A STUDY OF VOLTAGE DIPS, AND METHOD TO IMPROVE THE PERFORMANCE OF ADJUSTABLE SPEED DRIVES (ASD'S) DURING VOLTAGE DIP

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Abstract: This paper discusses issues of power quality in general, and voltage dips in particular. Voltage dips is one of the major power quality problems for users of electrical energy causing sensitive equipments like Adjustable Speed Drive (ASD) and process control equipments to malfunction. Investigation into the causes of voltage dips and their impact on the performance of ASD during voltage dips, looking into different possibilities to reduce the problems caused by voltage dips and methods to improve the performance of ASD during voltage dips are discussed in this paper. The main focus of the study is the redesign of ASD by introducing boost converter in the system without any additional energy storage devices. A case study has been performed at the Filrexbercham Industry in Ipoh, where voltage dips causes problems. Different values of voltage dips and boost converters were simulated using the simulation program MATLAB/Power System Blockset. The simulation results presented shows that boost converters provide ride-through to critical ASD loads during voltage dips as well as an improvement in the power quality.

Keyword: Index Term-power quality, Voltage dip, Adjustable Speed Drive, Ride-through, Per-unit (p.u)

INTRODUCTION

There are many types of power quality problems in the power system. They are categorized by the different types of distortion on pure sinusoid. Figure 1 shows the normal waveform of voltage during normal condition.

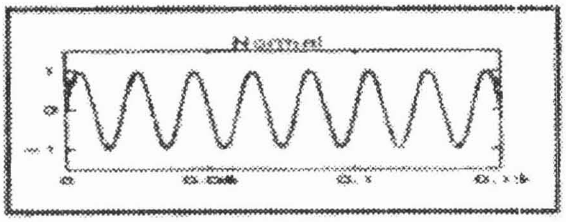

Figure 1: Normal Waveform

Voltage dips - A momentarily voltage dip that lasts for a few seconds or less is classified as voltage sag [1]. Figure 2 shows the waveform for voltage dip. There are two parameters that define voltage sag, the magnitude of the sag and its duration. Voltage sags may be caused by fault - more than 70% are weather related such as lighting- on the transmission or distribution system or by switching of loads with a large amount of initial starting/inrush current (motor, transformers and large dc power supplies).

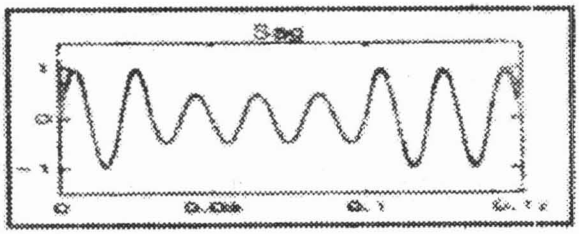

Figure 2: Voltage Sag/Dip

One of the major problems in monitoring power quality in power system is voltage dip or voltage sag. What are the differences between dip and sag? A voltage dip is the percentage down from nominal voltage. For an example, a 20% dip on a 240-volt system would be 192 V. Voltage sag is the percentage remaining. For example, an 80% on a 240 V system would be 192 V. Actually, these are the most common problems for utilities. Voltage dips occurs because of the faults in system, either on their generation system, transmission, distribution or in the industries itself. This is inevitable.

Computer equipment and controllers may power down depending on the duration and magnitude of the voltage dip. In addition, voltage dips cause loss of data. Fault also occurs in customer (or adjacent customers) internal power system. Voltage dips also can be the result of accidents involving power lines. For example, lighting or falling object may cause a line-to-ground fault. When the protective switchgear or autoreclosurer goes into operation to clear the fault, the voltage dips until the fault is isolated. Excessive load changes may also cause voltage dips [2].

It is important to understand the differences between an interruption (complete loss of voltage) and a voltage dip. Interruption occurs when a protective devices actually interrupts the circuit serving a particular customer. This will normally occurs during the periods of the fault for the faults over a wide part of power system. Faults on parallel feeder circuits or on the transmission system will cause voltage dips but will not result in actual interruptions. Therefore the voltage dips are much greater than if the equipment was only sensitive to interruption.

For this project, we will concentrates on the voltage dips that occur in power system. We have choosen a factory namely Flexibercham in Ipoh as a case study. This project involves the use of appropriate techniques and technology to ensure uninterrupted electrical power supply to consumers. By using MATLAB/Power System Blockset and calculation, the distortion of voltage dip will be ride-through. The voltage dip will be analysed and the equipments will be suggested in order to appropriate solve the problem.

MATERIALS AND METHODS

Power Quality Index

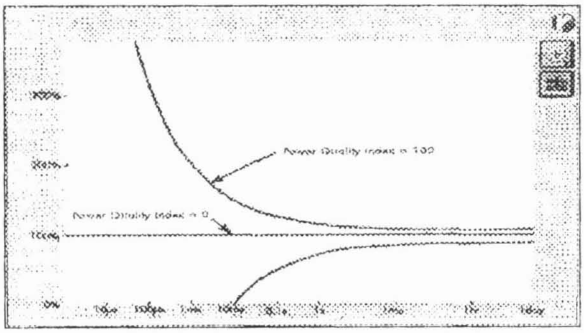

Figure 3: Power Quality Index Calculation

Power quality index (PQI) is not a simple concept; there is no single describing parameter, so it is difficult to quickly describe a change. One of the innovations is to describe a "power quality index" based on voltage disturbance events as a single number [3]. Perfect power is assigned a PQI of zero, while events lying on, for example the Computer Business Equipment Manufacturer's Association or CBEMA curve are assigned a value of 100, as shown in Figure 3. Events between the two, and events lying outside the curve, are assigned a value that is proportional to the distance from the curve.

The root mean square of the individual events is presented as the PQI for the site for the period of that survey, together with the maximum PQI for the period. Comparison of the PQI for a series surveys on one particular site gives a very quick appraisal for the trend in the quality of power and an idea of where to concentrate further effort.

Adjustable Speed Drive (ASD's)

The application of adjustable speed drives (ASD's) in commercial and industrial facilities is increasing due to improved efficiency, energy susceptible to voltage disturbances such as sags, swells, transients (e.g. due to capacitor switching) and momentary interruption (outages). Depending on the application, and the characteristics of disturbances, the ASD controlled process may be momentarily interrupted or permanently tripped out. This can significantly lead to loss in revenue and costly down time. Some drives are designed to ride-through voltage sags. The ride-through time can be anywhere from 0.05 sec to 0.5, obviously depending on the manufacturer and model.

In order to improve the performance of ASD and to provide ride-through, a redesign to the ASD rectifier stage is suggested. This method of control provides ride-through for most voltage dip condition. The proposed approach has the advantages such as low cost, due to minimal additional hardware and control, no semiconductor components in the main power flow path of ASD, provides ASD ride-through without additional energy storage devices, such as supercapacitor, batteries, etc; does not affect other loads connected to the point of common coupling (PCC) provides ASD ride-through for voltage dips which are frequent, repeated, and/or back-to-back occurrences, and the boost converter can be controlled to maintain a regulated dc-link voltage in the event of undervoltage condition at the input.

For this project, we have used Matlab/Power System Blockset to design and simulate the Adjustable Speed Drive (ASD's). The simulation for this topology includes displaying the input waveform and also the dip during the fault. In this case the fault is due to phase faults. MATLAB will be used to presents the voltage dip waveform. The dip can occur at two areas, utilities site (TNB properties) and system side or customer's equipment. In order to keep the customers equipment's safe from damage due to the fault, the author tried to develop a technique to cater for the dip by redesign the equipment by adding some components or circuit that is boost converter.

RESULTS AND DISCUSSIONS

Simulation of Voltage dip-A Case study at FILREXBERCHAM Factory

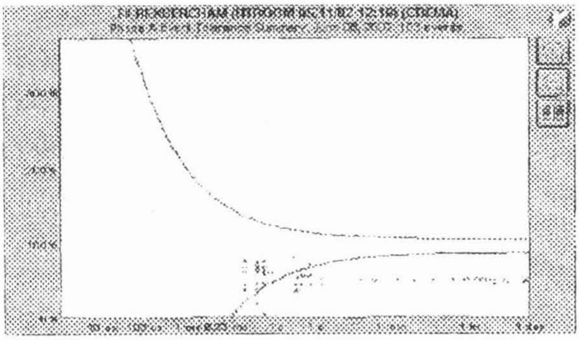

Figure 4: The Event Refer to CBEMA Curve for FILREXBERCHAM's Industry

Figure 4 shows the events that occurred at FILREXBERCHAM industry in Ipoh supplied by TNB (Distribution) using Power Quality Recorder (PQR). It shows about 103 events occurred as stated in the Power Quality Index (PQI) graph. By referring to the power quality index, most power quality problems occurred at the factory is voltage dip. Note that the voltage dip/sag occurs between < 1 minutes (0.5 sec < t < 60 sec) duration. In order to determine the voltage sag disturbance, reference was made to Figure 5 for standard duration disturbances of voltage dip.

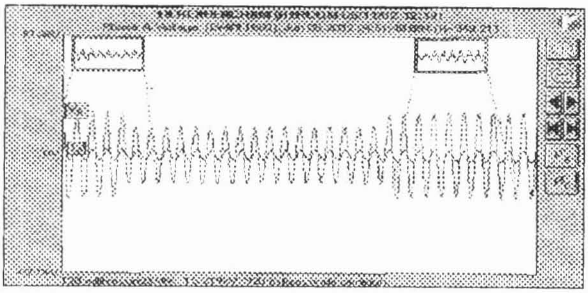

Figure 5: The Voltage Dips Waveform Using Power Quality Recorder (PQR)

The sinusoidal voltage waveform in Figure 5 shows the voltage dips that occur at Filrexbercham factory. The waveform is recorded using PQR equipment which shows the voltage dropping to 15.219 kV in about 0.32 seconds duration. The dip is about 50% (sag also 50%) from the supply voltage of 33 kV.

Redesign of Adjustable Speed Drive (ASD's) using MATLAB/Power System Blockset - A Technique to Ride -Through Voltage Dips

Method I-ASD Boost Converter: I have proposed a redesign the ASDs to ride-through the voltage dip. Shown are experimental results on a 415 V, 22 kVA ASD subjected to a variety of voltage dips to demonstrate the effectiveness of the proposed system.

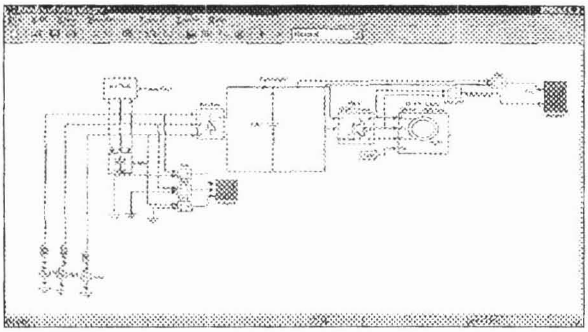

Figure 6: ASD Topology Circuit By Using MATLAB/Power System Blockset

Figure 6 shows the topology of ASD using MATLAB/Power System Blockset programming. This topology consists of a three-phase diodes rectifier, dc link and an inverter. D_1 - D_6 forms the rectifier diodes. L_s is the source impedance (typically 2%-5%), which is an optional component sometimes installed. A single – phase voltage dip, which is a most common occurrence, is first considered. It is assumed that one of the utility phase voltages V_{an}, V_{bn} or V_{cn} experiences a voltage dip disturbance.

Before any fault occur, a standard three phases voltage supplied from a standard 415 V, three phases, 50 Hz voltage is supplied to the ASD devices. The nominal AC source is sinusoidal for all the three-phase line in the transmission line. The waveform at the normal condition for all three phases line V_{an}, V_{bn} and V_{cn} at duration time is shown in Figure 7.

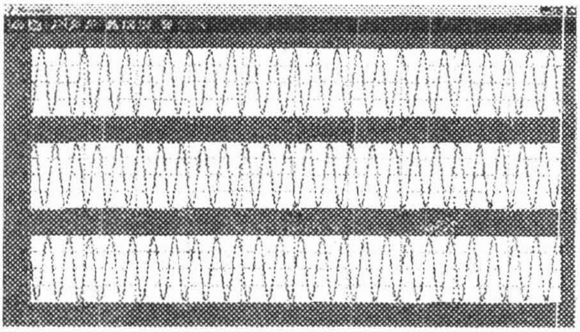

Figure 7: The Waveform for Each Line without Any Fault Applied

Let's assume that phase V_{cn} dips, to 50% for 30 cycle's duration. At the interception of the voltage dip on V_{cn}, the rectifier diodes D_5, D_2 cease to conduct and the line current in phase c of the rectifier collapses to zero. This is due to D_5, D_2 being reversed biased due to reduction in V_{LN} voltage due to a dip.

In effect the three-phase rectifier essentially is single phased, and this state continues for the entire duration of the voltage dip on phase c. Note that single phased operation of the three phase diode rectifier will occur for 10% drop in voltage (90% sags, due to reverse bias of diode D_5 and D_2), and is independent of the voltage dip magnitude. When the fault occurs at V_{cn}, the waveform of the phase c will drop until the end of the chosen sampling time chosen. Figure 8 the setting at V_{cn} with a sampling time about 0.1 to 0.4 sec.

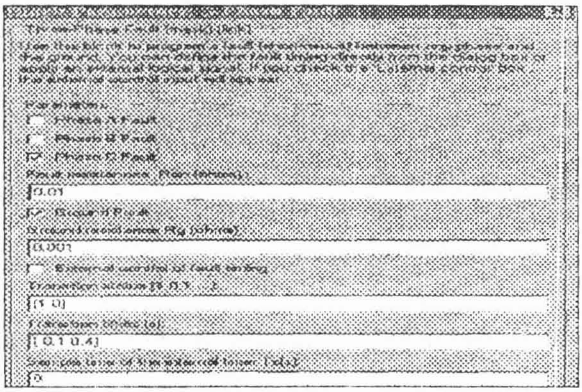

Figure 8: The Block parameter for fault Sampling Time at Phase V_{cn}

When the voltage sources at each phase were simulated, V_{ab} and V_{bn} are still in normal condition, but the dip will occur at phase c line. Figure 9 shows the waveform for voltage dip at phase c

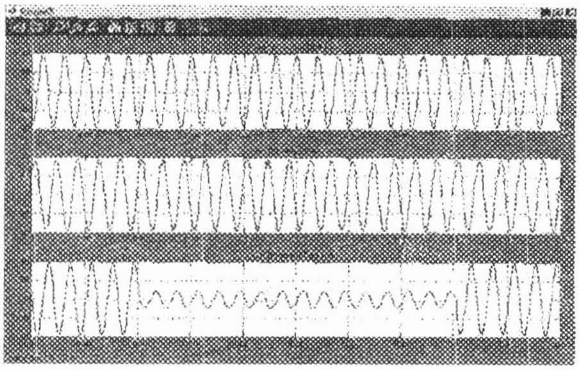

Figure 9: The Waveform for all Phase a, b and Fault on Phase c

The fault (voltage dip) occurs at phase c also will affect the voltage on dc-link (bus) in ASD. Figure 10 below shows the waveform of voltage sag that occurs at dc-link (bus) due to the fault V_{cn} at ASD topology. The voltage sags to about 50%.

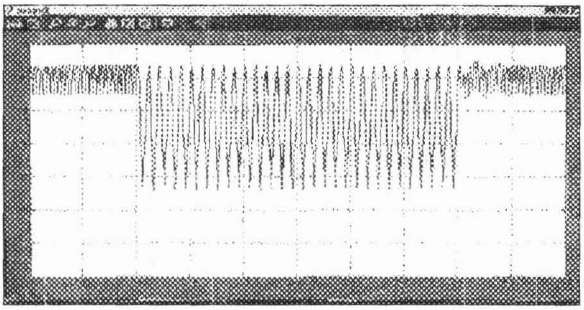

Figure 10: The Voltage Sag Waveform on DC-link (Bus) Due to Fault on Phase V_{cn}

In order to ride-through the voltage dip/sag disturbance in phase c, a redesign of ASDs has been proposed. This redesign involves the addition of extra components to create a boost converter device as an Add-On module. Figure 11 shows the proposed ASD with Boost Converter Ride-Through Devices by using MATLAB/Power System Blockset.

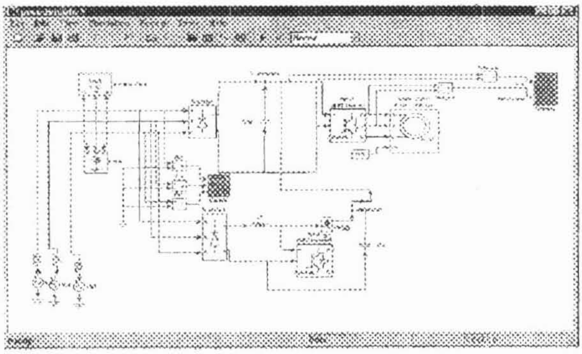

Figure 11: The Proposed Redesign ASDs with Boost Converter Ride -Through Devices as an Add-On Module

This approach provides ride-through to critical ASD load during voltage dip without any additional energy storage devices. Upon detection of voltage dip, the boost converter operates with suitable duty ratio and maintains dc-link voltage within acceptable limits. A boost converter can be used to maintain the dc-link (bus) voltage during voltage sag, and can either be integrated into new drives between the rectifier and the dc-link capacitors or retrofitted as add-on modules. The add-on module is used to retrofit existing with ride-through capabilities, or for multiple drives with a common dc-link, such as synthetic fiber drives.

During voltage sag, the boost converter will sense a drop in the dc link and begin to regulate the dc link to minimum voltage required by the inverter. In this case of a retrofit where a boost module is added to an existing ASD, proper coordination of fault protection logic is necessary. Figure 12 shown the waveform of dc-link in ASD has been ride-through to get a better quality of voltage.

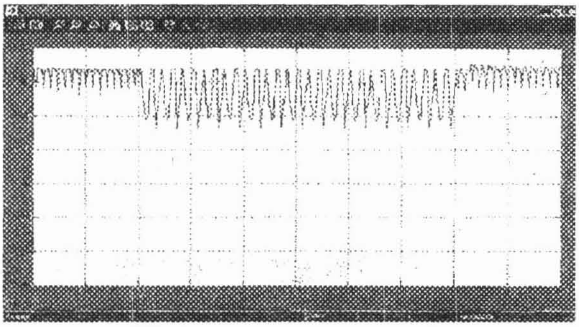

Figure 12: The Voltage Waveform of DC-link with Proposed Boost Converter Devices of Redesign ASD Description

Rectifier in induction motor ASDs supply dc voltage inverter. The three-phase full wave (six-pulses) diode rectifier is most commonly employed. At any time, only two out of six diodes conduct the output current i_o. These are the diode, subjected to the highest line-to-line input voltage. For instance, if at any given instant the highest line-to-line voltage is V_{ab}, certain diode conduct the output current, so that $i_a = i_o$ and $i_b = 1$. The other four diodes are then reverse biased, while the output voltage, V_o equal to V_{AB}.

Method II-Additional Capacitor: By adding the capacitor to the dc bus, additional energy needed for full power ride-through during voltage sag can be provided to the motor. A typical 415 V, 50 Hz, 10 hp motor drive can be assumed to have a dc link capacitance of C = 5000 μf. Assuming continuous conduction, the dc-link voltage is given by: -

$V_{LL} = 415$ V

$V_{dc} = 1.35 * V_{LL} = 1.35 * 415 = 560$V

A typical ASD is set to trip if the dc-link voltage drops 0.9 times the nominal value, which is

$V_{dc,trip} = 0.9 \times 560$ V= 504 V

Also, the average dc-link current for 10hp (P_o) load is

$$I_{dc} = \frac{P_o * 746}{V_{dc}} = \frac{10 * 746}{560} = 13.32 \text{ A}$$

Now, under short-term power interruption, the filter capacitor must provide the power to the ASD motor. The ride-through duration t_r can be computed as follow: -

$$t_r \approx \frac{C * \left(V_{dc} - V_{dc,trip}\right)}{I_{dc}}$$

$$\approx \frac{5000 * 10^{-6} (560 - 504)}{13.32} \approx 21.0\, ms$$

A t_r of 21.0 *ms* translates into 1.55 cycles at 50 Hz frequency. Thus, 5000μF on the dc-link can only provide a full power ride-through of 10hp for 1.55 cycles. If the outages were to last for 0.5 seconds (i.e. $t_r = 0.5$, 30 cycles) the capacitance required to provide ride-through can be calculated as: -

$$C = \frac{I_{dc} * t_r}{V_{dc} - V_{dc,trip}} = \frac{13.32 * 0.5}{(560 - 504)} = 0.097 \text{ F}$$

From this, it is clear that an additional 20 x 5000uF capacitors would have to be added to the dc-link. Therefore, if the user were to use 2500μF caps rated at 400 V connected in series, and then would need 160 capacitors, connected in 80 groups.

Figure 13 shown the waveform of voltage dip to the ASD without any additional of capacitor at certain time when the fault occurs.

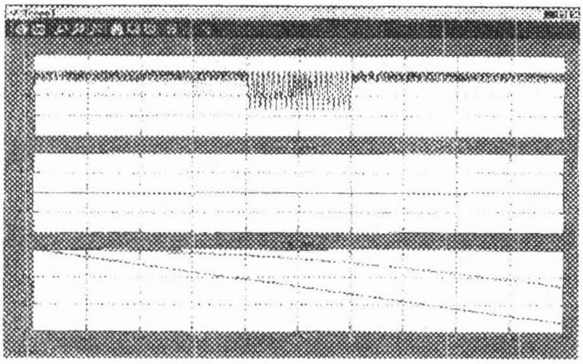

Figure 13: The Voltage Sag Waveform at DC-link for ASD Normal Capacitor

Figure 14 then show the waveform of dc-link (bus) of ASD for additional capacitor (increase the value of capacitor)

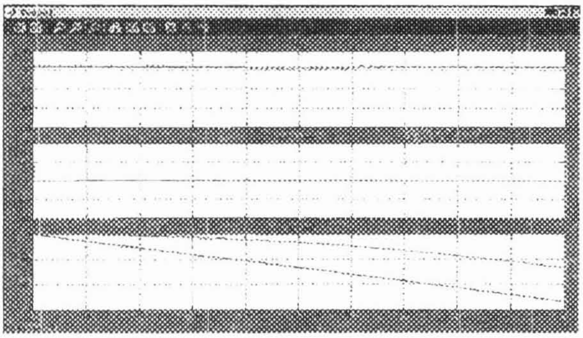

Figure 14: The Waveform of ASDs DC - Link for Increasing Value of Capacitor

This method has their its advantages, which is simple and rugged approach, and can provide limited ride-through for minor disturbances when compared to the method I (Boost Converter Add-on Module), the voltage can be better improved with additional capacitor. Theorically, the voltage cannot be stabilized for a long time due to the charging and discharging characteristics of the capacitor.

Alternative Ride-Through of ASD

A number of other alternative are available, due to time constraint. The author has listed all the other. The other methods available are:-

1. Battery back-up System
2. Superconducting Magnetic Energy Storage (SMES)
3. Operate ASD's at reduced Speed/Load

CONCLUSIONS

Voltage dips are becoming a real concern for process industries due to increased automation. Electronic controllers used are sometimes more sensitive to voltage dips than other load. The sensitivity of industrial equipment to voltage dips varies greatly. Approximately 80% the voltage dips problem can be overcomed with installing some device in customer installation.

By redesigning the ASDs, the problem of voltage dip/sag that occurs has been overcome. So this simulation has successfully achieved the objectives of the project, which is to ride-through and improve the performance of ASD during voltage dip. With these two alternatives of the voltage dips ride-through, the proposed ASD is available to be implemented in the real life at any industrial plant required the ASD devices.

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REFERENCES

1. Rohaizad Abdul Wahid, 1996, *"Power Quality Monitoring, Analysis & Mitigation"*, TNB Distribution Engineering.

2. Wilson E.Kazibwe & Musoke H. Sendaula, 1993, *"Electric Power Quality Control Techniques"*, Van Nostrand Reinhold, New York, pg. 11.

3. David Bradley, March 2002, *"Voltage Dips-Predictive Maintenance-The Key to Power Quality"*, Rhopoint System Ltd