INCREASING THE EFFICIENCY OF SMALL HYDRO POWER PLANT FOR CHANGING WATER FLOW

Ondrej Rubes[1]

Doctoral Degree Programme (1), FEEC BUT

E-mail: ondrej.rubes@vut.cz

Supervised by: Dalibor Cervinka

E-mail: cervinka@feec.vutbr.cz

Abstract: This paper deals with increasing the efficiency of a small hydro power plant in a low power operation. Problem of the low power operation is low efficiency. Both, turbine and generator, are optimized for nominal power. On the other hand, in the low power operation they have low efficiency. The losses in generator are analysed and possible improvements are suggested. This should contribute to higher efficiency in the low power operation. Water turbine efficiency is showed for different water flows and ways to improve efficiency for lower flows are presented. Calculation of nominal efficiency and possible new higher efficiency is made.

Keywords: Small hydro power plant, Efficiency, Converter

1 INTRODUCTION

Eco-friendly solutions are often discussed, because of high number of technologies which produce pollution. One big part is energy generation. Traditional coal-fired power plants produce lot of air pollution which means big problem for living environment. New solutions as renewable sources are being finding but they often have another problem, for example vision impact of solar photovoltaic power plants or wind power plants. Problem of hydro power plants often lays in huge dams which devastates countryside, mainly forests and green fields. This problem does not concern in small hydro power plant which are often made on historical localities such as old water mills etc. However, this type of power plants has problem with variable water flow, because it misses the dam. This variable flow is space for improvements in electromechanical part of the power plants. Low power of small hydro power plants enable to use a converter to invent new type of operation.

2 LOW POWER OPERATION MODE OF HYDRO POWER PLANT

As was said in introduction, small hydro power plants are sensitive to changing river flow. The power plants very often work at lower power than nominal power is [1]. That is because they have lower efficiency due to constant no-load losses of generator and lower efficiency of water turbine. An example of this power plant is small hydro power plant in the Czech Highlands (MVE Jimramovske Paseky). There is horizontal Francis turbine. It has controllable stator blades regulating water flow which changes the output power to constant water level. The turbine is coupled with induction generator using flat belt. Figure 1 shows a view onto a mechanical room of the power plant.

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Figure 1 View on the generator and output shaft of the small hydro power plant

The nominal power of this power plant is 15 kW, for which the power plant is optimized. Figure 2 shows average power in each month for the last three years. Most of the year, the average power is lower than 10 kW and big part of the year, the power is about 5 kW, which is one-third of nominal power. The efficiency in this low power operation is lower and it is place to improvements.

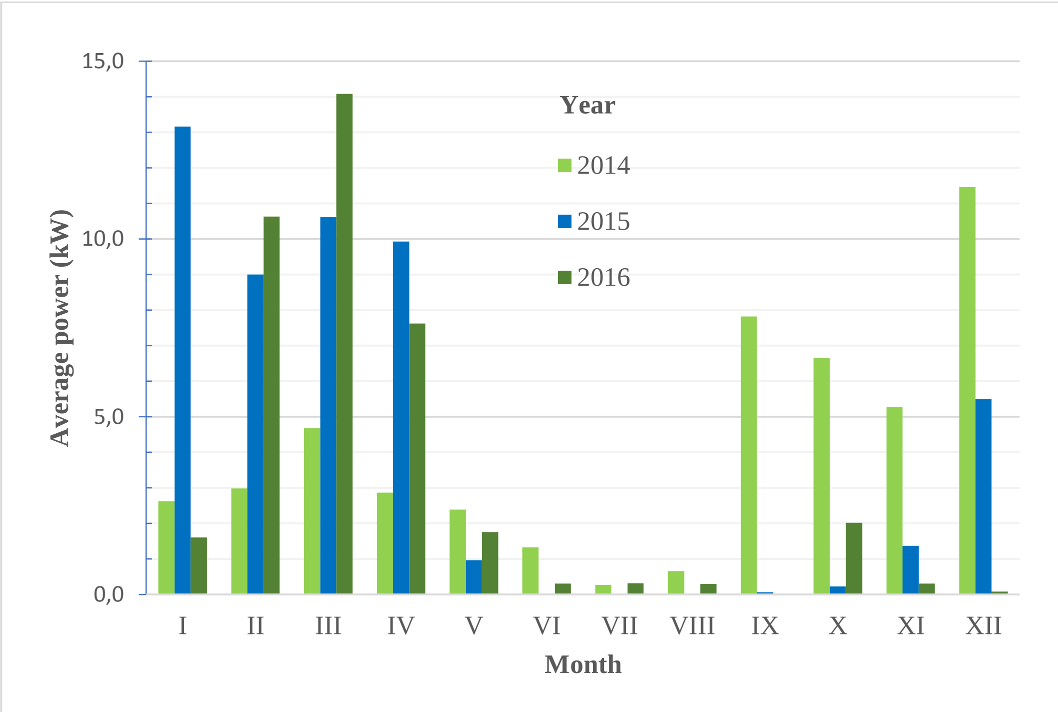

Figure 2 Average power in each month for the last three years

3 EFFICIENCY ANALYSIS

The loses in a hydro power plant are shown in the Figure 3. They can be divided into two main groups; loses in a hydro turbine and loses in an induction generator. Figure 3 illustrates main loses in both groups and their dependency on changeable operation values.

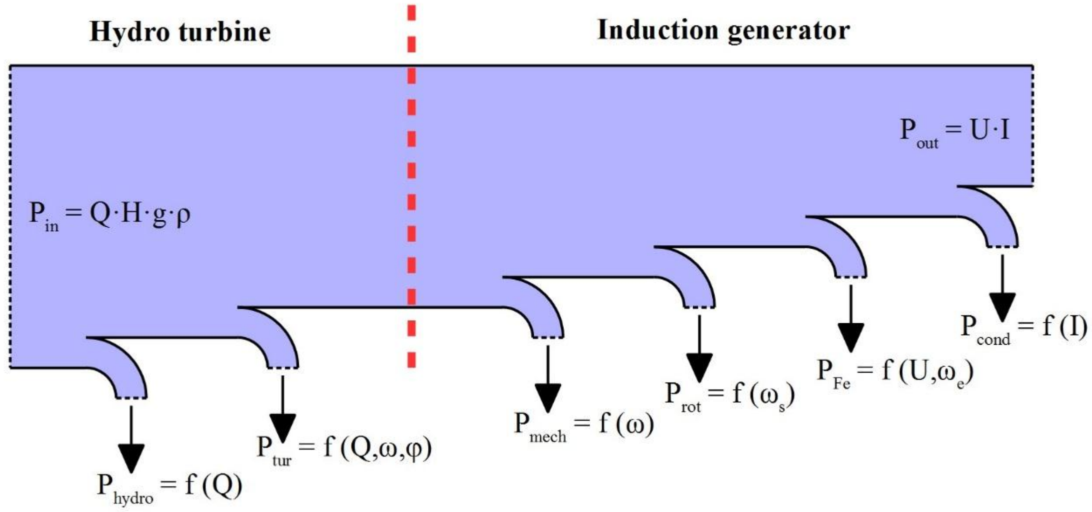

Figure 3 Power loses in a hydro power plant

Detailed analysis of all of them is huge issue and it exceeds the range of this paper. Loses in hydro turbine are explained by many authors, for example the presentation [2]. Losses in induction machine in the paper [3]. For this paper, the loses are summed together for each part of whole plant and are represented by the efficiency. The efficiency of power plant is composed of efficiency of generator and turbine, as Figure 4 shows. The final efficiency of hydro power plant is described by equation (1).

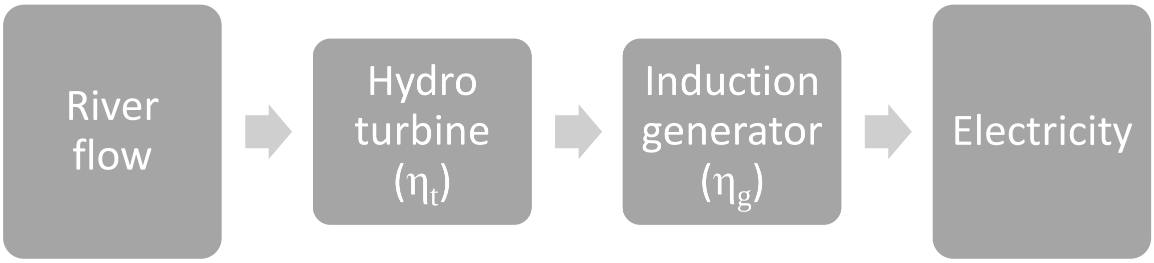

Figure 4 Process of power flow in a hydro power plant

$$\eta = \eta_t \cdot \eta_g \qquad (1)$$

3.1 EFFICIENCY OF THE GENERATOR

In the paper [4], analysis of generator efficiency is presented. The result of that analysis is that for lower power is better to use lower voltage. Figure 5 shows efficiency depending on stator voltage for power around 4 kW, of 15 kW power generator. For nominal stator voltage 400 V the efficiency in low power operation is about 80% and optimal power can be 91% for voltage 230 V. This method simply increases efficiency only by changing delta/star stator mode. More sophisticated method is to use a converter, which enables to set an optimal stator voltage for each power.

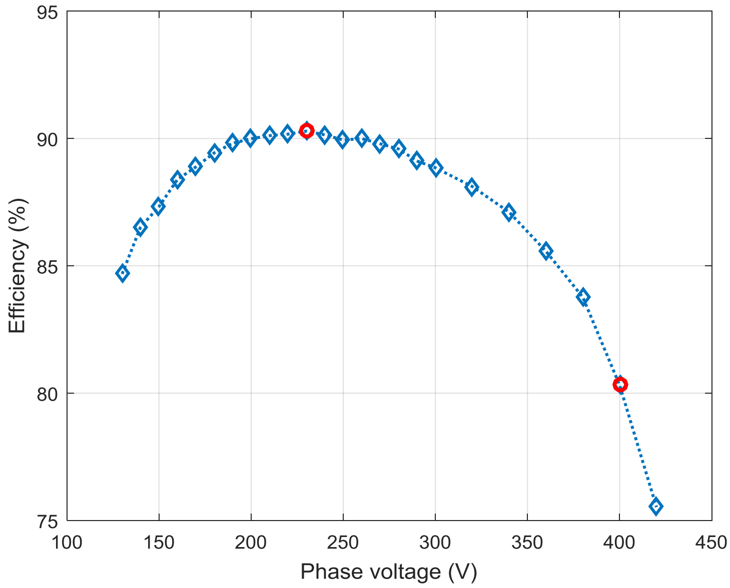

Figure 5 Efficiency of the generator in dependence on the stator voltage [4]

3.2 EFFICIENCY OF THE WATER TURBINE

Not only generator but also turbine has lower efficiency for lower power. Paper [5] analyses efficiency of some types of the water turbines. Authors present normalized efficiency of Francis turbine. For reference speed of rotation 50 rpm, the normalized efficiency is 100% for nominal flow 0,13 m^3/s. For flow 0,04 m^3/s, which is around one-third of nominal flow, the normalised efficiency for the same speed of rotation is around 36%. The highest efficiency for this flow could be 42% for slower speed 40 rpm. For bigger turbine, the difference could be more noticeable.

Real efficiency of Francis turbine from the first chapter is about 85%. This efficiency is equal to normalized 100% frequency. The efficiency for one-third power is 36% from to 85%, which makes 30%. The improved efficiency can be 42% from 85%, which is 36%. It means relative improvement of 20% on efficiency of turbine.

4 DISCUSSION

The efficiency of the whole power plant for one-third power of nominal value is originally:

$$\eta_1 = \eta_t \cdot \eta_g = 0.3 \cdot 0.8 = 0.24 \quad (2)$$

After improving, it can be higher:

$$\eta_2 = \eta_t \cdot \eta_g = 0.36 \cdot 0.9 = 0.32 \quad (3)$$

After improvement, the efficiency can be 8% higher, which means 33% relative improvement. As was said in previous chapter, the efficiency of turbine was from the article that deals with different type of turbines. So for a real turbine it can be higher but the principle of the improvement is the same.

The converter must be used to obtain improved efficiency. It has not 100% efficiency, so the efficiency of the whole plane should be recalculated:

$$\eta_{2\_real} = \eta_t \cdot \eta_g \cdot \eta_{conv} = 0.36 \cdot 0.9 \cdot 0.95 = 0.31 \quad (4)$$

The equation (4) shows that efficiency of the whole power plant with the converter can be also higher than traditional version.

5 CONCLUSION

Calculations show that efficiency of a small hydro power plant can be increased by changing of stator voltage and mechanical speed. Stator voltage affects generator efficiency. Calculation of generator efficiency is made from author's previous paper, where the calculation was verified by experiment. Calculation of turbine efficiency is used from paper [5], where similar, but not the same turbine was tested. It is expected that efficiency of turbine in presented power plant will be similar but also not the same. However, the trends in efficiency are identical.

Solution with the converter has higher efficiency. There is also one positive fact; It is possible to brake turbine to zero speed or simply connect it to a grid. The question is whether the solution with converter would be able to make enough money to pay it. There is possibility of using DC grids, which can contribute to cheaper converters without active rectifier.

The fact is that the calculations are not precis including deep physical models and equations. However, it was not the main aim of this paper. The goal was to analyse possible improvements for low power operation of hydro power plant which was successfully made. The next research step should be the precis physical model and mathematical analysis where optimal operation with the highest possible efficiency should be found.

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