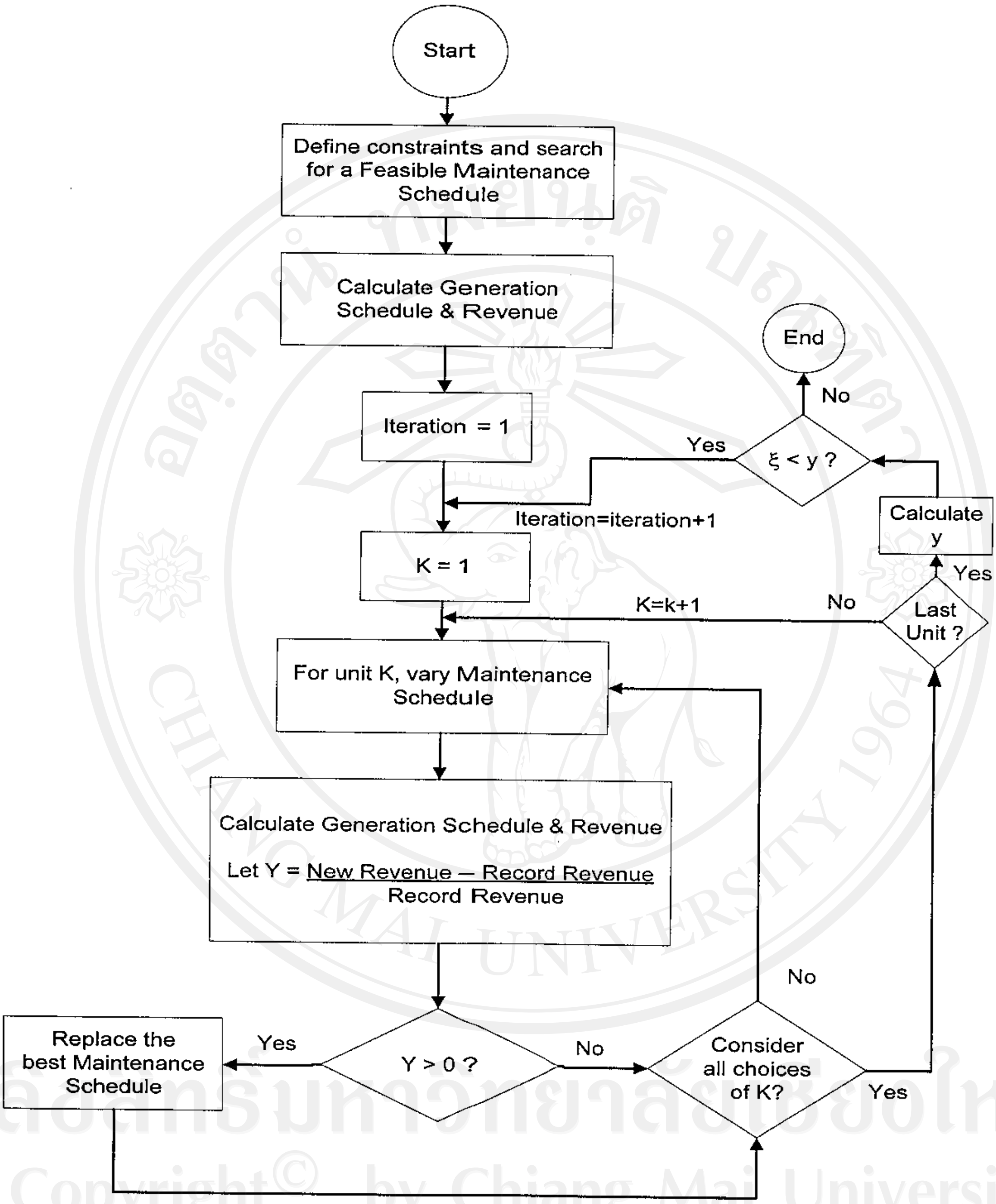

Figure 3.5 Search method of Maintenance scheduling