Effects of Voltage Sags on Pulp and Paper Industry

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***Abstract*-- This paper deals with the effects of voltage sags on the pulp and paper industry, a very important sector for the economy of many countries. As these industries are very sensitive to disturbances in the voltage supply, it is very important to know how different processes react when voltage sags occur and how to minimize them to save money. A real case in a large paper industry in Brazil has been studied, when possible problems and solutions were analyzed. By performing computer simulations it was possible to investigate the influence of the electrical configuration and load distribution on the magnitude of voltage sags as well as their economical impact over the industry.**

***Index Terms*—voltage sags, pulp and paper industry.**

I. Introduction

Voltage sags are a common problem on electric power distribution systems. Their magnitude and duration are linked to the power system network configuration and protection characteristics.

Pulp and paper industries are a very important segment in the economy of many countries. They represent a significant share of the international trade and of the investment. It is also an important electricity consumer because of the high amounts of energy and demand used in its processes.

Added to its economical importance, these industries are considered very sensitive consumers for power quality disturbances, especially for voltage sags.

Recent investigations in European industries show that the cost of poor quality is about €10 billions per year.

Brazil is the seventh largest paper producer and the tenth in pulp production. For the next seven years, investments of US$ 12 billions are expected. The pulp and paper industry employs directly, at least, 150 thousand people in 2267 companies. In 2004 the country exported US$ 3.1 billion, while the production grew 3.6% in comparison to 2003.

Pulp and paper processes have different behaviors when voltage sag occurs. It is very important to know how each process reacts and to analyze the impact of a sudden stop in the production for the final product.

Considering the importance of this industrial segment it is important to know how to minimize the costs caused by voltage sags in the production. A deep investigation has been done in a big Brazilian pump and paper industry considering the most sensitive production processes when possible solutions were identified.

II. Pulp and paper production

It is very important to understand the many processes of the pulp and paper production line to find out the sensitive pieces of equipment. That is one has to know the sensitive degree regarding voltage sags, as well as the economical impacts of a non-planed stop in the production.

The production can be divided in three stages: stock preparation, sheet formation and drying. Depending on the final paper use, special treatment is needed before, in and at the end of the production line.

Paper can be produced from pulp, mechanical paste or re-utilized paper with pulp addition. All these three kinds of paper production use wood as basic material.

The stock preparation is responsible for the transformation of the wood in a paste and gives the necessary chemical treatment for the pulp. If the paper is to be produced through mechanical paste, than more energy is necessary to grind the wood chips and transform them in paste. However it is an easier and faster process that demands less chemical treatment.

At the sheet formation, the paper paste runs with a constant speed on a horizontal screen leaving the wood fibers and the excess of water.

In the dryer, the paper sheet is pressed to remove all possible water. Then it is directed to the heated cylinders that evaporate all remain water. In this part the paper width is defined through its passage in the calender. After the dryer, the paper will be winded and prepared for transport.

The most sensitive production areas for voltage sags are the sheet formation and dryer because they both need an accurate speed control. All these production

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parts are in fact just a big machine (paper machine) with a continuous process. Some motors of this machine, responsible for the screen and cylinder movement (actuation system), need a special speed control, which is obtained by special drives called Sectional Drives. This is the most sensitive load in case as voltage sag regard, and therefore demand specific studies.

If one or more of these motors suddenly stop, the paper will break inside the paper machine. Sometimes it takes hours to clean and make it able to produce again.

III. OVERVIEW OF THE CASE STUDY

The case study considers an old paper industry in Brazil, which was built after the Second World War. After several enlargements and modernizations, the industry is still been one of the largest paper industry in the Country. It produces different kinds of paper in four paper machines. Up to 2008, a budget of US$ 600 millions is planed for a new paper machine, mechanical paste line, boiler and turbo-generator. Following this investment, the total paper production capacity is expected to be 900,000 t/year.

Since the plant is old, the electric power supply can be considered weak, i.e. it has a low short circuit level. There are three electrical sources for the mill, one single power transmission line in 69kV from the utility company, one double line from a hydro-electric power station with two hydro-generators (10.4MVA and 11.7 MVA) and one 34 MVA turbo-generator (TG7). There are three smaller turbo-generators that are to be turned off and cannot be considered. Considering as a new investment, one new 50 MVA turbo-generator will be installed to supply the new paper machine. The turbo-generators run with steam produced at the power boiler, that burns wood splinter. All these electrical sources are interconnected by a 69 kV substation as shown in figure 1.

As the generated electrical power is not enough, approximately 38 MVA are supplied by the electrical utility. However, because of the place where the industry is located and the characteristics of the transmission power line that supplies it, the short circuit level is very low (230 MVA) what means that the electrical grid is weak. As consequence, all internal busses in its electrical system are more sensitive to voltage sags.

Modern pulp and paper industries receive energy by 138 or 230 kV lines and usually have enough internal generation, what means that voltage sags problems are minimized. Regarding the case study, building a new substation in such a voltage is the best solution to reduce voltage sags problems, though it is an expensive solution and will take a long time to be concluded.

Medium voltage motors are supplied in 6.6 kV voltage level. At the mill, there are four very large motors that require careful starting procedure, namely two 8 MW units and two 6 MW units. They are motors used for the mechanical paste refining. Three of them are connected directly to the 69 kV substation through dedicated 69/6.6 kV transformers (TR-45, TR-50 and TR-110). The other motor is connected to the 13.8 kV busbar, through a 13,8/6.6 kV transformer (TR-102).

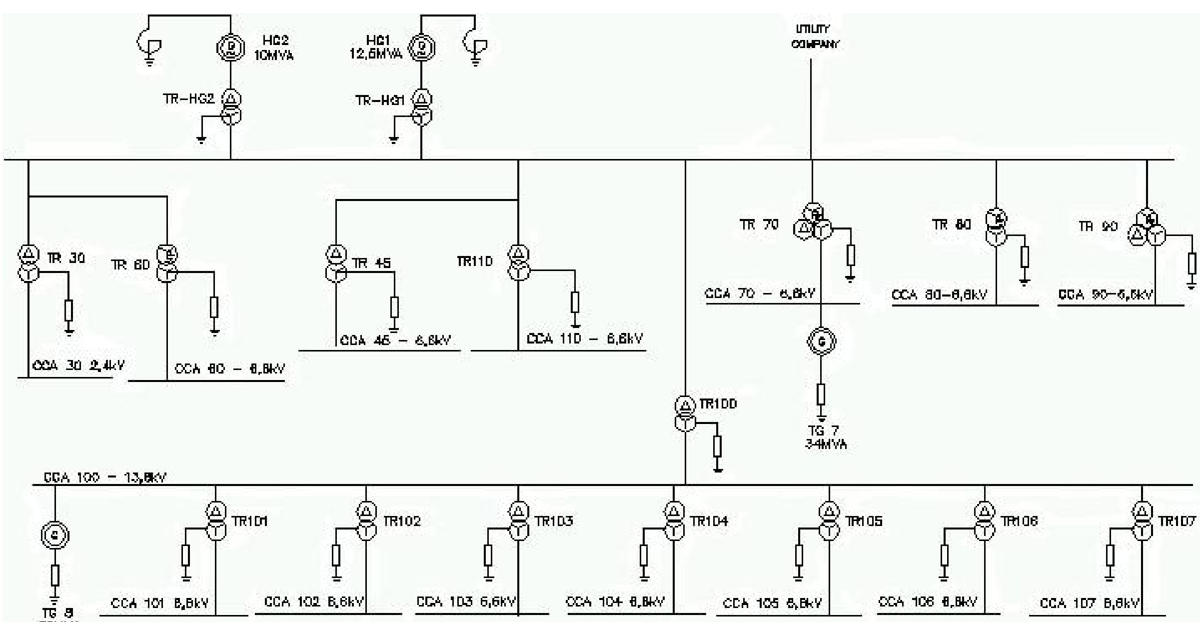

FIGURE 1 – Simplified One Line Diagram

A. Paper Machines

After the stock preparation, that is where the paper obtain its chemical characteristics, the formed past goes into the paper machine. As it is the final stage in the paper production, this machine is responsible to take out all water off the paste and to ensure the desirable paper width and superficial finish.

Following the entrance box, the paste goes through the horizontal screen, which is responsible to control the paper sheet formation, removing the excess of water. This screen runs in a constant speed. Any variation at the screen speed can move the paste more than necessary, what changes the paper sheet formation.

At the end of the screen, presses remove more water. Following that, the paper goes into the drier and, finally, to the winding.

In the case study, all paper machines have already been improved, by replacing the DC motors by AC motors. DC motors have been used for many years in pulp and paper industries because of their reliability in the motor speed control. However, taking into account the advance in power electronics, drives for AC motor control substitute the DC control, what led industries to utilize AC motors. This change provides a considerable economy in maintenance and machine interruption times.

Even with the mentioned modernization, paper machines still have been the most vulnerable part in the industry. This is because the sectional drive controls the most important motors of the paper machine. Being a drive the sectional control is very sensitive for voltage sags. Another aspect is that when the paper machine suddenly stops, it takes hours for it restart the production. Furthermore, when the screen is damaged, it needs replacement.

Figure 2 shows the CBEMA (Computer Business Equipment Manufacturers Association) curve for drives.

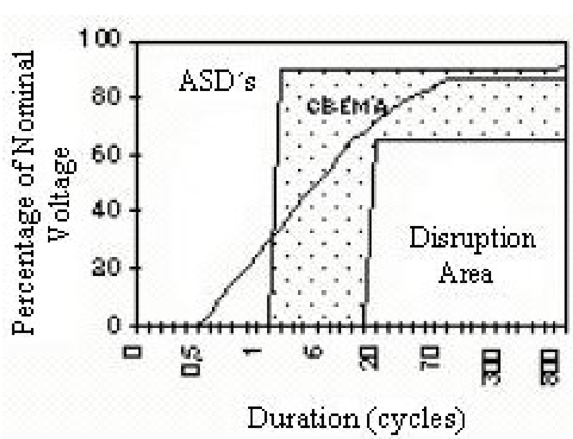

FIGURE 2 – CBEMA curve for drives

Voltage sags can be responsible for an output frequency variation or a drive stop caused by the action of the internal protection system (as the undervoltage protection).

In modern paper machines, the paper producer demands from the sectional drive supplier a specific immunity against voltage sags. In the case study, the new paper machine should not shut down until the voltage reaches 70% of the rated voltage for 0.3 seconds or 90% continuously (supply voltage can varies ±10% in any time).

There are a lot of ways to get this partial immunity. The most common one is to increase the capacitor of the DC link. However, sometimes the cost of improving the immunity of the drive can be too high, what leads to other alternatives.

B. Electrical System Configuration

The electrical system configuration, namely transformer connections, protection system, electrical sources and load distribution, has a big influence on the voltage sags duration and magnitude.

The studied industry has different electrical sources but, as discussed before, it relies a lot on the local utility company. Since the energy supplied comes from just one power line (69kV), when there is a momentary loss of this line, a load rejection system shall be activated immediately, otherwise there will be a total loss of the electrical sources.

Another characteristic that makes the electrical system vulnerable is the low short circuit level of the utility company. This makes more difficult for some the starting of big motors and contributes for deeper voltage sags in case of short circuits.

As all 69/6.6 kV transformers are grounded through a high resistance value, the phase to ground short circuit current is limited to 400A. However the three phase short circuit is high in the medium voltage level, mainly at the busbars bearing local generation (turbo-generators TG-7 and TG-8).

The 69/6.6 kV transformer connection is not standardized. The old ones are connected as Δ-Y grounded through high resistance. The ones that have been installed after the 80´s are connected as Y-Y-Δ, with primary and secondary windings grounded (secondary through high resistance and primary solid grounded) and the tertiary used just to deter homopolar harmonics. Low voltage transformers are standardized as Δ-Y (solid grounded).

The transformer connection has a big influence on the voltage sag magnitude, mainly for phase to ground short circuits. If a phase to ground short circuit produces voltage sag of 0.58 pu on phase A for a Y-Δ transformer, in a Y-Δ (isolated) transformer, the same short circuit would not cause any voltage variation. For the same example, if the connection is Y-Y grounded, as the case of TR-70, TR-80 and TR-90 (the ones where all paper machines are connected), the voltage sag magnitude will be 0.33 pu. If both sides of the transformer are solid grounded, than the voltage goes to zero.

IV. Computer Simulation

Using the software PTW (Power Tools for Windows) short circuit simulations have been carried out to analyze the magnitude of voltage sags in some substations, mainly the ones responsible for the paper machines and at the utility company busbar (in the 138 kV system that supplies the city and the mill). Only the high (69 kV) and medium voltage (13.8 and 6.6 kV) systems have been modeled. All medium voltage transformers, synchronous and induction motors and cables have been considered. Pre-fault voltage was considered as 1.0 pu.

All medium voltage motors contributions to the short circuit have been calculated. Phase shifts in transformers have also been considered. Table 1 shows the voltage sags (0.5 cycle) caused by a single line to ground fault in important busbars.

Short Circuit	Busbar	Sag (pu)		
		AN	BN	CN
Utility	SE-69 kV	0.91	0.89	1.00
	MP-1	0.95	0.94	1.00
	MP-6	0.95	0.94	1.00
	MP-7	0.95	0.94	1.00
	MP-9	1.00	0.95	0.94
	CCA-90	0.95	0.94	1.00
SE-69 kV	MP-1	0.37	1.04	0.99
	MP-6	0.37	1.04	0.99
	MP-7	0.37	1.04	1.00
	MP-9	0.91	0.61	0.96
	CCA-90	0.27	1.11	1.06
CCA-100	SE-69 kV	0.80	1.00	0.77
	MP-1	0.88	1.00	0.86
	MP-6	0.88	1.00	0.86
	MP-7	0.88	1.00	0.86
	MP-9	0.55	0.56	1.00
	CCA-90	0.88	1.00	0.87

Table 1 – Phase to Ground Short Circuit

V. Voltage Sag Analyzes

The short circuit simulation resulted in the evaluation of the voltage sag magnitude for the main busbars. Special attention shall be taken for CCA-70, CCA80 and CCA-104 that are the ones responsible to feed the paper machines.

The second aspect that shall be analyzed is the voltage sag duration. This information added to the voltage sag magnitude allow, even without 100% of assurance, whether the drive will trip or not.

Short Circuit	Busbar	Sag (pu)
Utility	SE-69 kV	0.55
	MP-1	0.73
	MP-6	0.73
	MP-7	0.73
	MP-9	0.73
	CCA-90	0.74
SE-69 kV	MP-1	0.39
	MP-6	0.39
	MP-7	0.40
	MP-9	0.39
	CCA-90	0.41
CCA-100	SE-69 kV	0.59
	MP-1	0.75
	MP-6	0.75
	MP-7	0.75
	MP-9	0.00
	CCA-90	0.76

Table 2 – Three Phase Short Circuit

The protection system and its parameters allows for the estimation of the voltage sag duration. In the case study, digital ones have already replaced most original relays. At the 69 kV substation, they are from the family 7SJ (Siemens), whereas for the above system, all of them are from ABB (models SPAM, SPAJ …).

Even using digital relays, there is not any logical protection system. Considering this, the operation time can be high in case a short circuit occurs near the 69 kV substation, to provide the adequate protection coordination.

Each transformer has a ground relay for phase to ground short circuit protection. The low voltage system transformers (6.6/0.44 kV) are fuse protected, what makes the operation time faster once there is no delay in relays and circuit breakers operation.

Some parts of the electrical system have not been completely modernized and the panels were not substituted. In these cases, the medium voltage circuit breakers still have been oil isolated. This kind of circuit breakers takes typically 5 cycles to clean the fault while SF6 or vacuum circuit breakers take 3 cycles. Considering this, the systems fed by oil circuit breakers will have longer voltage sag. Obviously it happens when this circuit breaker is the one responsible for the fault cleaning.

If motor starting is analyzed as the voltage sag cause, the conclusion is that the sag duration can be until 10 s, depending on the motor starting time. However, the magnitude of this kind of voltage sags decrease with time, so quite always it does not make damages in the machines connected to the electrical system.

As pulp and paper industries have a sophisticated control system, in the studied mill, all control system is done by local PLCs and some DCSs (Digital Control System). As these systems are very sensitive to voltage sags, dedicated Uninterruptible Power

Systems (UPS) should supply them, with autonomy for 30 minutes that isolates the control system from the power system.

In medium voltage panels, the control system is obtained through a direct current system fed by batteries.

Considering this, the control system is always immune to voltage sags. The only exception is the internal control system of low voltage Motor Center Control that comes from an internal transformer. For old MCCs this is not a problem for they do not use intelligent relays. However, for the new ones, this can become a vulnerable point.

Analyzing the maintenance history it is possible to verify that in 2003 and 2004, the paper machines 6 and 7 have had some stops caused by voltage sags. In PM-6, there was an unsymmetrical voltage sag that affected in different ways the screen motors. This resulted in the break of the screen, what increased the machine interruption time and the maintenance cost.

VI. Solution

Since the main problem at the electrical system is the energy supplied by the utility company, the most effective solution is to build another 230 kV substation to feed the existing one (not substituting the existent transformers that would be very expensive). In this voltage level, energy would be supplied from a substation that has a higher short circuit power (600 MVA).

The second possibility is the installation of a new turbo-generator to supply, with the existing ones, the entire mill. This would not just minimize the voltage sags problem but would also increase the operational reliability.

Local solutions can be done as UPSs, minimizing the drive sensibility through the increase of the capacitor at the DC link, and other solutions that can be discussed with manufacturers.

VII. Conclusion

In this paper, a typical pulp and paper industry has been studied. Its electrical system was identified as weak and vulnerable. The power supply and internal generation did not bear the needed capacity for all loads.

By using this case study, the main idea was to show how common is to a large pulp and paper industry to have problems with voltage sags and the sensitivity of its processes.

A complete study was carried out by calculating the magnitude of voltage sags through computer simulations. By analyzing the protection system, an estimation of the duration of these disturbances was possible.

As it is possible to see in Tables 1 and 2, deep voltage sags can happen in the paper machines substation causing problems in the paper production.

This kind of study identifies the weak points. Thee results can then be used to try and minimize the number of production interruptions as well as the maintenance cost and time.

Computer simulations confirmed what have been verified by the company's maintenance department, namely voltage sags as being one of the main reasons for paper machines interruptions.

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IX. Biographies

Thiago Corrêa Farqui was born in 1979 in Santos, Brazil. Graduated in electrical engineering with emphasis in power systems in 2001 by the Federal University of Engineering of Itajuba (UNIFEI). He works as electrical engineer in pulp and paper industry projects. He is finishing his M.Sc. in the University of São Paulo (USP). His areas of interest are electric power systems and power quality.

Marcos Roberto Gouvêa (M'79 D'94) electrical engineer, graduated from the Polytechnic School of the University of São Paulo in 1972; was awarded a Master's Degree (1979) and a Doctorate in Engineering (1994) in the area of Power System by that same Institution. He joined THEMAG ENGENHARIA in 1972, working as engineer and consultant until 1995. As Chief Commisary of CSPE (Comissão de Serviços Públicos), Dr. Gouvêa was responsible for the technical area of the entity form 1998 to 2000. Since 1989, he has been a Professor at the Department of Engineering and Automation of the Polytechnic School of the University of São Paulo. Dr . Gouvea is the author of more than 50 articles, which were presented in congress and published in specialized journals.

Nelson Kagan was born in São Paulo, Brazil, on October 8th, 1960. He graduated from Polytechnic School, University of São Paulo in 1982. His MSc degree in 1988 is from Polytechnic School, University of S. Paulo and his Ph.D. degree was obtained in 1993 in the University of London. He lectures at Polytechnic School, University of S. Paulo since 1983, where he is an Associate Professor. His main areas of interest are Power System Planning and Power Quality.