Effects of Voltage Sag on Electrical Drives in Mazandaran Wood & Paper Industries, Simulations and Real Time Measurements

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ABSTRACT

With the increasing of non-linear loads in electric power system, power quality distortion has become a serious issue in recent years. In pulp and paper industries, due to presence of concentrated high power non-linear loads such as electric drives, this problem is a greater concern. In this paper, power quality problems such as voltage sag and swell in Mazandaran Wood and Paper Industries (MWPI) are presented. Using actual data, the interaction of these voltage transients on behavior of the main production line motor drive is investigated. With simulation by Matlab software, the effects of different kinds of voltage sag on speed, torque, and current of motor are analyzed.

KEYWORDS

Power quality, Voltage sag, Voltage swell, Paper mill, Electrical drive, Simulation

1. INTRODUCTION

Power distortions such as power interruptions, voltage sags and swells, voltage spikes, and voltage harmonics can cause severe impacts on the loads in the electrical systems. They cause improper operation of sensitive and electronic loads. In modern power systems, due to increase of non-linear loads, power quality has become a great concern. The main production line in paper industries needs a high quality of power, because there are several motors, working together with precise speed. For instance, in the South African Pulp and Paper Industries (SAPPI) plant, voltage sags with more than 20% amplitude and 40 mS duration cause paper breaks that require a long time to clean the machinery and resume production. They may also blow the rectifier fuses in the DC drives because of higher transient current [1]. In the Caledonian paper mill, there are 23 DC drives on the paper machine working together. A voltage sag of more than 10% results in drive trips to prevent thyristor damage. Tripping the paper machine usually causes other areas of the paper mill such as wood handling and pulp preparation to stop [2]. The latest investigations in Europe show that the cost of poor power quality is about €10 billions per year [3]. The transient voltage variation results from lightening strike, switching of power line/capacitor bank, system fault and large motor start-up [4]-[7]. Simulation and experimental results of voltage sag on adjustable speed drives show that voltage sag affects drives functionality [8]. Therefore, a good power quality monitoring system is essential for the paper mills, in order to decrease the downtime and increase the efficiency [9]. The results of a one year power quality study (2004/2005) in MWPI are presented in this paper. To provide detailed analysis of the system, one of the DC drive systems is simulated using Matlab/Simulink in presence of voltage sag and the results are presented. To provide detailed analysis of the system, one of the DC drive systems is simulated using Matlab/Simulink in presence of voltage sag and the results are presented.

2. OVERVIEW OF MWPI PLANT

MWPI is the largest paper manufacturer in IRAN with capacity of 175000 tons of paper production per year (90000 tons of newsprint, printing and writing paper and 85000 tons of fluting paper). Power demand of the plant is 35 MW and consists of the following sections: [10]

1. Water treatment (p(nom)=3000 kW)
2. Wood handling plant (6821 kW)
3. Pulp plant (25000 kW)
4. Chemical recovery plant (4907 kW)
5. Steam production plant (3887 kW)
6. Effluent treatment (2500 kW)

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7. Paper machine no.1 or PM1 (22000 kW)
8. Paper machine no.2 or PM2 (12200 kW)
9. Finishing (3500 kW)

A part of single line diagram is shown in Fig.1. Power distribution system of MWPI consists of 43 transformers as follows: 36 at 2MVA 20kV/400V, 5 at 5MVA 20kV/6.6kV, 2 at 20 MVA 20kV/6.6kV.

The 20kV incoming line is fed from a 90MVA 230kV/20kV network transformer. Some power quality related disturbances and problems have been reported in MWPI over the past few years. From the power quality point of view, the paper machine section is the most important one, because of continuous process. Most of the variable speed drives of the plant are used in the paper machine section, and work continuously with multi drive control strategy. There were under voltage trips in DC drives of the paper machine. AC & DC dives are more sensitive to the voltage sag, because of the power electronic switches [6], [11]. There are 18 DC drive for PM2 (Paper Machine for producing fluting paper 113&127gram) and 22 DC drives and 16 vector control AC drives in PM1 (Paper Machine for producing 48 gram newsprint). Nominal linear speed of PM1 is 1000 MPM (Meter Per Minute) and 600 MPM for PM2. Each DC drive has microcontroller processor board and its speed is regulated with static accuracy lower than 0.01% and dynamic accuracy lower than 0.1% with pulse transducer(1024 pulse per cycle) as speed feedback. MWPI's DC drive system is ABB made Tyrak MidiII model. The multi drive system control is performed by a central computer (Masterpiece). The cost of 1 minute production stop is about €200 for MWPI. The cost would increase if there is board or instrument damage. Therefore, every production stop due to the voltage sag will cost about € 15000 for the plant.

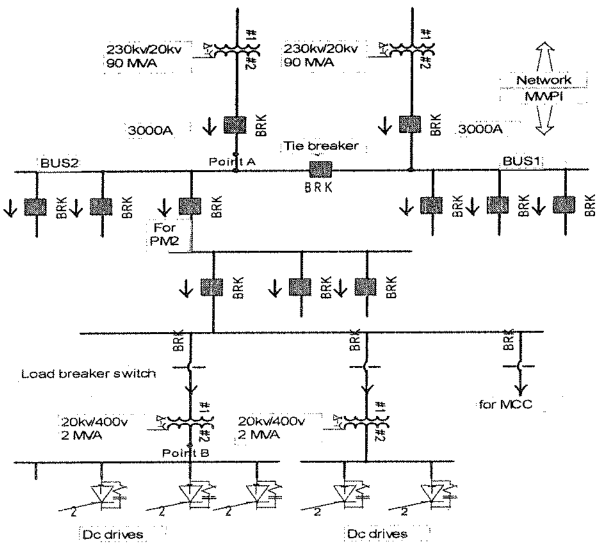

Fig.1.Part of single line diagram of MWPI power system.

3. POWER QUALITY MEASUREMENT

Two power analyzers were used to monitor the power quality parameters. One of them was installed on the 20kV incoming feeder of the plant (point A Fig.1), and the other was portable and installed on the 400V paper machine drive incoming feeder (point B in Fig.1). In point A, there were only 2 PT for voltage measurement, therefore, only 2 phases out of 3 phase voltage could be monitored. Sampling rate of analyzer was about 7000 sample/sec (140 samples per cycle). It samples 3 voltages and 3 currents. By RS232 serial port and Labview software, the recorded data was transferred to computer. The quantities such as power factor, THD, harmonic order magnitude, active and reactive power, demand, sag and swell were calculated by the software. In the cases of under voltage, over voltage and over current, 20 cycles waveform (10 cycles before and 10 cycles after event) were saved in the analyzer for later analysis. The under voltage threshold was set to 18 kV for the fixed analyzer, and 210V for the portable one. The over voltage threshold was set to 22 kV for the fixed and 250V for the portable analyzer phase to ground voltage. The nominal voltage was 20kV and 230V, respectively. The over current thresholds were set to 3000A and 500A, for the fixed and portable analyzers, respectively.

4. ANALYSIS OF DATA

During about one year (2004/2005) power quality monitoring, 77 voltage sags (amplitude reduction of supply voltage more than 10% within half cycle up to one minute) and 3 voltage swell occurred in the MWPI. Fifteen event out of them cause to stop paper machines due to under voltage trip. The detailed information of voltage sags in 3 months is given in Table 1 and complete report is given in Fig.2. Nominal voltage of each phase to ground is 230 volt. Three out of 10 cases (highlighted rows in Table 1) caused MWPI trip. For example, one of them (No.6) caused paper machine to trip and it took 39 minutes for PM2 and 86 minutes for PM1 to reproduce paper.

Table1. MWPI Voltage Sag & swell report in 3 months

No.	ph.	time	Date	vol.(V)	%nom	Duration
1	v1	11:46:56	6/3/2004	201.48	87.6	40ms
2	v3	12:36:41	24/3/2004	201.48	87.6	50ms
3	v3	17:59:56	28/3/2004	199.64	86.8	60ms
4	v3	12:24:49	29/3/2004	204.36	88.9	50ms
5	v3	12:11:09	30/3/2004	204.13	88.8	30ms
6	v1	18:59:56	26/4/2004	186.07	80.9	60ms
7	v3	16:51:59	5/5/2004	191.13	83.1	70ms
8	v1,v2,v3	23:15:00	12/5/2004	203.78	88.6	350ms
9	v3	14:36:32	13/5/2004	350.06	152.2	60ms
10	v3	13:56:37	5/6/2004	132.48	57.6	60ms

The voltage and current waveforms of these events, captured with 20kV analyzer, are shown in Fig.3. In this figure, only 2 phases (VR and VT) are shown because only 2 PT were installed in 20kV incoming. The waveforms show that an increase in current of one phase (IS) causes the voltage sag. Therefore, this voltage sag was created within MWPI. The waveforms of the paper machine DC drives are shown in Fig.4.

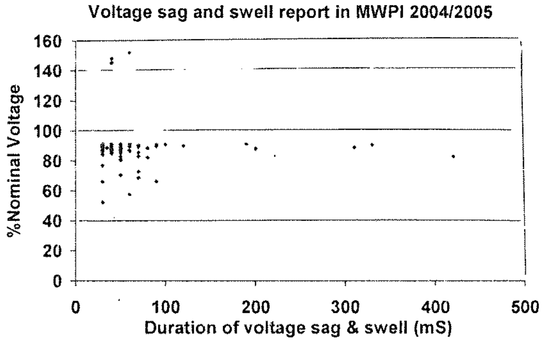

Fig.2. Voltage sags & swells report in MWPI during one year

Waveforms shown in Fig.3 and Fig.4 reveal that the voltage sags on the 20 kV incoming feeder has occurred on the 400V drive supply as well. The DC drive current increase was considerable (about 30% increases). Other events (voltage sag events no.1-5 and 8, 9 in Table 1) did not trip the paper machines. Voltage sag No. 7 in Table 1 tripped only the wire and press section in PM1. In this event, one electronic board of the DC drive in the press section is also damaged. The threshold of the under voltage trip for DC drives in the paper machine of MWPI was 85% of the nominal voltage and 3.3 mS in duration. So, the voltage sag of 80.9% in amplitude and 60 mS duration in case no.6 activated the under voltage trip. A short circuit in one of the plant transformers was the reason of this voltage sag. It took 50 mS and caused the paper machine trip. In case no.7, the voltage sag causes a change in amplitude of current. The origin of this type of voltage sag was determined to be outside of MWPI and from the utility grid. Consequently from power quality monitoring device waveforms of voltages and currents, the source of voltage sag can be identified [12], [13].

5. SIMULATION OF DC DRIVE BEHAVIOR DURING VOLTAGE SAG

In this section, DC drive performance of a DC drive is simulated by Matlab/Simulink software in presence of voltage sag. The drive systems in MWPI consist of speed and current control for the armature and current control for field. The block diagram of a drive control is shown in Fig.5. In order to increase the precision of the simulated system, input source voltage harmonic orders of 5,7,11,13,17, and 23, according to real time measurement are also considered [14], [15].

DC motor parameters are determined according to an actual DC motor in the Press section of PM1 as follows: Power=453kw, Speed=1390rpm, Armature Voltage=470V DC, Armature Current=1019A, Field Voltage=310V DC, Field Current=16.2A, Moment of Inertia=406 kgm^2 (including motor, gear box and load moment of inertia).

Three types of voltage sags are investigated include: single-phase to ground, two -phases, and 3 phases. The input voltage is assumed to have a voltage sag of 80.9% within 60mS (35~35.06 S) for all three cases according to case no.6 in Table 1. From this simulation current waveform during voltage sag was analyzed (voltage and phase currents are shown in Figs.6-9). The motor speed, torque and armature current during voltage sag are simulated and results are shown in Figs. 10-12.

When the voltage of phase A decreases (voltage sag 80.9%), the current of phase A decreased and currents of phases B, C increased about 25% (Figs. 6-9).

From simulation results of Fig. 7-12, the effects of voltage sag on the DC drive system can be identified. During one phase to ground voltage sag, the speed of the motor does not change significantly as shown in Fig.10. This is due to high moment of inertia of load (J=406 kgm^2). However, the armature current of the DC motor increases as shown in Fig.12. Therefore, if drive system does not trip in this case, the fast acting fuse of the armature circuit will be blown. Torque of motor changed same as armature current (Fig.11). This relationship is very important for the paper machine because it causes the paper to break and production to stop. For this reason, the DC drive system will be tripped (under voltage trip) when the network voltage decreases below 85% of nominal voltage and lasts more than 3.3 mS. The simulation results for two phases to ground voltage sag are shown in Figs.13-15. The variation of motor speed is shown in Fig. 14. The waveform of armature current is shown in Fig. 15, which represents developed torque as well. Figs. 16-18 show the waveform of speed and armature current in the case of three-phase voltage sag. In MWPI, linear speed variation of the paper machine motors should be lower than 0.01% using pulse transducer as speed feedback. According to power quality monitoring reports, the most probable voltage sag is single-phase to ground. Additionally, according to simulation results, single-phase voltage sag causes more variations in speed, torque, and armature current of the DC motors.

6. POSSIBLE POWER QUALITY SOLUTION

According to actual data from paper mill, possible solutions that investigated for improving interactive effects are as follows:

1- Using servo stabilizer for voltage stabilizing is not proper solution because of its slow response.

2- Using servo stabilizer and output passive filters that is very big size and expensive for 2MVA power range and also has low confidence.

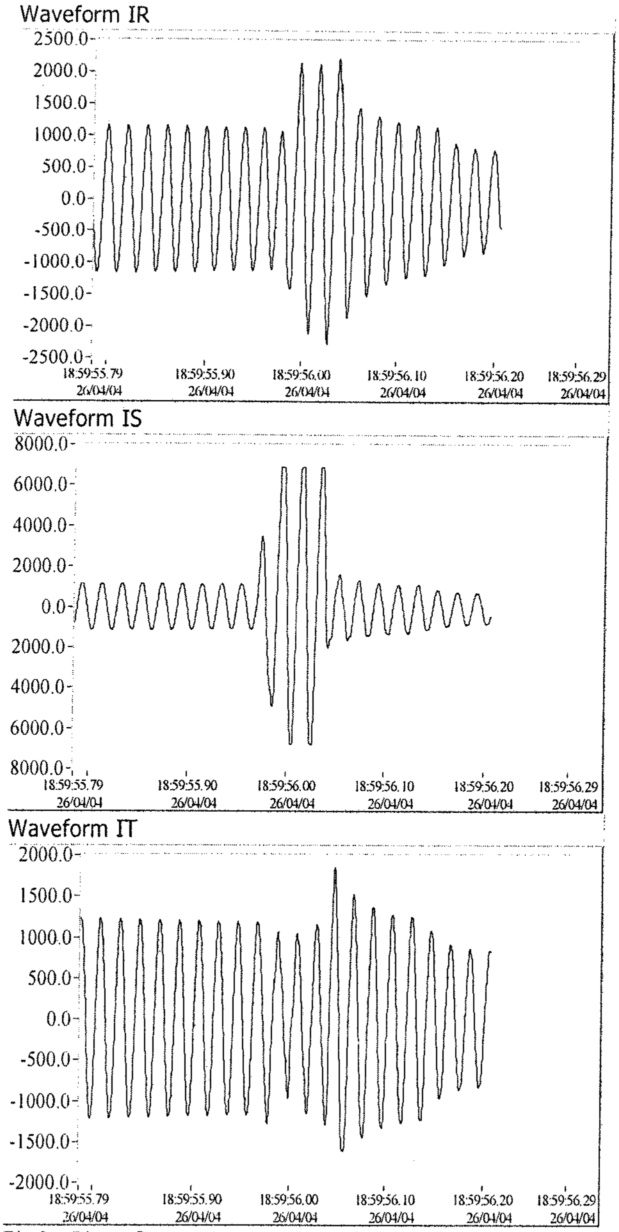

Fig.3a. Phase Currents measured at point A during voltage sag (case number6)

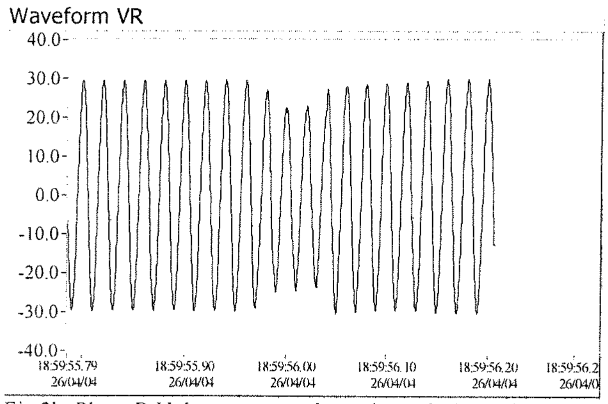

Fig.3b. Phase R Voltage measured at point A during voltage sag (case number 6)

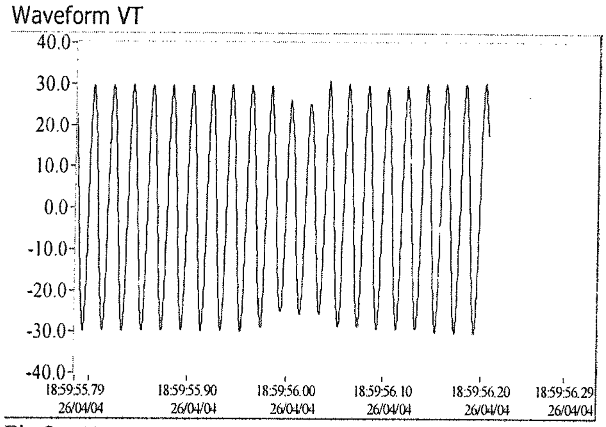

Fig.3c. Phase T Voltage measured at point A during voltage sag (case number 6)

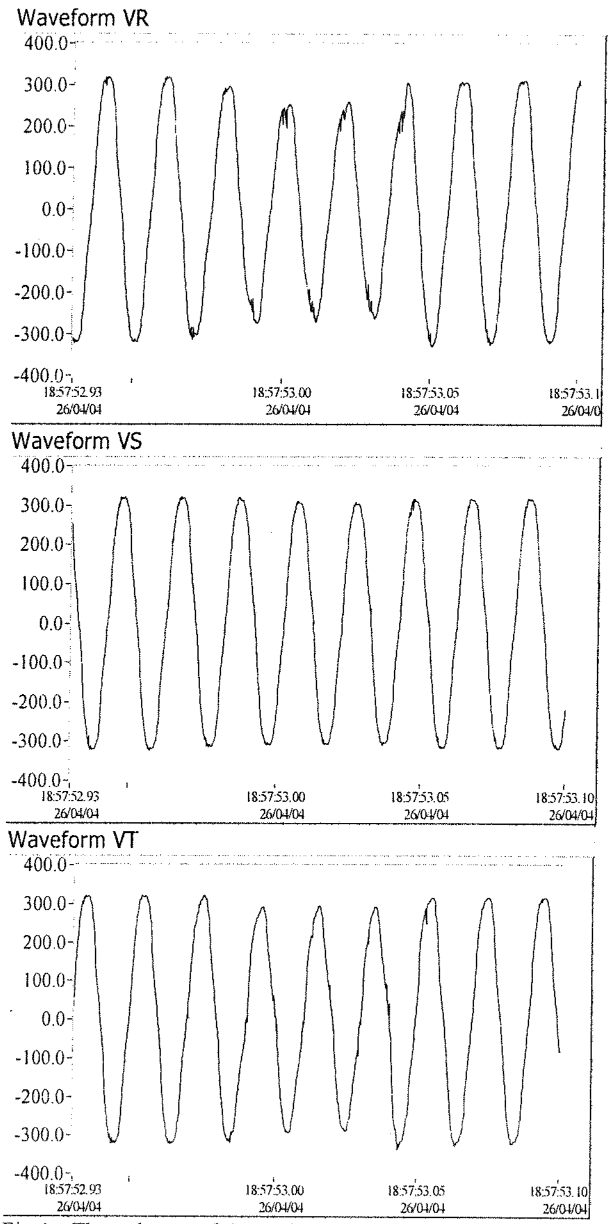

Fig.4a. The voltages of three phases measured at point B (drive supply) during voltage sag of case number 6.

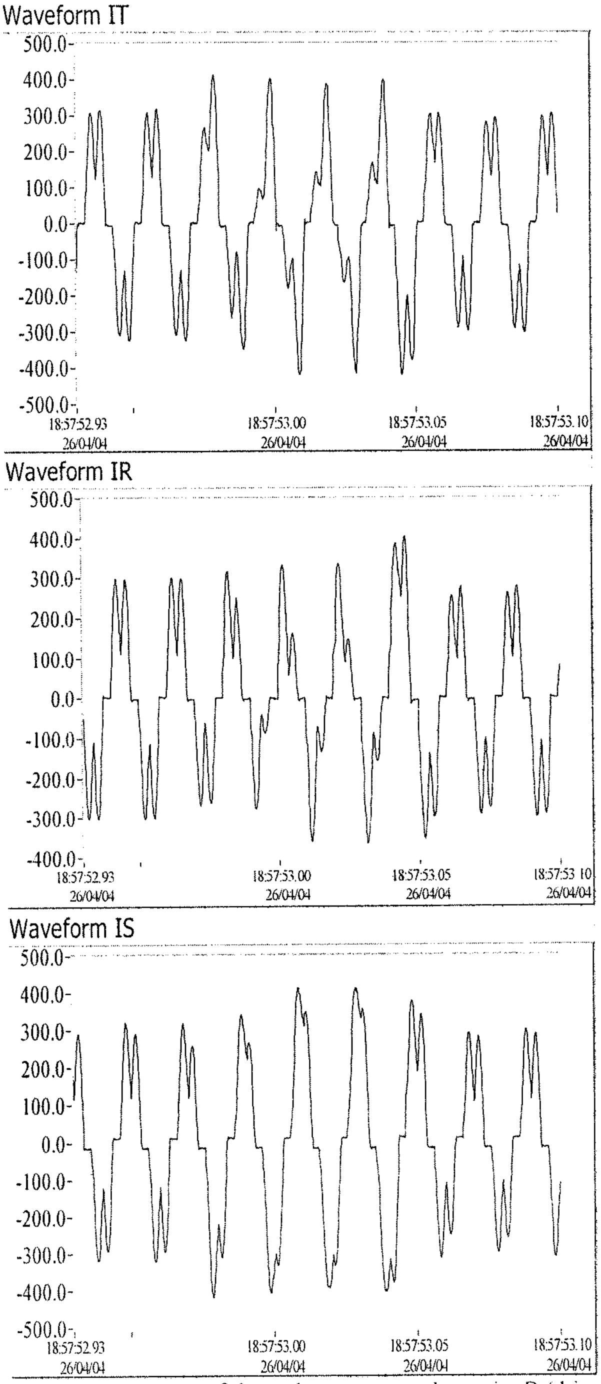

Fig.4b. The currents of three phases measured at point B (drive supply) during voltage sag of case number 6.

3- Using online UPS that is also not good for paper machine because the voltage sag duration is very low about 100mS.

4- Using dynamic voltage stabilizer for voltage stabilizing and also improving harmonics is proper solution for paper mill because of its fast and confidential response.

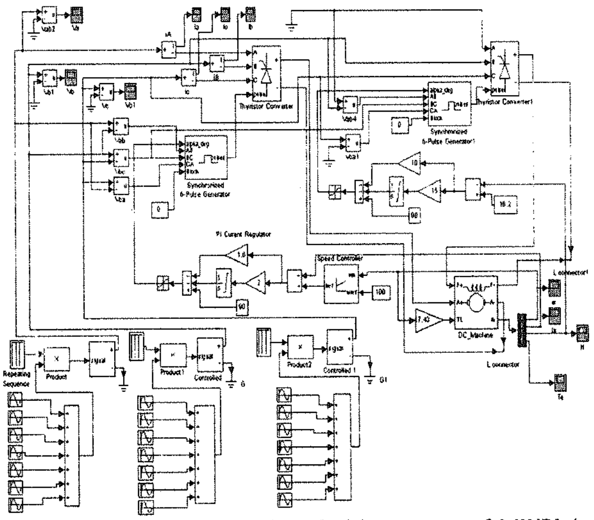

Fig.5. Block diagram of main DC drive system of MWPI in Simulink.

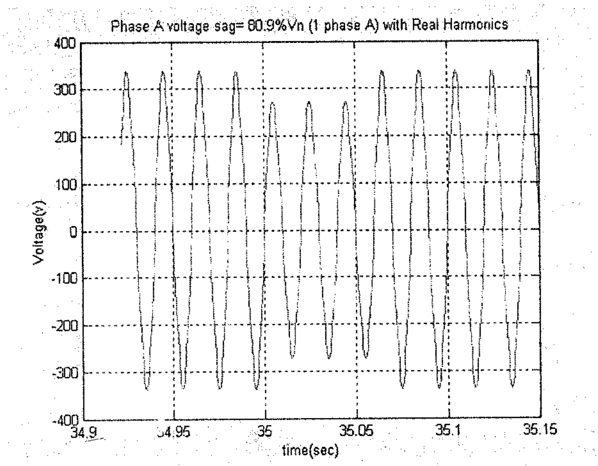

Fig.6. Voltage sag for simulation (3 cycle 35 ~ 35.06 sec and 80.9% Vn)

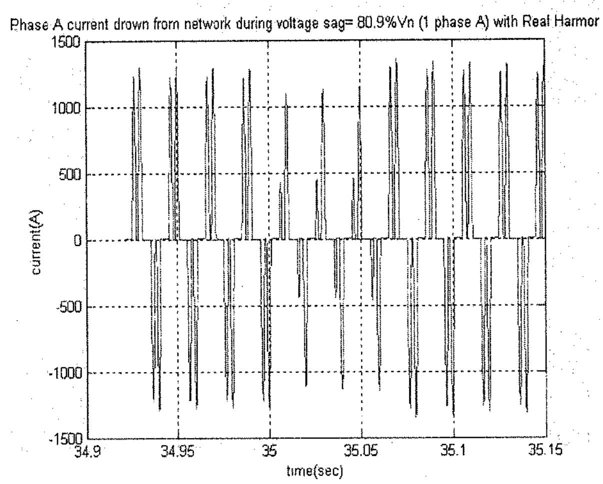

Fig.7. DC Drive Phase A current drowns from network during 1 phase (phase A) to ground voltage sag.

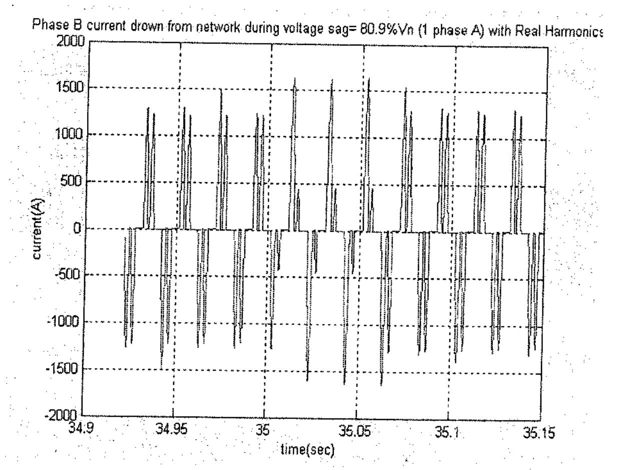

Fig.8. DC Drive Phase B current drowns from network during 1 phase (phase A) to ground voltage sag.

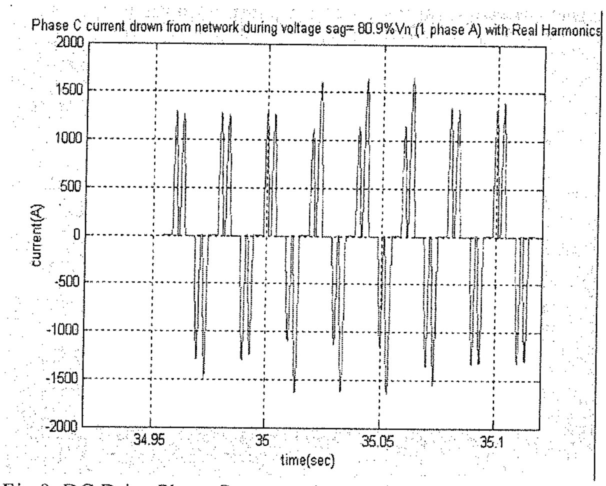

Fig.9. DC Drive Phase C current drowns from network during 1 phase (phase A) to ground voltage sag.

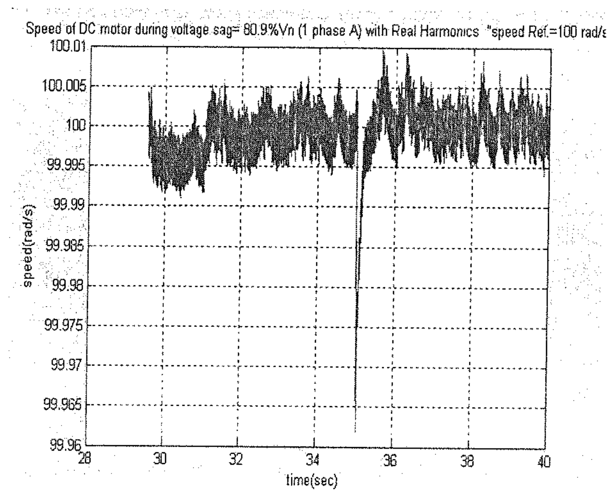

Fig.10. DC Drive motor speed (speed ref. =100 rad/s) during 1 phase to ground voltage sag.

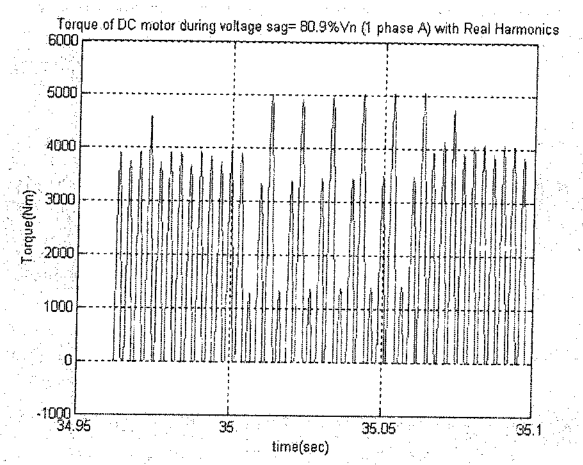

Fig.11. DC motor torque (Load torque = 1740 N.m.) during 1 phase to ground voltage sag.

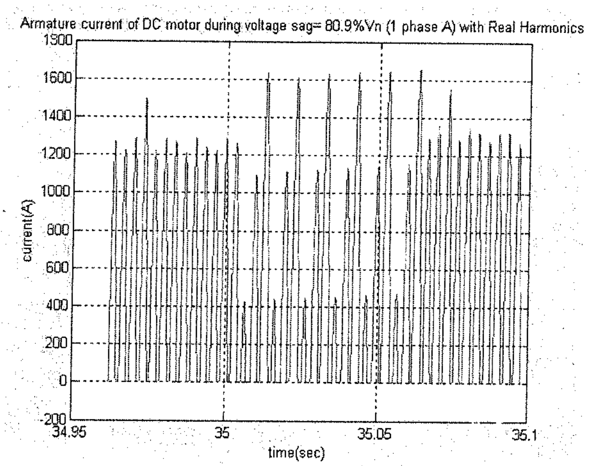

Fig.12. DC Drive motor armature current during 1 phase to ground voltage sag.

7. CONCLUSION

In this paper, the results of power quality monitoring in MWPI are presented. The results of the measurements show that 77 recorded voltage sags and 3 voltage swells have occurred during a one year in MWPI. 15 events out of these occurrences tripped the plant. The sources of these voltage sags have usually been located outside MWPI. By simulation of a DC drive system with Matlab/simulink software, effects of different kinds of voltage sags on speed, torque, and armature current of the motor have been analyzed. Simulation results show that during single phase voltage sag armature current of the DC motor will be increased. This current increase may cause the fast acting fuse on the armature circuit to blow. In single phase sag, the current drawn from the sagged phase is decreased but currents of the other two phases are increased. The speed of the motor is not affected significantly due to high moment of inertia of the load. Tripping of drives is very important for paper machine because it cause to break paper and stop production and reproduction of paper is very time consuming.

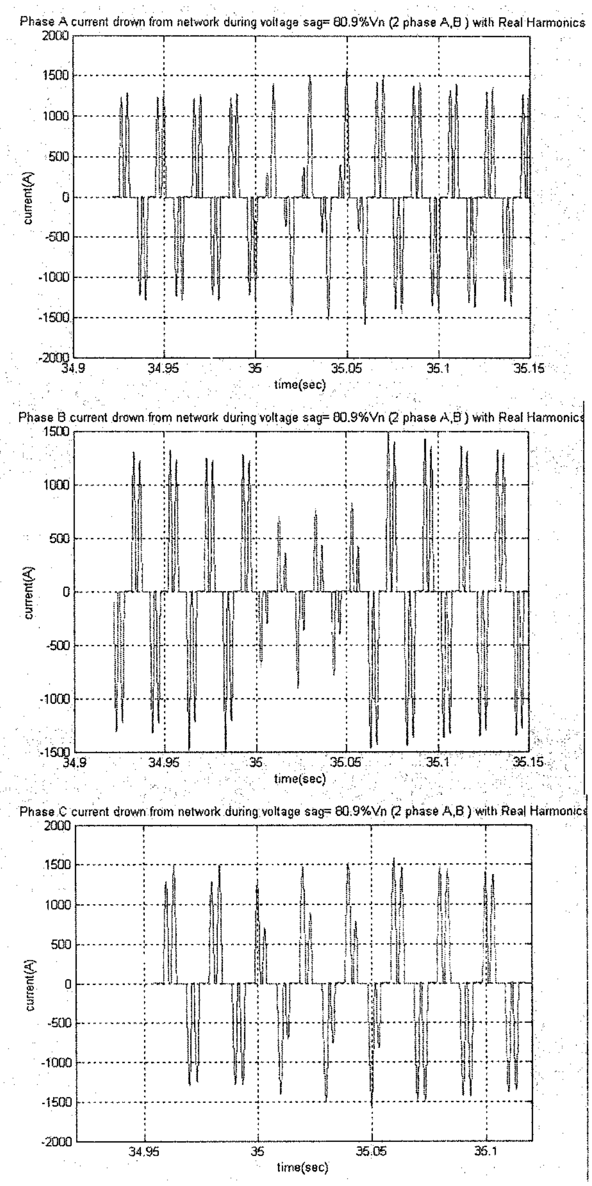

Fig.13. DC Drive phases A, B, C currents from network during 2 Phases (A,B) to ground voltage sag=80.9%Vn.

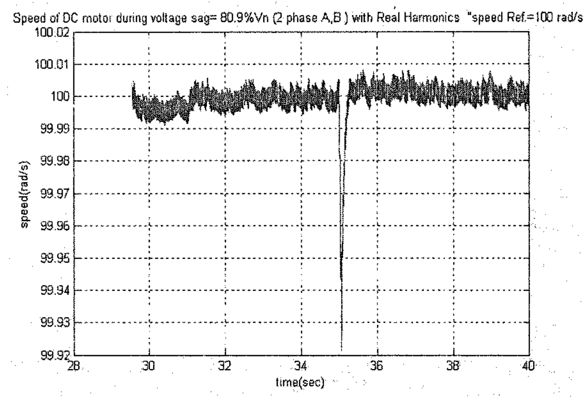

Fig.14. DC Drive motor speed (speed ref. =100rad/s) during 2 phases to ground voltage sag=80.9%Vn.

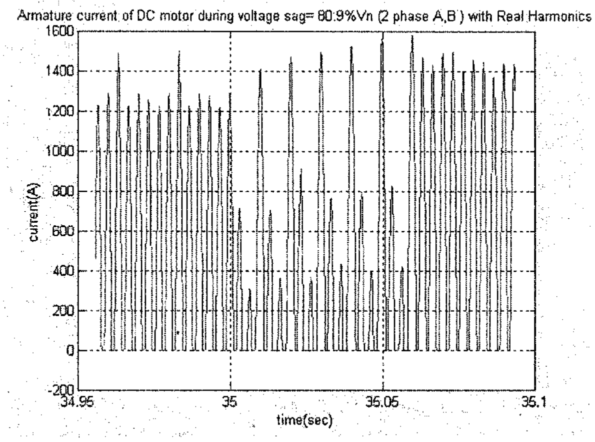

Fig.15. DC Drive motor armature current during 2 phases to ground voltage sag=80.9%Vn.

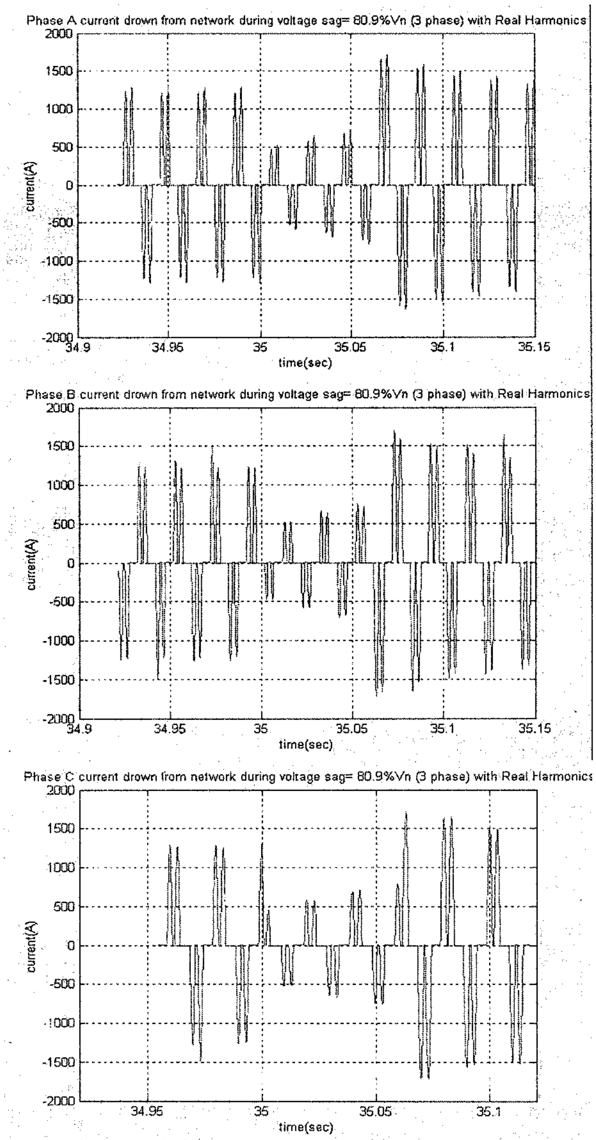

Fig.16. DC Drive phases A, B, C currents from network during 3 phases to ground voltage sag=80.9%Vn.

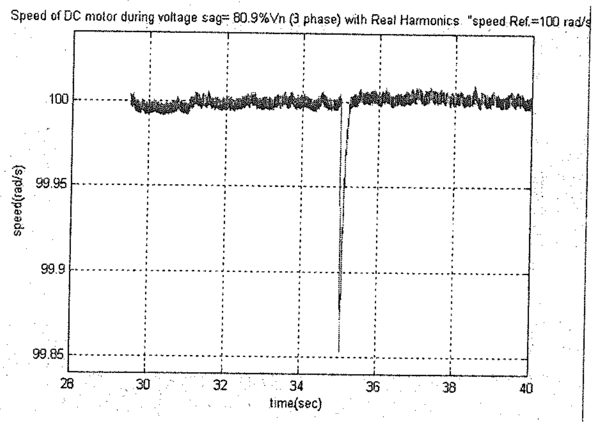

Fig.17. DC Drive motor speed (speed ref. =100rad/s) during 3 phases to ground voltage sag=80.9%Vn.

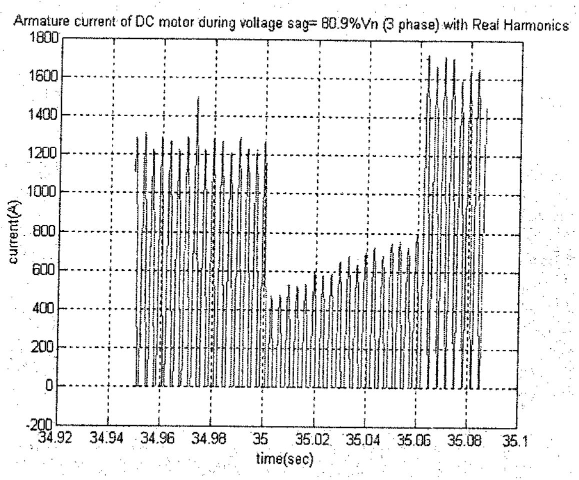

Fig.18. DC Drive motor armature current during 3 phases to ground voltage sag=80.9%Vn.

8. ACKNOWLEDGEMENT

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