Hydropower Cooperation for Firm Power Production of Hydropower Plants System in Central 1 Region of Laos People's Democratic Republic

Leechuefue Sayaxang*, S. Premrudeepreechacharn, and K. Ngamsanroaj

Abstract— *This paper presents multi-hydropower plants cooperation to produce the appropriate power energy of the hydroelectric power plant system in the central region 1 of the Lao People's Democratic Republic (Laos PDR). The main objective is to guarantee the stable firm power energy supply to the customer in domestic under constraints such as water inflow, water outflow, water storage, and power production of each hydropower plants. The case study considered 10 hydropower plants which the hydropower's technical data and consecutive hydrological daily inflow data year 2018 of each hydropower plants were selected to simulation firm power production. The linear programming is used to solve this cooperation problem and this research use MATLAB program for simulation. The simulation result has shown that multi-hydropower plants cooperation firm power production is 14,520 mw per month. and maximum power production is 252,732 MW per year (for the year 2018). The cooperation model could help the operator's decision in the purchase of sale electrical energy as firm and semi-firm energy. Moreover, it could apply to another case.*

Keywords— **Hydropower plants cooperation, Linear programming, Firm power output.**

1. INTRODUCTION

Currently, electricity management of EDL system is divided into four main parts as Northern, Central 1, Central 2 and Southern the detailed is shown in Figure1 [1],[2].

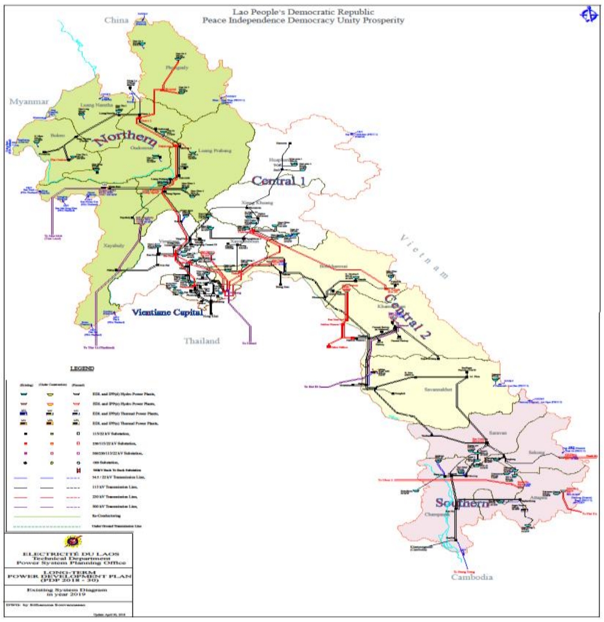

Fig. 1. The power system of EDL in Laos PDR (2019)

In Lao People Democratic Republic (Lao PDR), hydropower plants are important for generating energy that is essential to business, industry, living, and it is the main source of EDL energy power to respond to the customer. Hydropower plants, which have many various types in this system such as reservoir hydropower plants or call Storage hydropower plant and Run-Of-River (ROR). the storage dams store water and regulate water flow so that the power from the storage projects dispatch can follow a pre-planned schedule. ROR projects are uncertain because the water flows in the river, and hence power production capacity is largely determined by uncertain whether factors. Due to most of the generation is hydropower plants which are different power production in the seasonal years. Such as dry season, energy production has not enough, while in the rainy season it has more energy production. So, it has an impact on the price of energy as selling energy low price, non-firm, and unreliability. Therefore, this research studies the hydropower cooperation for the firm and maximum power production of this hydropower system.

From the literature reviews there are many researchers who have studied which can summaries below. S. Yuan, et al [3] have presented the evaluating and optimizing cooperation by a general LINGO-based integrated framework for estimated maximum power generation and firm energy power output. hydropower plant system in the upper yellow river in china was selected as a case study. The trade-off maximum energy production and firm output of hydropower operation have been formulated for the multi-objective model. The nonlinear programming (NLP) solvers embedded in the LINGO software which can be solved this optimization problem.

Li. F. F, et al [4] presented the multi-objective reservoir optimization balancing energy generation and firm power output and the optimization via Non-dominated Sorting Genetic Algorithm-II (NSGA-II) is

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used to develop the comprehensive benefits of hydropower. The Three Gorges Cascade Hydropower System (TGCHS) is a case study. S. Guo, et al [5] presented hydropower system joint operation of the Three Gorges and Qing Jiang cascade reservoirs. The choosing maximization and revenue of hydropower generation as objective functions respectively. The multi-reservoir models were solved by the progressive optimality algorithm. The simulation result is compared with the traditional design operation rule curve. Joshi, G.R. [6] presented about hydroelectric power generation and distribution planning under supply uncertainty. The Integrated Nepal Power System is used to study which combines both ROR projects and storage dam projects. the problem was solved by stochastic programs to minimize the cost of energy generation and distribution under ROR projects supply uncertainty.

The paper will proceed as follows. Section 2 Explain the Principal feature and the hydrological water inflow data of each hydropower of this system in the centra 1 region. Section 3 describes the linear programming, formulates the objective optimization model for the hydropower cooperation model system and describes the process of research methodology. Section 4 presents the results and discussion obtained. Finally, Section 5 concludes the paper.

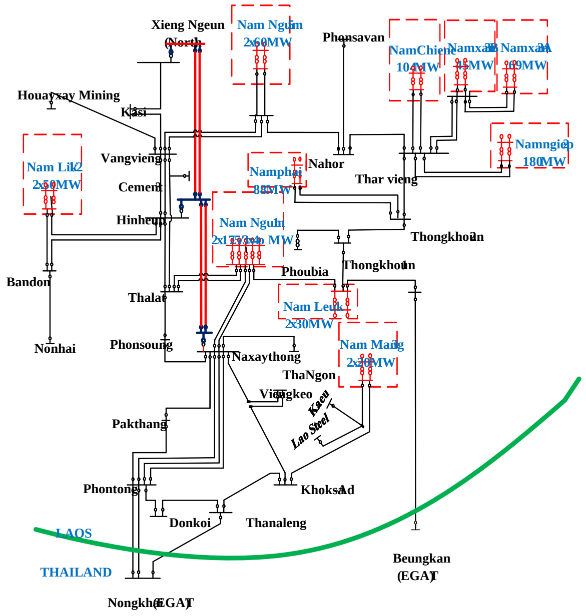

Fig. 2. Single line diagram of the transmission system in central-1 network of EDL.

2. THE HYDROPOWER PLANS SYSTEM IN CENTRAL 1 REGION OF LAOS PDR

In the central 1 region of Laos PDR, it is a larger load demand more than another part. The power generation supply to the major load is namely: Nam Ngum 1, Nam Leuk, Nam Mang 3, Nam Ngum 5, Namsan 3A, Namsan 3B, Namchiene, Nam phai, Nam ngiep2 and Nam Lik1-2 hydropower plant. These hydropower plants are responsible under Electricite Du Lao Generation Public Company (EDL-Gen) and Independent Power Producer (IPP). Nam Ngum 1, Namchiene, Nam Leuk, Nam Mang3 hydropower plants are directly responsibility of EDL-Gen. the single line diagram in central 1 as shown in figure 2 [11].

Table 1. The Principal feature of 10 hydropower plants

Hydropower Name	Description			
	Install Capacity (MW)	Outflow (m^3/s)	Effective Storage (MCM)	Rated Head (m)
Nam Ngum1	155	466	4,714	47.5
Nam Mang3	40	18	53.5	534
Nam Leuk	60	39	145	180
NamLik 1/2	100	156	1,095	82
NamNgum 5	120	42	251	337
Nam Phai	86	14	128	735
Nam San 3A	69	12	0.449	676
Nam San 3B	45	17	0.551	298
Namchiane	104	29	12.74	533
Nam Ngiep 2	180	43	12	450

Note: MCM is million cubic meters

Historical water inflow data

Water inflow data was collected and analyzed from 10 hydropower plants of year 2018 (historical data) it shows in Figure 3 and Table 2 [2].

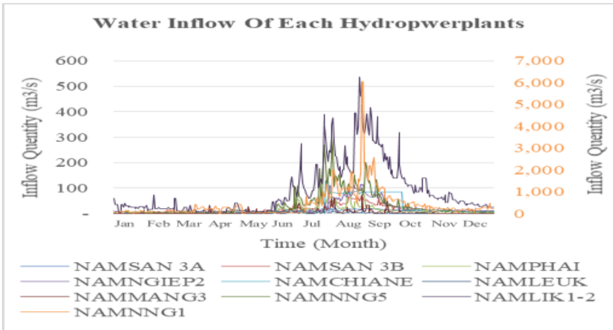

Fig. 3. Time Series Inflow of each hydropower plants year 2018.

Note: This figure shows two Y axis

Left axis: Represent of 9 hydropower plants

Right axis: Represent of Num Ng1 hydropower

Table 2. The monthly water inflow data of 10 hydropower plants year 2018

Month	m^3/s
Jan	4,311
Feb	4,671
Mar	6,087
Apr	8,374
May	3,269
Jun	7,114
Jul	30,72
Aug	71,69
Set	56,97
Oct	21,092
Nov	11,10
Dec	10,75

3. LINEAR PROGRAMMING METHOD

Linear programming can be applied in to manage problems in the industry, banking, education, transportation, agriculture, and others. The planning of resource allocation by applying the problem in the form of a mathematical model is called a mathematical program.

Basically, the program consists of mathematical variables which determine the volume of activities to consider. The constraint is a condition that indicates what this problem can do, or what activities cannot be done, mainly the resource constraint, which is written in relation to the resource utilization rate of each activity and the objective function. The objective function shows the effectiveness of the use of resources to do these activities [13].

3.1 Maximum hydropower generation

The aim of the hydropower cooperation is to obtain maximum energy production of the hydropower system. The maximum objective function as follows [4]-[7].

$$MAXE = \sum_{i=1}^{T} p_t \times \Delta t = \sum_{i=1}^{n} 9.81 \times \eta_{i,t} \times q_{i,t} \times h_{i,t} \quad (1)$$

where T is the over-all amount of the calculation time space index, n is all number of hydropower plant; i is the index's number of hydropower plant; Δt is the time interlude; t is the index of the existing period; Pt is power output in the t period; η(i,t) is the effectiveness's hydropower generation in t period of i reservoir; Qi,t is water relief over the turbines of i reservoir in the t period; H(i,t) is the reservoir water level and tail-race water level of i reservoir in t period; E is all sum power generation of n hydropower.

3.2 Maximizing Firm Power

The firm power is the energy that can be produced throughout of the years which can be described as follows [4][13].

$$MAXF = max\{min(\sum_{i=1}^{n} p_t)\} \quad (2)$$

3.3 Subject to the flowing constrain

(1) Water balance equation:

(For run-off-river)

$$V_{i,\ Inflow} = V_{i,\ Outflow} \times \Delta t \quad (3)$$

(For storage)

$$V_{i,\ Inflow} = V_{i,\ Storage} - (V_{i,\ Initial} + V_{i,\ Outflow}) \times \Delta t \quad (4)$$

(2) Limits of reservoir level:

$$RL_{i,t} \le R_{i,t} \le RU_{i,t} \quad (5)$$

(3) Water outflow limits:

$$QL_{i,t} \le Q_{i,t} \le QU_{i,t} \quad (6)$$

(4) Power generation limits:

$$PL_{i,t} \le P_{i,t} \le PU_{i,t} \quad (7)$$

where $V_{i,\ Inflow}$ is water inflow of i reservoir at t period; $V_{i,\ Outflow}$ is water outflow of i reservoir at t period; $V_{i,\ Storage}$ is the water storage at t period; $V_{i,\ Initial}$ is initial water storage of i reservoir at t period; $RL_{i,t}$ is lower water level in t period; Ri,t is normal water level in t period ; $RU_{i,t}$ is upper water level in t period ; $QL_{i,t}$ is minimum of water discharge i reservoir; $Q_{i,t}$ is normal water discharge of i reservoir in t period; $QU_{i,t}$ is the maximum water discharge of i reservoir; $PL_{i,t}$ is the minimum power generation in the t period; $P_{i,t}$ is the normal power generation in the t period; $PU_{i,t}$ is the maximum power generation in t period.

3.4 Methodology

The target of hydropower plant cooperation is to find the firm power output of all hydropower plants that can be confirmed under the objective function and limit the constrain of each hydropower plant.

The process of cooperation model for firm power production there is consists of each step as flows.

Collection and prepare data such as water (inflow, outflow, initial storage) and specific data of hydropower plants.

Create modelling linear programming by script function in MATLAB 2018b.

Compare the result with the condition of the setting of the hydropower plant.

The firm power output was increase and stopped by the limit setting. It can be explanted as Figure 4 below.

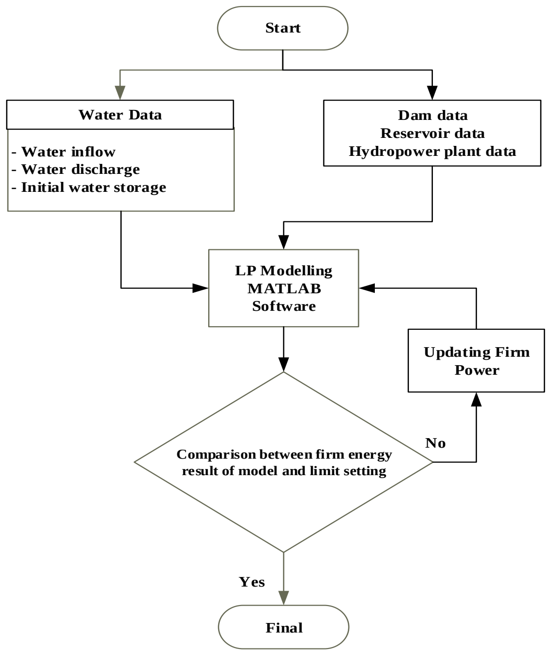

Fig. 4. Flowchart of the methodology research.

4. RESULTS AND DISCUSSION

The research has studied by using the basic technique design and water inflow data year 2018 for hydropower cooperation of 10 hydropower. The operating model was simulated by MATLAB program to simulate firm power output.

The simulation resault from linear programming method will be compare with the actual operation method as show below.

4.1 Water outputs simulate result

The water output result of each hydropower plants as show be low.

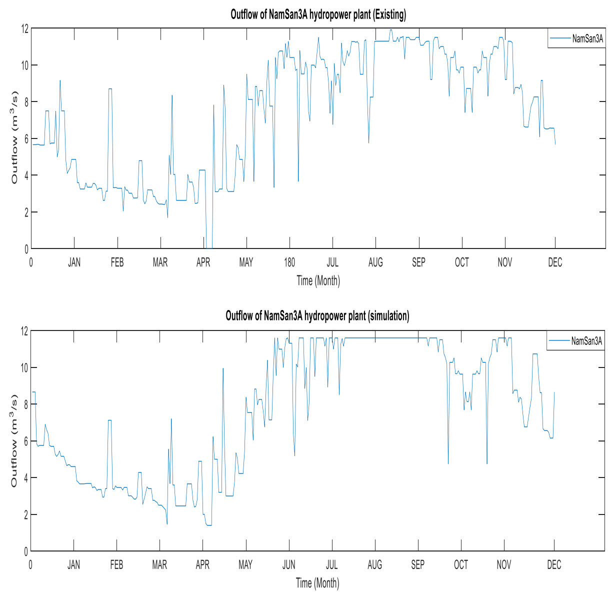

Fig. 5. Compare water outflow of NamSan3A.

- Water output Actual and Simulation result of NamSan3A (Run of river)
- Water output actual and Simulation result of NamSan3B (Run of river)

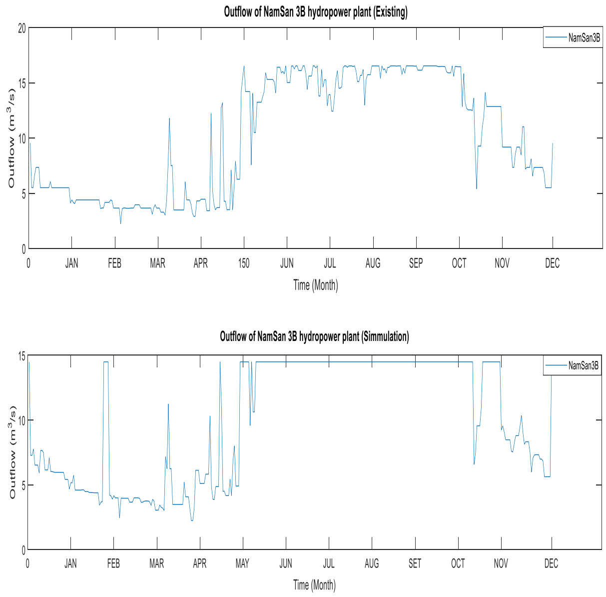

Fig. 6. Compare water outflow of NamSan3B.

- Water output actual and Simulation result of Namphai (Reservoir)

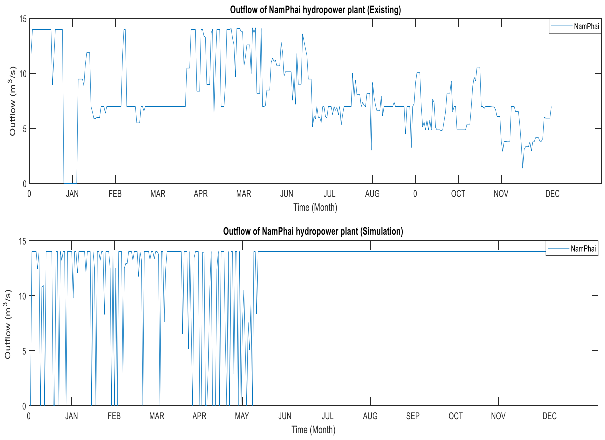

Fig. 7. Compare water outflow of NamPhai.

- Water output actual and Simulation result of NamNgiep2 (Reservoir)

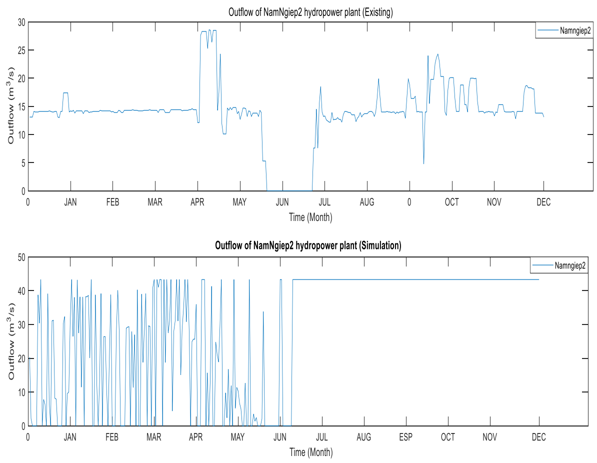

Fig. 8. Compare water outflow of NamNgiep2.

- Water output actual and Simulation result of NamChiane (Reservoir)

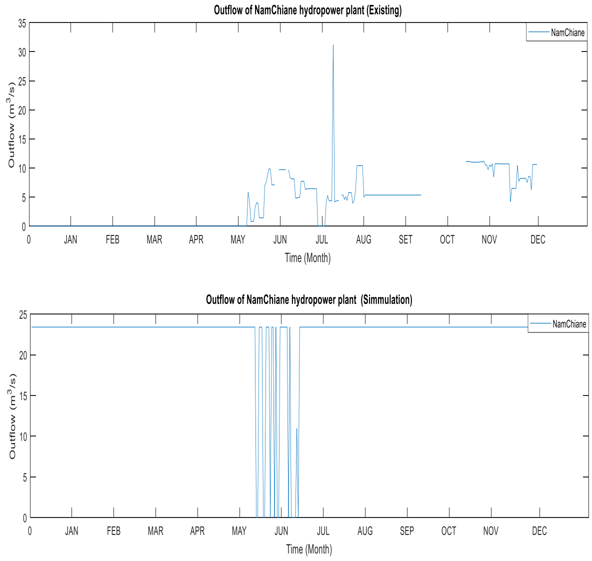

Fig. 9. Compare water outflow of NamChiane.

- Water output actual and Simulation result of NamNgum1 (Reservoir)

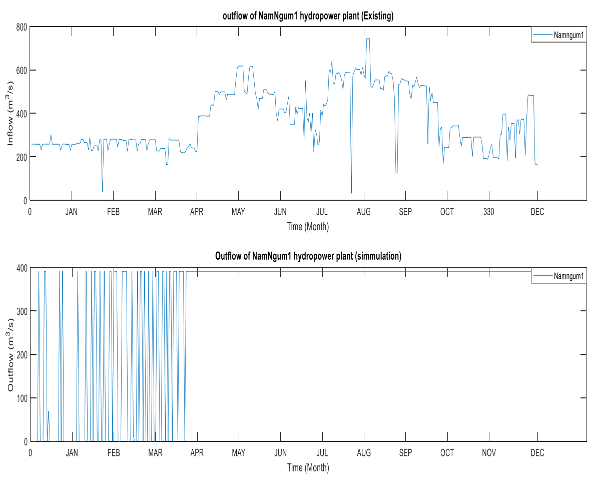

Fig. 10. Compare water outflow of NamNgum1.

- Water output Actual and Simulation result of NamLeuk (Reservoir)

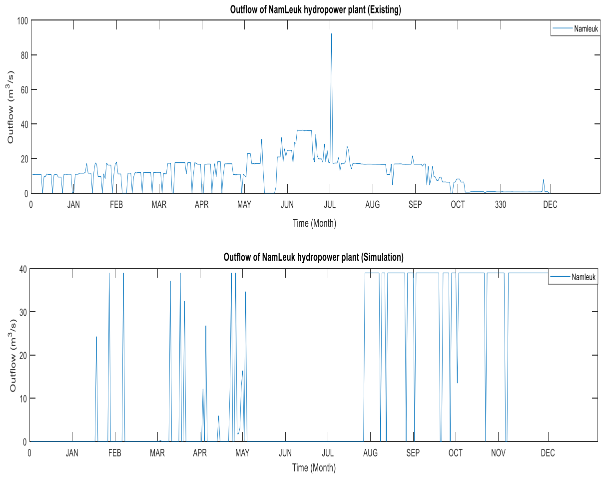

Fig. 11. Compare water outflow of NamLeuk.

- Water output actual and Simulation result of NamMang3 (Reservoir)

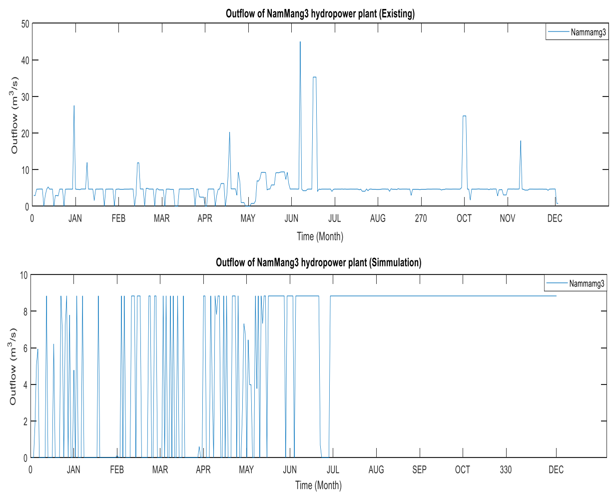

Fig. 12. Compare water outflow of NamMang3.

- Water output Actual and Simulation result of NamNgum5 (Reservoir)

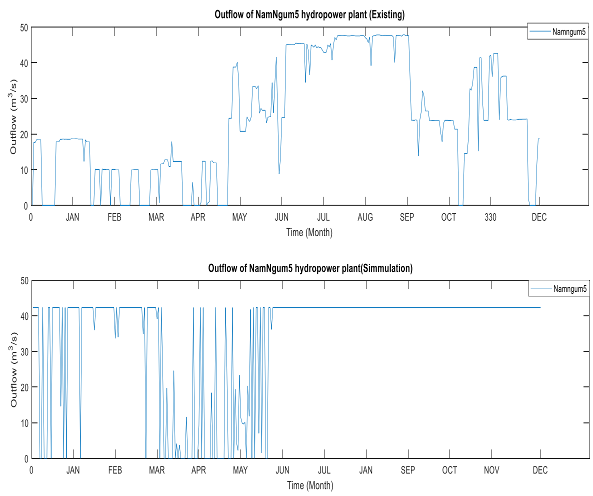

Fig. 13. Compare water outflow of NamNgum5.

- Water output actual and Simulation result of NamLik1-2 (Reservoir)

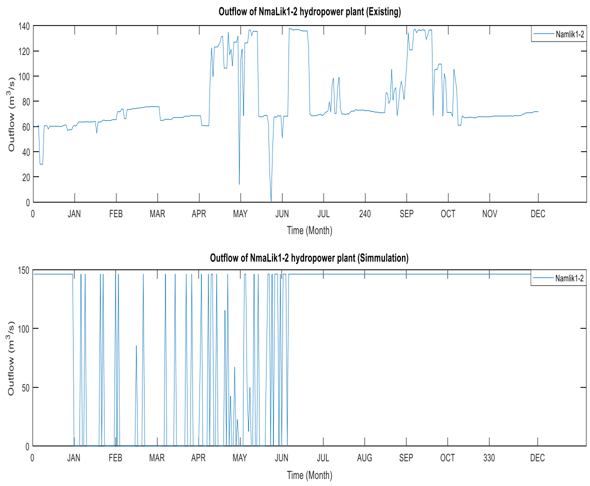

Fig. 14. Compare water outflow of NamLik1-2.

- Water Summation output actual and Simulation result of all 10 hydropower plants

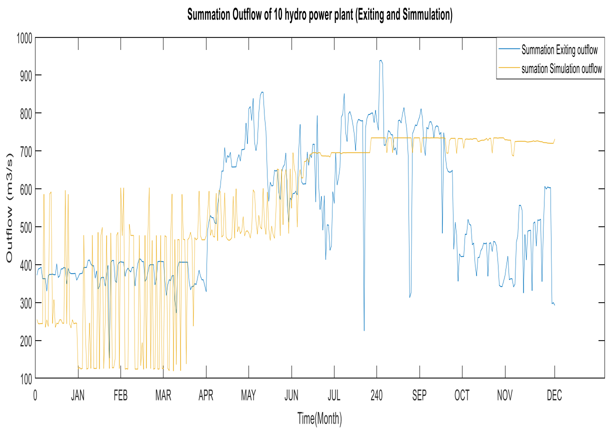

Fig. 15. Compare Summation water output of simulation and actual of all hydropower plants year 2018.

Table 3. The monthly Simulation water outflow of 10 hydropower plants

Month	Actual (m^3/s)	Simulation(m^3/s)
JAN	11,250	9,031
FEB	11,265	7,955
MAR	11,724	8,668
APR	10,811	12,155
MAY	19,177	15,233
JUN	20,500	16,341
JUL	18,078	20,160
AUG	22,334	21,056
SEP	22,228	21,918
OCT	19,574	21,853
NOV	12,931	21,882
DEC	14,085	25,292
YEAR	194,026	201,500

The hydropower cooperation model was simulated by MATLAB program. The water output simulation and actual of the hydropower plants year 2018 are summarized as below.

4.2 Power outputs simulate result

The power output result of the hydropower cooperation as show below.

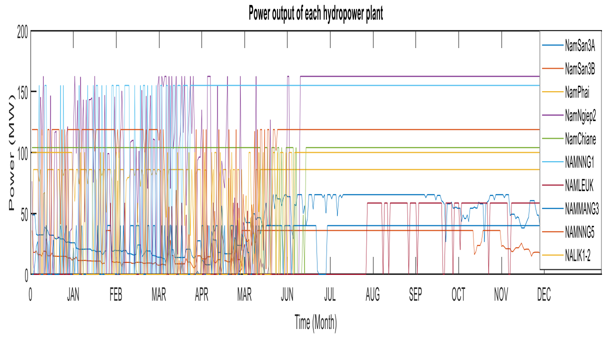

Fig. 16. Power output from simulation of each Hydropower plants year 2018.

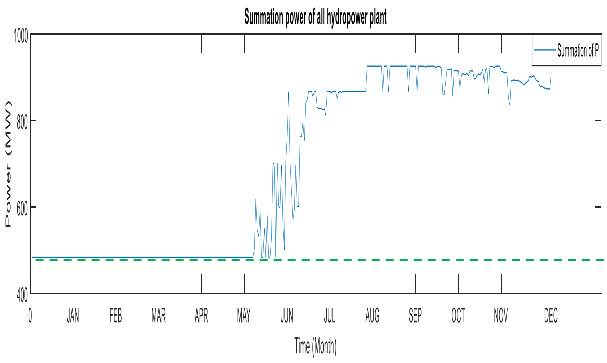

Fig. 17. power summation and firm power output of all Hydropower plants year 2018.

Table 4. Monthly power output summation and firm power of all hydropower plants

Month	Summation Power (MW)	Firm power (MW)
JAN	14,520	14,520
FEB	14,520	14,520
MAR	14,520	14,520
APR	14,520	14,520
MAY	14,520	14,520
JUN	16,787	14,520
JUL	23,611	14,520
AUG	26,926	14,520
SEP	27,610	14,520
OCT	27,402	14,520
NOV	27,307	14,520
DEC	31,119	14,520
YEAR	252,732	174,240

From the figure 17 was shown power output of all hydropower plant cooperated simulation results revealed that during the month from January to May, power output generation is constant because it is less water inflow to the reservoir (dry season). On the other hand, the power output has increased and fluctuate from May to December that occurs from the uncertainty of water inflow (wet season). The detail can summarise as shown in Table 4.

To easily understand, the energy production of the model simulation was compared with the actual simulation result. It found that the energy production from new model operation increase more than actual operation in each month as shown in Figure 18 below.

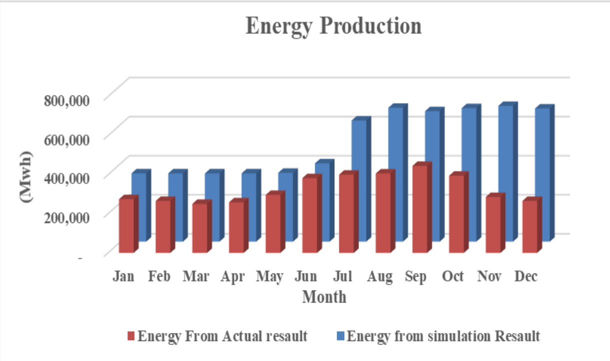

Fig. 18. Power summation and firm power output of all Hydropower plants year 2018.

5. CONCLUSION

This research has studied the hydropower cooperation of 10 hydropower plants in the central1 region of Laos PDR by linear programming. The firm power production by linear programming techniques in MATLAB R2018b software. The simulation result of hydropower cooperation can be concluded that firm power output is 14,520 Mw per month or 349,680 Mwh (for the year 2018). This study is one guideline for EDL to improve and develop hydropower cooperation in the future.

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REFERENCES

[1] Electricite du Laos, Power Development Plan (PDP 2015-2025), *Vientiane, Lao People's Democratic Republic, August 2015.*

[2] Electricite Du Laos-Generation Public Company (EDL-GEN). *Annual Energy Generation Report, Vientiane, Lao PDR. (2017)*

[3] Si, Y., Li, X., Yin, D., Liu, R., Wei, J., Huang, Y., ... & Wang, G. (2018). Evaluating and optimizing the operation of the hydropower system in the Upper Yellow River: A general LINGO-based integrated framework. *PloS one*, *13*(1).

[4] Li, F. F., & Qiu, J. (2015). Multi-objective reservoir optimization balancing energy generation and firm power. *Energies*, 8(7), 6962-6976.

[5] Guo, S., Chen, J., Li, Y., Liu, P., & Li, T. (2011). Joint operation of the multi-reservoir system of the Three Gorges and the Qingjiang cascade reservoirs. *Energies*, *4*(7), 1036-1050.

[6] Joshi, G. R. (2016). *Hydroelectric power generation and distribution planning under supply uncertainty* (Doctoral dissertation, Colorado State University-Pueblo).

[7] Zhang, R., Zhou, J., Zhang, H., Liao, X., & Wang, X. (2014). Optimal operation of large-scale cascaded hydropower systems in the upper reaches of the Yangtze River, China. *Journal of Water Resources Planning and Management*, *140*(4), 480-495.

[8] Fu, X., Li, A., Wang, L., & Ji, C. (2011). Short-term scheduling of cascade reservoirs using an immune algorithm-based particle swarm optimization. *Computers & Mathematics with Applications*, *62*(6), 2463-2471.

[9] Zhu, C. J., Zhou, J. Z., Yang, J. J., & Wu, W. (2006, October). Optimal scheduling of hydropower plant with uncertainty energy price risks. In *2006 International Conference on Power System Technology* (pp. 1-6). IEEE.

[10] Deevanhxay, P., Premrudeepreechacharn, S., & Ngamsanroaj, K. (2012, November). Optimal operation scheduling of Nam Ngum-1 and Nam Leuk hydropower plants. In *2012 International Conference on Renewable Energy Research and Applications (ICRERA)* (pp. 1-6). IEEE.

[11] K.Vongsomphone, S. Premrudeepreechacharn, S. Nuchprayoon. (2007). Optimal Dispatch of Power Generation in the Central-1 Network of Electricite du Laos Chiangmai University, Faculty of Engineering, Department of Electrical Engineering.

[12] Rao, S. S. (2019). *Engineering optimization: theory and practice*. John Wiley & Sons.

[13] He, L., Li, B. Y., & Li, H. (2011). Maxmin model for determining the guaranteed output of a hydropower plant based on dynamic programming. *Power Syst. Clean Energy*, *27*, 78-85.