ECONOMIC IMACT OF POWER QUALITY DISTURBANCES

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ABSTRACT

This paper describes some economic impacts due to power quality disturbances, in the paper mill in the eastern Croatia. Power quality has great importance to all power system operators in modern liberalized energy markets. Voltage sags and short interruptions are probably two of the most serious power quality problems. Total economic losses due to voltage sags are high because there is a significant number of voltage sags during a specific period of time and voltage sags affect a large number of customers. So this paper presents the procedure of voltage sags economic evaluation for complex process of paper production.

INTRODUCTION

In the recent years, economic losses have significantly increased due to the disturbances in power supply. The main reason is the widespread use of electronic equipment in industry and commercial installations.
Liberalization of energy market establishes new rules in relationship between customers and utility companies. Customers can now choose utility company so power quality objectives are now of great importance to all power system operators in modern liberalized energy markets.
Voltage sags and short interruptions are probably two of the most serious power quality problems [1]. They cause irregular operation of industrial equipment and commercial and domestic installation. In comparison with short interruptions, total losses due to voltage sags are higher because one can expect more voltage sags during specific period of time and voltage sags affect a larger number of customers [2], [3], [4]. The most sensitive applications are continuous production lines, (paper mill, cement production etc.) lighting and safety systems and computer equipment. For assessing the total annual cost resulted from voltage sags, it is essentially to detect how many dips are expected. In this paper, an economic evaluation of voltage sags in paper mill was performed.

ECONOMIC EVALUATION OF VOLTAGE SAGS

Evaluation of voltage sags costs can be performed through the following three steps [5]:

1. Estimation of the voltage sag performance of the supply system.
2. Evaluation of the effects of voltage dips on components and equipment.
3. Economic analysis.

These three steps will be described in more detail in the following.

Stochastic assessment of voltage sags performance

In order to make economic evaluation as accurate as possible, it would be useful to assess the expected number of sags and their characteristics on the specific place in the power system network, in a specific period. It can be assessed in two different ways: by long term monitoring or by stochastic prediction.
Voltage sags are short duration reductions in rms voltage and can be characterized by residual voltage (or depth), duration and annual sag frequency. They are caused by short circuits, overloads or by starting of large motors. The interest in voltage sags is mainly due to the problems they cause on several types of equipment: adjustable-speed drivers, process-control equipment, computers etc. [2].
Stochastic prediction methods use modeling techniques to determine results. They are as accurate as the model and the data used [1].
The method of fault position is the best known method for stochastic assessment of voltage sags induced by short circuits in large power systems. By this method, expected number of voltage sags and their magnitudes are calculated. Accuracy of the method depends on the number of fault positions in modeled power system, and can be improved by larger number of fault positions.

Evaluation of the effects of voltage sags on components and equipment

There are two basic procedures to estimate the impact of voltage sags to a specific component or process. First procedure requires knowledge of sensitivity of this specific component to voltage dips [5]. Many manufacturers provide voltage tolerance curve for their components. Second procedure is to use some of the well-known curves for evaluation the effects of voltage sags, as the Computer Business Equipment Manufacturers Association (CBEMA), the Information Technology Industry Council (ITIC) and the Semiconductor Equipment and Materials International (SEMI).

Economic analysis

Economic analysis should be based on knowledge and experience about specific industrial process, and also on historical data. For one industrial process disruption, due to voltage sag, costs should include raw material scrap, unload labor due to disrupted production process, lost profit, repair parts, repair labor and production start-up.

Finally, the total financial losses of the specific process are obtained by multiplying the total cost of one process disruption by the number of disruptive dips per year [5].

RESULTS OF ECONOMIC EVALUATION OF VOLTAGE SAGS IN PAPER MILL

Paper mill Belišće d.d. produce paper on two paper machines. As a big consumer of energy, like others paper mills, Belišće d.d. has its own industrial cogeneration power plant for supply paper production with thermal energy and electricity. Own electricity production covers approx. 60 % of the mill needs, while the rest is bought from supplier on 110 kV voltage level via overhead line which is connected on the HEP TSO (Croatian transmission system operator company) transmission system. Both installed generators are in operation during the year, but normally not at the same time. Normally, industrial power system operates in parallel mode with HEP TSO electric grid with one generator in operation. Electricity is distributed by two main medium voltage switchgears (*1AL* and *2AL*) on 6,3 kV voltage level. The generators *G2* and *G3*, each 20 MVA, are directly connected to the switchgears *1AL* and *2AL* busbars respectively. Installed distribution transformers (6,3/0,4 kV) and installed medium voltage motors are connected to the switchgears (*1AL* and *2AL*) via cables. Scheme of paper mill industrial power system is given by Figure 1.

Assessment of voltage sags characteristics

As it was mentioned before, annual number of sags for high voltage (110 kV) busbar in paper mill was received in two different ways: by monitoring (measuring) and by stochastic prediction (method of fault position).
Power quality measurement lasted 175 days, and the results are presented in Table 1.

Table 1. Measured voltage sags in paper mill.

Phase L1, L2, L3	0 < 20 ms	20 < 40 ms	40 < 60 ms	60 < 80 ms	80 < 100 ms	100 < 120 ms	> 120 ms
85 - 90 %			**5**	**2**			
80 - 85 %			**1**	**2**			
75 - 80 %					**1**		
70 - 75 %			**1**	**3**			
60 - 70 %			**2**	**1**	**3**		**1**
50 - 60 %				**2**	**3**		
40 - 50 %							
30 - 40 %						**1**	
20 - 30 %							
10 - 20 %							
< 10 %					**1**		

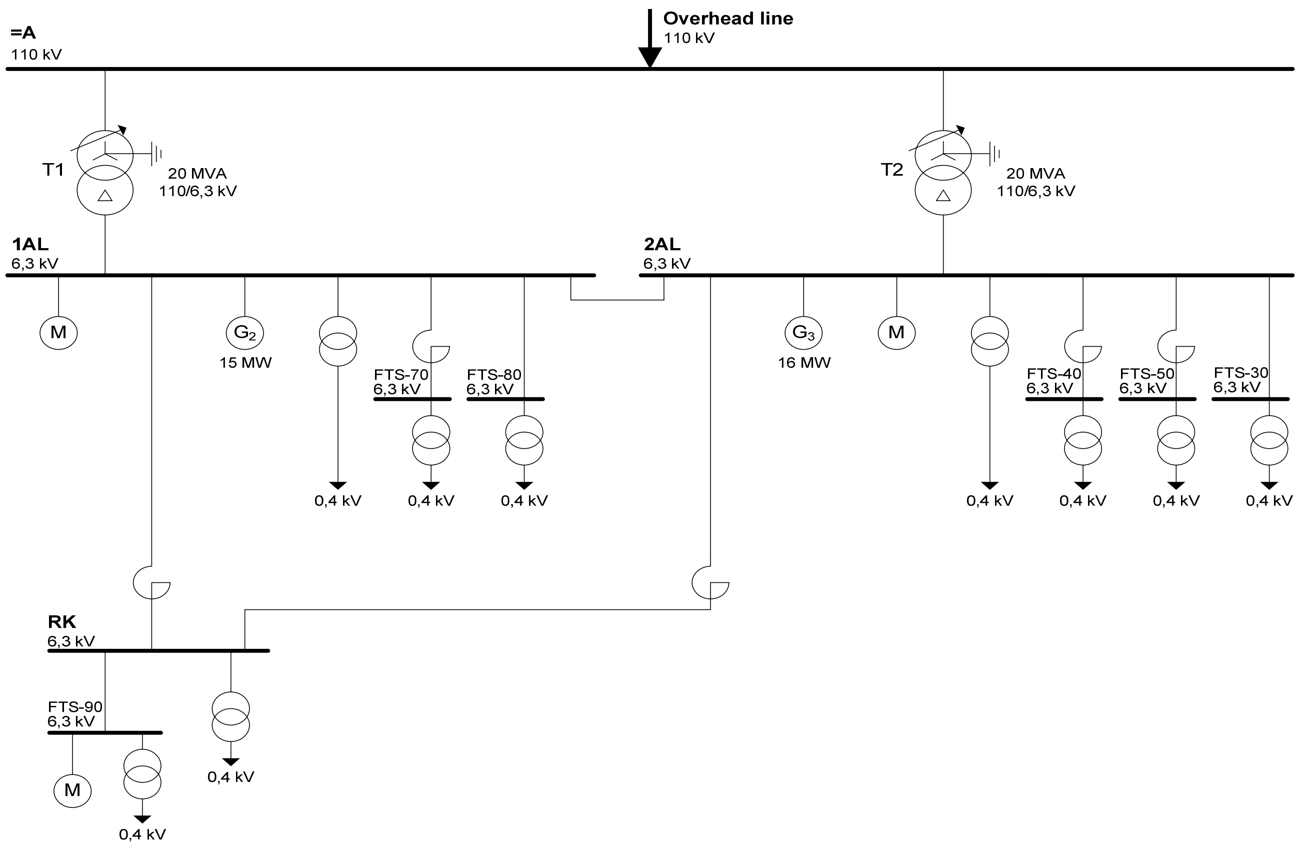

Figure 1. Industrial power system of paper mill.

In order to get the annual number of voltage sags and because of easier comparison, measured values were extrapolated to duration of 1 year and are presented as cumulative values, Table 2. So, on HV busbar in paper mill, about 60 sags per year are expected.

Due to stochastic prediction of voltage sags, the method of fault position has been applied to the real part of the power system, i.e. the part of the existing transmission network. The analyzed system consists of 41 buses, 48 lines, 9 transformers, 5 generators, and 8 terminals (links with neighboring systems). There are three basic voltage levels in the modeled system: 400 kV, 220 kV and 110 kV. Figure 2 shows a comparison of measured values with the values obtained by modeling. It can be concluded that the modeled cumulative function fits very well the cumulative distribution of recorded voltage dips.

Evaluation of the effects of voltage sags on paper production process

The impact of voltage sags on paper machines, which partially operate on 0,4 kV voltage level, depends on:

- which generator is in operation (the generators have different excitation systems);
- load of the generator;
- ratio of own production and intake from HEP TSO grid;
- loading of each distribution transformers (depends on the production of different types of the paper);
- duration and depth of voltage sags.

Table 2. Cumulative extrapolated values of measured voltage sags in paper mill.

L1, L2, L3	0 ms	20 ms	40 ms	60 ms	80 ms	100 ms	120 ms
90%			60,49	41,71	20,86	4,17	2,09
85%			45,89	37,54	20,86	4,17	2,09
80%			39,63	33,37	20,86	4,17	2,09
75%			37,54	31,29	18,77	4,17	2,09
70%			29,20	25,03	18,77	4,17	2,09
60%			14,60	14,60	10,43	2,09	
50%			4,17	4,17	4,17	2,09	
40%			4,17	4,17	4,17	2,09	
30%			2,09	2,09	2,09		
20%			2,09	2,09	2,09		
10%			2,09	2,09	2,09		

By monitoring the conditions in power network and paper machines production, it has been noticed that regulated motor drives cause most paper production disruptions. Also they cause profit loss and additional costs due to direct and indirect damages on paper machines equipment.

Thus, the characteristics (duration and depth) of voltage sags, which cause paper production disruption, have been determined: remaining voltage is 75 % of nominal voltage and duration is 80 ms. If these limits are applied to tables 1 and 2, it can be concluded that the paper production process can be stopped only by the sags from the gray fields in mentioned tables.

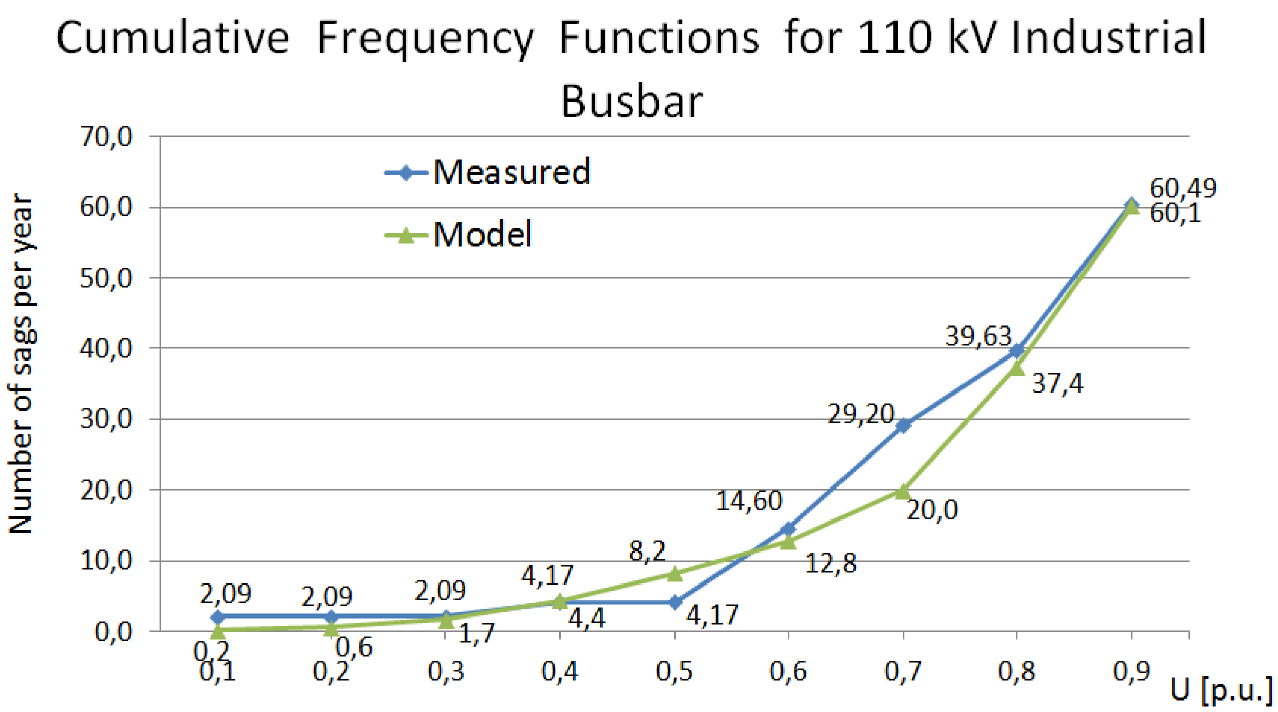

Figure 2. Cumulative frequency functions for paper mill industrial busbar.

According to the Table 2, this means that about 19 disruptions during one year can be expected.
However, the generator has a beneficial influence on disturbances which occurs in paper mill power network, due to voltage sags in HEP TSO grid. Namely, a group of loads (distribution transformers and medium voltage motors) which are connected to the same switchgear busbar as generator in operation are less affected by the disturbances in relation to a group of loads which are connected to busbar without generator in operation. In addition, for the same disturbance with the same load, the responses of the generators are different, because of different generators excitation systems.
So, it can be expected that, due to the configuration of industrial power network, the number of interruptions of the paper production process in one year will be less than 19. According to the measurements and records, during the measurement period of 175 days, there were 5 disruptions of process, which means 10,43 process interruption per year.

Economic analysis

The amount of average total cost, caused by one voltage sag, is 19.282 €. That amount has been obtained from cost analysis which is based on historical data and experience (structure is given by Table 3).

Table 3. Costs of voltage sag in paper production process.

Costs	EUR/sag
Paper and raw material scrap	750
Unload labor due to disrupted paper production process	600
Lost profit	5.000
Repair parts (mech. & electr. parts, felts, etc.)	7.000
Repair labor	72
Production start-up (raw material, energy, etc.)	4.270
Inefficiently CoGen Power Plant operating (costs of technical minimum)	1.590
TOTAL	**19.282**

Cost of damaged equipment, duration of stoppage for repair and replacement of damaged equipment, due to voltage sag, varies from case to case. For example, in the cost analysis, 2 hours have been taken as average stoppage duration. This includes 0,5 hour for start-up paper production needed for achieving satisfactory paper quality. Realistically, sometimes durations of stoppage last much shorter, and sometimes much longer. Average cost of damaged equipment is 7.000 €. Realistically, equipment damage is sometimes considerably lower, but sometimes considerably exceeds the amount specified herein.

Finally, when both the total cost of one process disruption (19.282 €) and the number of disruptive dips per year (10,43 sags) are known, the total financial losses of paper production can be calculated:

$$19.282\,€/sag \times 10{,}43\ sags/y = 201.111{,}26\ €/y$$

So, the total financial losses of paper production, due to voltage sags are 201.111,26 € per year.

CONCLUSION

Voltage sags cause huge damage in industry processes and are related to significant expenses. Total cost comprises not only unload labor due to disrupted process and lost profit, but also raw material scrap, repair parts, repair labor, production start-up etc. This paper presents such a procedure of economic evaluation of voltage sags for complex process of paper production.
The assessment of voltage sags characteristics is performed by means of monitoring and stochastic prediction. In the next step the evaluation of the effects of voltage dips on paper production process is made. Finally, using the results from previous two steps and cost analysis (which is based on historical data and experience), expected annual costs due to voltage sags are calculated.

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