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# The model of joint control system for HPP featuring the function of active power distribution in proportional equality of control ranges

**V E Zakharchenko**

SMS-Automation business group, Galaktionovskaya 7, Samara, 443020, Russian Federation

Vitaliy.zakhachenko@sms-a.ru

**Abstract**. The aim of the article is hydro power plant (HPP) efficiency improvement via optimization power distribution function in HPP joint control system. Traditional function with equal power distribution is compared with new suggested function, which distributes power proportional equality of hydro units control ranges. Comparison is provided for one day and for one year (for HPP hydrological cycle). The results revealed that same conditions, same HPP equipment, same tasks, same work modes show better optimization range for function with proportional equality of control ranges regarding maximum efficiency of hydropower units. The function also provides possibility to add in joint control hydro units of different types. So it means the JCS with suggested distribution function can handle HPP task with less numbers of working hydro units and more efficient way.

In modern trends of developing smart industries, well known as Industry 4.0, modeling takes one of key directions. The following models of industries are created: digital twin, consolidation of overall documentation and interconnection between technological components of in database, models of industrial objects and systems for automatic test and adjustment for control systems, for operator training systems, for optimization of systems and industrial processes. This article presents a new model of hydropower plants (HPP) joint control system featuring the function of active power distribution in proportional equality of control ranges regarding to maximum efficiency of hydropower units (HU). The main aim of the article is HPP efficiency optimization.

Today the most common algorithm of joint control systems distributes active power among hydro units of the HPP equally. Simplified, each unit has its task which is equal to total HPP task divided by number of units in joint control system (JCS): $P_{Hi} = \frac{P_{HPP}}{N}$. This simple algorithm has several noticeable disadvantages: 1) It suggests that efficiency function of different hydro units at HPP are equal, but hydro units could have different power, control ranges and efficiency functions, could be provided by various manufacturers, and even hydro units provided by the same manufacturer could have differences, considering individual conditions of their usage (installation points, operation hours, modes and so on); 2) the algorithm cannot be used for hydro units with restriction zones in their control range (like Sayano-Shushenskaya HPP) 3) When task for HPP is close to range edges, the control speed of HPP is decreasing, as hydro units don't reach their limits simultaneously, so, task execution is provided by all other hydro units (which haven't reached their limits); 4) The algorithm

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doesn't take into account efficiency of hydro units. So, it cannot control for all HPP hydro units the best way.

In the article [1] it was suggested to use some other functions for distribution of active power in JCS, and some abstract examples showing its efficiency. The function with proportional equality of control ranges regarding to maximum HPP efficiency was found the most perspective. For each unit the power with maximum efficiency is calculated for current water head. The sum of these powers is most efficient power task of HPP. So, it is an ideal state of HPP to aim. When HPP task deviates from the ideal task, the tasks for each unit are calculated proportionally their charge or discharge ranges.

$$P_{HPPmax\eta} = \sum_{i=1}^{N} P_{Himax\eta},\ DP_{ch\arg e} = \sum_{i=1}^{N}\left(Pmax_{Hi} - P_{Himax\eta}\right),\ DP_{disch\arg e} = \sum_{i=1}^{N}\left(P_{Himax\eta} - Pmin_{Hi}\right),$$

$$\begin{cases} P_{JCS} > P_{HPPmax\eta} : \alpha_{ch\arg e} = \dfrac{P_{JCS} - P_{HPPmax\eta}}{DP_{ch\arg e}} \\ \quad P_{Hi} = P_{Himax\eta} + \alpha_{ch\arg e}\left(Pmax_{Hi} - P_{Himax\eta}\right), \\ \\ \text{else} : \alpha_{disch\arg e} = \dfrac{P_{JCS} - P_{HPPmax\eta}}{DP_{disch\arg e}} \\ \quad P_{Hi} = P_{Himax\eta} + \alpha_{disch\arg e}\left(P_{Himax\eta} - Pmin_{Hi}\right) \end{cases} \tag{1}$$

The described function is free of disadvantages of equal distribution: it can be used for various types of hydro units, and increasing the number of unit's types would not influence on JCS algorithm's complexity. 2) It fits for hydro units with restriction zones inside control range. In case of working in restricted area limits of the current zone are used for calculation task. 3) The system control is always conducted by all hydro units, all units reach their limits simultaneously. Approaching HPP control limit means it is necessary to change HPP state: start or stop hydro unit or change it over to the next unrestricted zone for HPP range increasing. 4) The function is based on efficiency of hydro units, it is easy to see ideal state of HPP and deviation from it, also it is always possible to turn HPP to ideal state. Below we will call the function optimal (just to be shorter).

In this article we compare models of JCS with different distribution functions in valuable period. Information from a real HPP will be taken as source data.

The HPP contains 24 Kaplan turbines of 3 types (with different ranges, efficiency graphs and so on). The task for HPP can be changed every 30 minutes (plan of energy market). The 30-minutes values of hydro units active power and HPP water head are used in models for one hydrologic cycle = one year. Firstly, we build up model of JCS with traditional equal distribution function, the different types of units will be separated from joint control. Then the same conditions will be used for creation of JCS with proportional equality of control ranges regarding maximum HPP efficiency. The models and their results for one year will be compared.

The method of potential losses [2] will be used for models comparison. Each unit according to its efficiency function has maximum on defined water head. It means, when unit works with maximum efficiency, it uses less water for providing same power, or using the same water could bring more power. So the difference between generated power and the power that could be generated with the same water, is called potential power losses. [3]. The sum of potential power losses for hydro units shows HPP overall potential (2).

For getting low level efficiency estimation the HPP power losses after one hydro unit state change is used. Selection of hydro units allows to minimize HPP power losses. Number of unit and its type of state change (when it make power losses less) we will call "model recommendation", like it is in rational control system for HPP states. So, minimal power losses that could be recovered via one operation over units (one HU state change). Common estimation of HPP efficiency for one timeslice is

an interval, the sum of interval estimations for all time range shows efficiency HPP for the selected period.

$$dP_{Hi} = P_{Hi} - P_{Hi\,ideal};\ where\ P_{Hi\,ideal} = \frac{P(\eta = \max) * Q_{Hi}}{Q_{Hi}(P(\eta = \max))}$$
$$dP_{HPP}^{\max} = dP_{HPP} = \sum_i dP_{Hi} \tag{2}$$

$$dP_{HPP}^{\min} = dP_{HPP} - dP_{HPP\,\Delta Hi}$$
$$DP = [dP_{HPP}^{\min}; dP_{HPP}^{\max}] \tag{3}$$

The graphs of recommendations and sum of potential losses for one day is shown in the figure 1 for equal distribution, in figure 2 for optimal distribution.

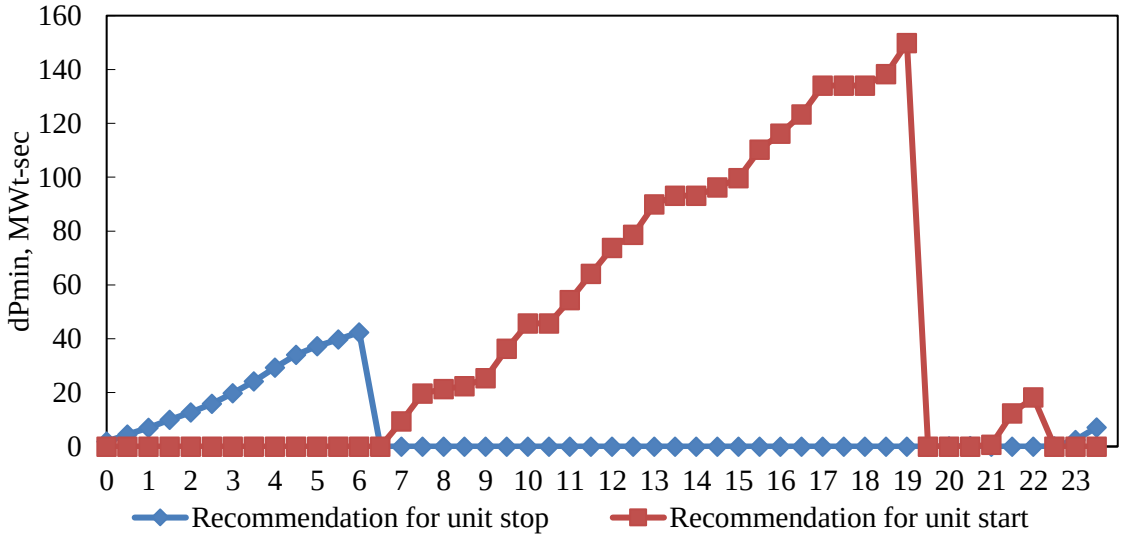


**Figure 1.** HPP minimal potential power losses with equal power distribution for a day, MWt-sec.

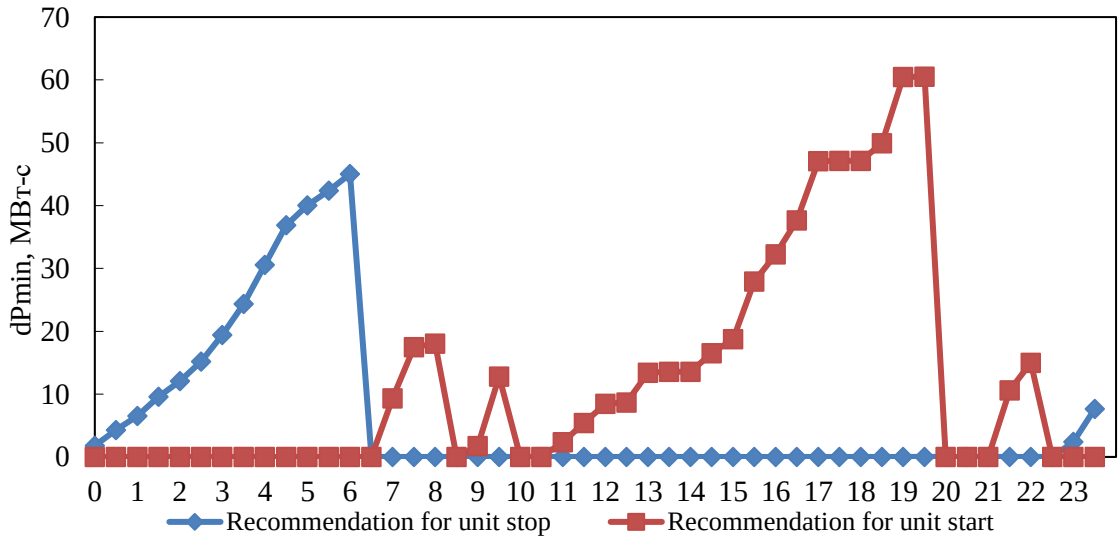


**Figure 2.** HPP minimal potential power losses with optimal power distribution for a day, MWt-sec.

Note, behavior of curves is not really different: from the start of the day HPP works with underload. Units work close to minimal limit of their range. Until 6:30 recommendation for one unit stop is active. After 6:30 hydro units almost always work close to upper limit of their range, so recommendation for unit start is active.

Build up recommendations graphics for one year for both distribution functions: equal (figure 3) and optimal (figure 4). The period with high water (from the middle of April to the beginning of June) is excluded from analysis because at the time main optimization criteria of HPP changes from optimization efficiency to increasing water flow through HPP.

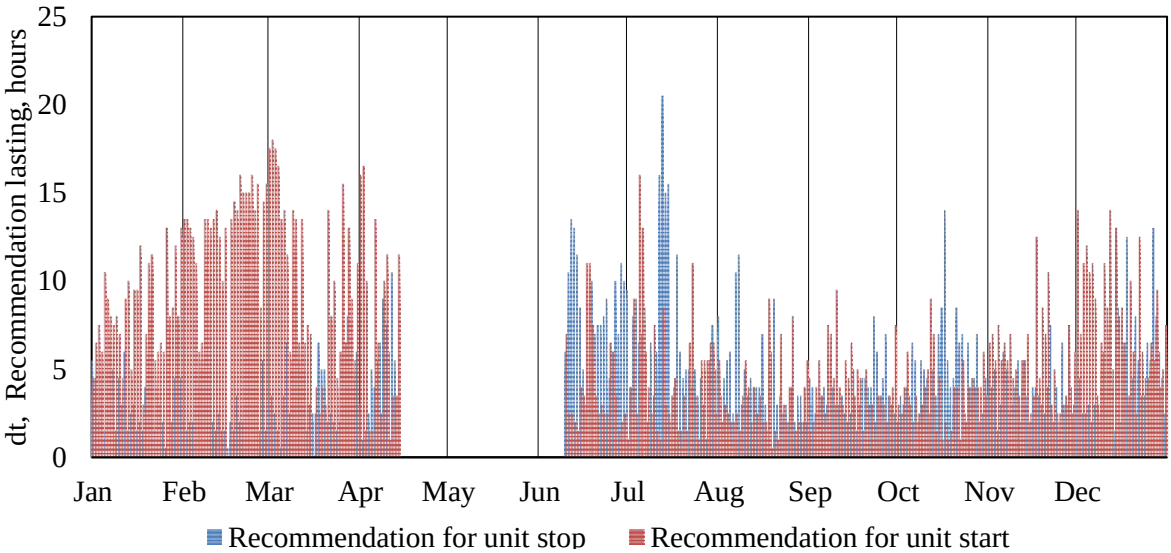


**Figure 3.** Recommendation lasting for JCS with equal power distribution for a year, hours.

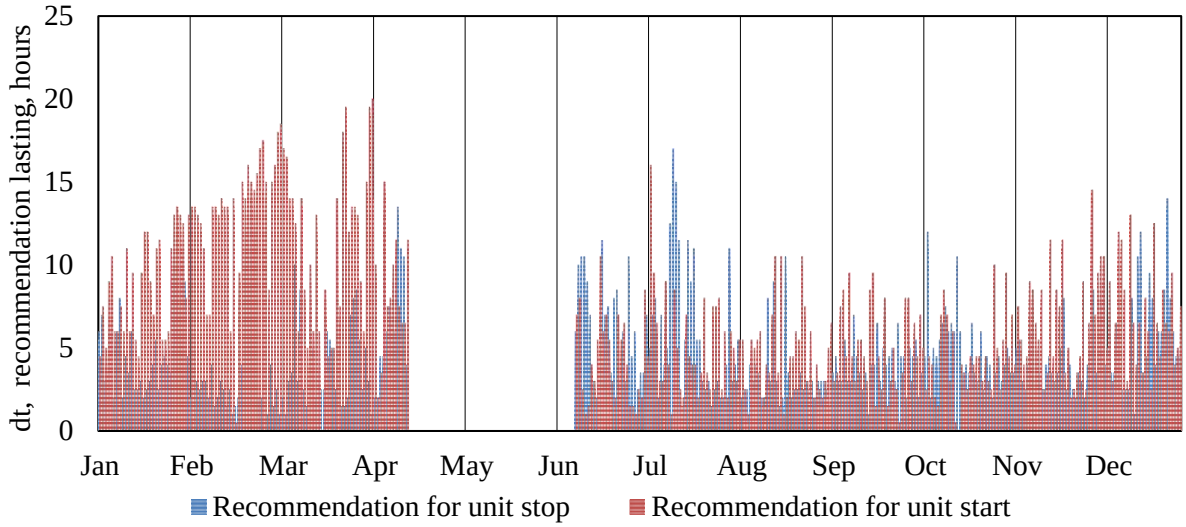


**Figure 4.** Recommendation lasting for JCS with optimal power distribution, hours.

For a selected year the model with equal distribution 10921 time slices out of 17520 HPP worked not optimal, i.e. there were 5 231 recommendations for start and 5690 recommendations on stop, recommendations for start average lasted about 3,73 hours, average recommendation for stop was 2.18 hours long. Common interval estimation of power losses is [42470.9; 82381.9] megawatt-seconds.

For selected year the model with optimal distribution 11530 time slices out of 17520 HPP worked not optimal, i.e. there were 5898 recommendations for start and 5 632 recommendations for stop, recommendations for start average lasted about 4.12 hours, average recommendation for stop was 2.23 hours long. Common interval estimation of power losses is [50067.1; 118597.9] megawatt-seconds.

The experiment showed that the joint control system with optimal distribution leads to increasing both number of recommendations by 5% and potential power losses by [18%; 43%]. Such effect is

explained by 1) more effective power distribution and, 2) connection with 2 lowpower hydro units, that cannot be used by JCS with equal distribution.

It is important to understand potential power losses in meaning of opportunities and possibilities for optimization of HPP states. Optimization can be done with implementing a rational control system, which optimizes units and HPP states. In the experiment same conditions, same equipment, same tasks, same work modes show better optimization range for function with proportional equality of control ranges regarding maximum efficiency of hydropower units. The function also provides possibility to add in joint control hydro units of different types. So it means, the optimal function can handle HPP task with less numbers of working hydro units and more efficient way.

## Conclusion

Different functions of active power distribution for HPP JCS were compared: traditional with equal power distribution and optimal with proportional equality of control ranges regarding maximum HPP efficiency. The suggested method showed good results in all HPP modes for its hydrological period. The number of recommendations were increased by 5 %, potential power effect is increased by 18% minimum. The shown results became possible due to more efficient distribution of active power among hydro units. Materials of the article can help develop a new distribution algorithm of HPP JCS, implement the system rational control for HPP operated units, build up the training of HPP operators and maintenance staff system.

## References

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