OPERATION EFFECT TO VOLTAGE SAG IMMUNITY LEVELS OF AC CONTACTORS AT PETROCHEMICAL PLANT IN PAHANG, MALAYSIA

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ABSTRACT

Frequent voltage sag events at Gebeng Industrial Area posed a significant impact on the process lines of a petrochemical plant. Several of its important electrical/electronic equipment which is controlled by AC contactors had tripped, resulting in long downtime and high losses. In order to understand this power quality issue, the plant had collaborated with TNB Energy Services, a wholly owned subsidiary of Tenaga Nasional Berhad to evaluate its equipment immunity levels with respect to voltage sag. This paper aims to study and compare the immunity level of the AC contactor which is used in industrial operation over period of time. The contactors were sampled randomly and test was conducted at site. The response is benchmarked against Malaysian Standard MS IEC 61000-4-11 voltage-tolerance curve. Subsequently the result for test conducted within period of four (4) years is presented. Three out of five AC contactors show weakening of immunity levels and four out of five contactors exhibit an increase of exposure level when compared with actual power quality data. Finally, the options of improvement to ensure high ride through capability is proposed.

INTRODUCTION

Since the last two decades, rapid development of electrical supply system in line with fast economic growth of the country heighten the interest in Power Quality (PQ) issues in Malaysia. The unavailability of supply (long interruption) has become a rare occasion and thus customer are always expecting better quality of supply from the utility. Although power quality event such as voltage sag are less damaging compared to an interruption, the higher frequency of it massively impact the industry [1].

According to IEEE, a voltage sag is a decrease in root-mean-square (rms) voltage between 0.9 p.u to 0.1 p.u. The duration is between 0.5 cycle up to 1 minute [2]. In 2014, a survey by Malaysia's Energy Commission found that the cost of voltage sag events that violates IEC 61000-4-34 curve is estimated to be USD340 million across Malaysia [3]. In industrial perspective specifically for petroleum refineries and petrochemicals sector, the cost of voltage sag disturbances per event is estimated at USD 48,000 and USD 40,000 respectively [3].

To most petrochemical plants, voltage sag poses a serious problem. An occurrence will cause electrical and/or electronic equipment to trip and lead to costly process shutdown. Modern industrial processes which utilises programmable logic controller (PLC), variable frequency drive (VFD) and motor contactors are sensitive to voltage sags. These sensitive equipment often found in vital machineries, which their loss leads to unavoidable production shutdown, and subsequently significant financial loss [4].

A petrochemical plant located in Gebeng Industrial Area among the affected by these issues. As a result of voltage sag, most of its AC contactors which control the motors have been frequently tripping thus interrupting the process line. While the motor itself is able to ride through some degree of sag, it is observed that the sensitive nature of the contactor is the reason for this tripping [5]. Thus it is very important to obtain the immunity/sensitivity level of the equipment.

Immunity level is defined as minimum level of electromagnetic disturbance that a piece of equipment are able to withstand [6]. Sensitivity level on the other hand can be define as a condition where the equipment starts to malfunction and cause nuisance [7]. Both immunity and sensitivity level will be used interchangeably according to context in this paper as it correlates to the similar curves.

Previous research has indicated that no clear relations between the sensitivity and the contactor size or age [5]. However this was done by comparing different sets of contactors (new, old but unused and used). This paper aims to study and compare the immunity level of the AC contactor which has been used in industrial operation over period of time.

METHODOLOGY

Power Quality Standards

In this study, the PQ standard referred as guideline is the 'Malaysian Standard' MS IEC 61000-4-11. This is the similar standard as the internationally recognised IEC 61000-4-11 which serves as a guideline to the industry regarding immunity level of an equipment. The standard voltage-tolerance curve is shown in Fig. 1.

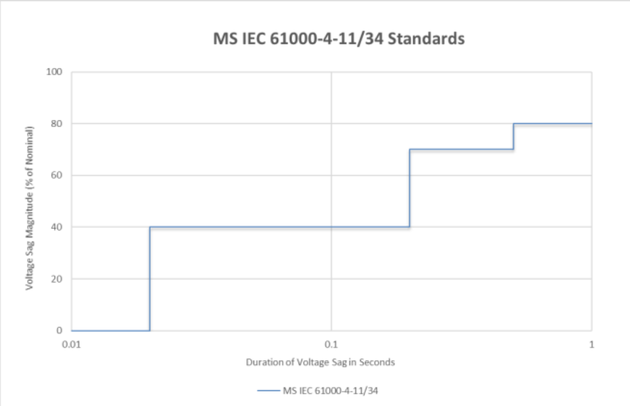

Fig. 1: MS IEC 61000-4-11/34 Standards

Equipment Under Test

The Equipment under Test (EUT) was picked from sets of AC contactors according to the following criteria:

a) The contactors are primarily in operation and not a spare or actively in standby mode.
b) Different contactor sizes were sampled randomly to represent the whole installation base. They were selected from various sizes and only from a single manufacturer.
c) The same contactors were tested after four (4) years. No changes has been made to the main AC contactors. This will increase the credibility of the results.

Thus, the list of AC contactors that were chosen is summarized in Table 1. All of the contactor's coil are rated 230Vac at 50Hz.

No.	AC Contactor Circuit	Contactor Size (kW)
1.	Contactor 1 (C1)	7.5
2.	Contactor 2 (C2)	22
3.	Contactor 3 (C3)	30
4.	Contactor 4 (C4)	55
5.	Contactor 5 (C5)	90

Table 1: Equipment Under Test Summary

Voltage Sag Generator

The test equipment used for this study is the Power Standards Lab (PSL) Industrial Power Corruptor (IPC). The rated voltage and current for the equipment is 480Vac and 200A respectively. It is capable to generate voltage sag in 2.5% steps and 20ms duration. Prior to the actual test, a sample voltage sag was performed to verify the IPC data collection software accuracy with a calibrated PQ recorder. Fig. 2 shows an example of output graph collected via IPC data collection software.

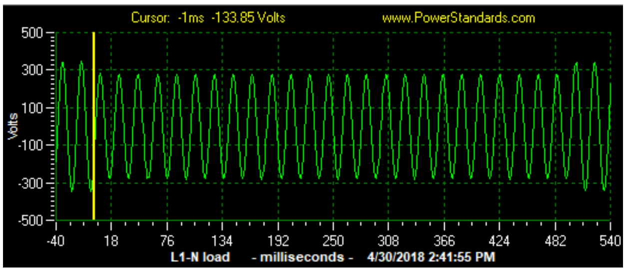

Fig. 2: Output Sine Wave of 80% Voltage Sag at 500ms

Test Procedure and Setup

Due to certain restriction by the plant, the test can only be conducted offline during available shutdown window. That is done by racking out the motor starter cubicle and putting it on a test table. The study will then use a separate 230Vac source from the original circuit. To energize the contactor's coil, a manual push down of the movable contact is needed as the control circuit in the motor starter cubicle is wired through a normally open (NO) auxiliary contact. A better representation of test setup can be seen in Fig 3.

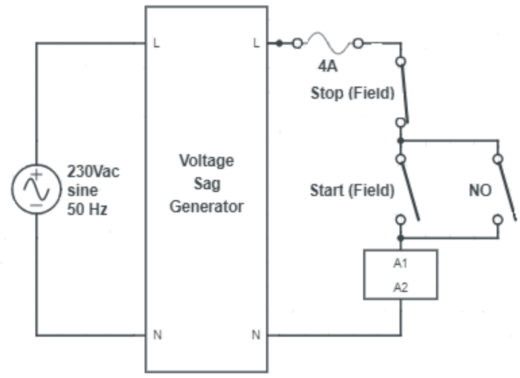

Fig. 3: Simplified Diagram of Test

During the test, the sag generator will apply a nominal voltage (230Vac) before and after a voltage sag. The setup in Fig. 3 will not cause any automatic re-energization of the coil after a sag event thus further adjustment of the circuits is unnecessary. Any disengagement of the contactors during simulation sag will be a true disengagement.

The point on wave for the first test is 0° and can be seen in Fig. 2. For the second test, the results on different point of wave of sag initiation (interval of 15° up to 90°) is documented for future analysis. Some of the contactors shows typical effect on point of wave at deepest sag at 0° as seen in previous works and research at [4] and [6]. However for this paper, the effect of different point on wave will not be further discuss and elaborated. Furthermore, the immunity levels are represented by simple rectangular voltage-tolerance curve.

The test was conducted from the least severe magnitude event starting from 90% of voltage sag and varying duration from 20ms (1 cycle) up to 1000ms (50 cycle). Duration of more than 1000ms will not give more information to this study. It is then repeated with more severe depth up to the point of contactor's disengagement. Typically the interval of test is 5-10% for voltage and 20ms-200ms for duration. Every disengagement were tested twice to confirm the result.

TEST RESULTS

Both results of first test in 2014 (green line) and second test in 2018 (red line) are shown in the same figure for easy reference and accessibility.

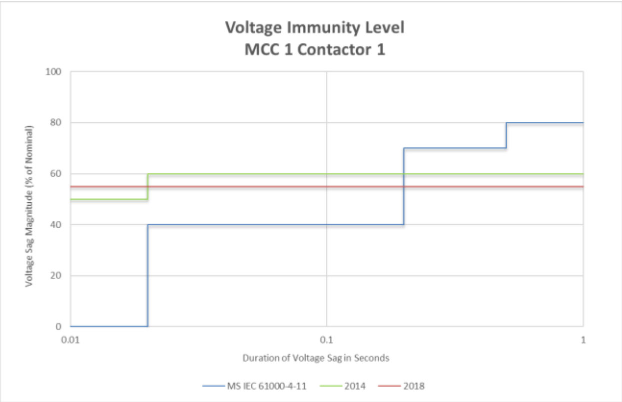

Figure 4: Contactor 1 Immunity Levels

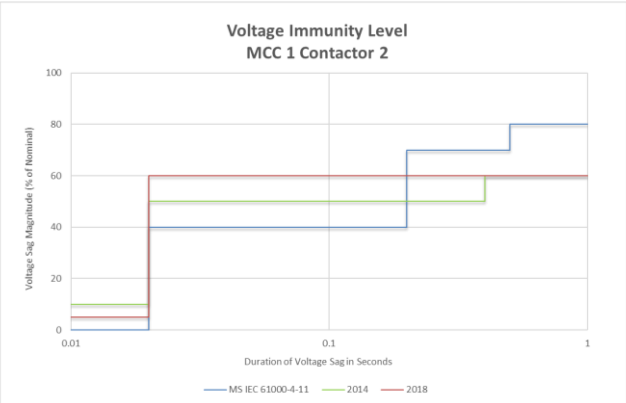

Figure 5: Contactor 2 Immunity Levels

In Fig. 4, C1 show some weakening of immunity levels only on the first 20ms of the test. From 50% to 55% of voltage sag, translated to 5% of increase in sensitivity. However for the remaining tests, it shows an improvement of immunity levels of about 5%.

In Fig. 5, for the first section of curves from 0 to 20ms, the results show that the latest test demonstrate a better immunity levels of about 5% from the earlier test. However EUT shows a weakening of 10% immunity levels from 20ms to 400ms section. From 400ms up to 1 second, EUT shows a similar immunity for both test.

In Fig. 6, EUT C3 shows an increase in sensitivity of 30% for the first 20ms of the curve. For 20ms to 1 second duration, it recorded 10% immunity level weakening from previous test of 60% to 70% voltage sag. Similar behavior is seen in Fig. 8 with C5 immunity levels of 65% up to 1 second in the first test to 70% up to 1 second on the most recent test. This is some 5% increase in sensitivity.

However for C4, mix results were obtained. On the first 20ms, the latest test shows an improvement of 50% immunity. From 20ms to 40ms, immunity level again improve for 15% and from 40ms to 200ms an improvement of 5% voltage sag. On the contrary from 200ms up to 1 second its immunity level weakens for about 10%. The result is illustrated in Fig. 7. Summary of all EUT immunity levels presented in Table 2.

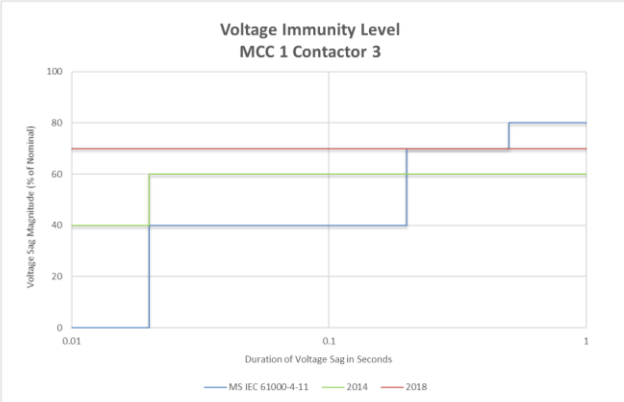

Figure 6: Contactor 3 Immunity Levels

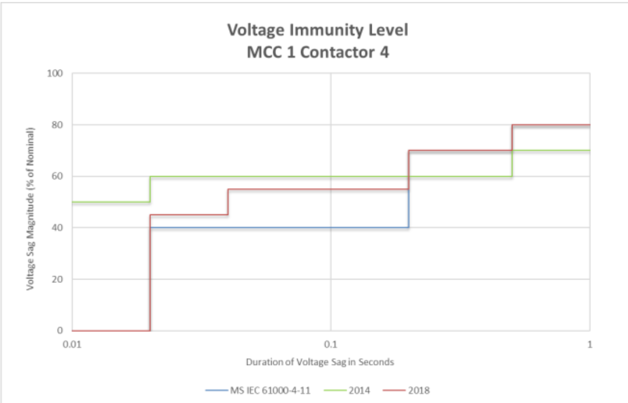

Figure 7: Contactor 4 Immunity Levels

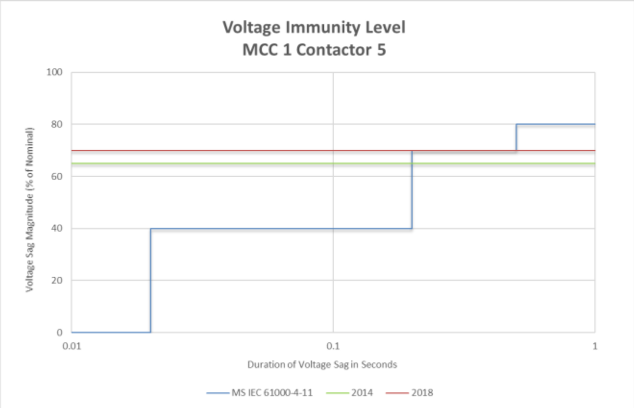

Figure 8: Contactor 5 Immunity Levels

AC Contactor	2014 Immunity Level	2018 Immunity Level
C1	a) 50% for 20ms b) 60% for 1s	a) 55% for 1s
C2	a) 10% for 20ms b) 50% for 400ms c) 60% for 1s	a) 5% for 20ms b) 60% for 1s
C3	a) 40% for 20ms b) 60% for 1s	a) 70% for 1s
C4	a) 50% for 20ms b) 60% for 500ms c) 70% for 1s	a) 0% for 20ms b) 45% for 40ms c) 55% for 200ms d) 70% for 500ms e) 80% for 1s
C5	a) 65% for 1s	a) 70% for 1s

Table 2: Summary of Immunity Levels

ANALYSIS AND DISCUSSION

As the sensitivity levels of all the contactors have been established, the next step is to quantify the severity of the voltage sag. As discussed in [6] there are two methods which is available, the power quality monitoring and stochastic assessment. The former method is chosen due to availability of permanent power quality recorder in nearby utility substation. Using the data as reference, the plant will be able to estimate whether its equipment operates normally during an event and subsequently estimates each equipment's exposure level towards voltage sag.

Evaluation Based on Grid Events

Power Quality Monitoring System (PQMS) is one of the initiatives undertaken by TNB for PQ issues which performs systematic monitoring and reporting. Around 150 monitoring sites are currently connected to PQMS all over peninsular Malaysia. The system automatically gathers data, store, process and later capable to generate required information to be use for further analysis. The historical voltage sag data from 1 January 2013 to 31 December 2018 (6 years or 72 months) is retrieved to compare the exposure level of both tests. The data is then plotted into the voltage-tolerance curve for each EUT.

Subsequently, the exposure level per year is estimated by the following equation;

$$Exposure\ Level = \frac{\sum v}{m}\ x\ 12 \qquad (1)$$

Where v is total number of voltage sag events below the immunity level in the number of months (m) the data is collected.

The calculated exposure level for contactor C3 from equation (1) is 3.0 times in year 2014 as shown in Fig 9. However, it increases significantly to 6.2 times in 2018. This mean that C3 suffered 3 times more voltage sag event now compared to the earlier benchmark in 2014. As for contractor C4 the exposure level increases slightly from 3.0 to 3.3 times in period of four years, despite the multiple changes in immunity levels. The summary of all exposure level is tabulated in Table 3.

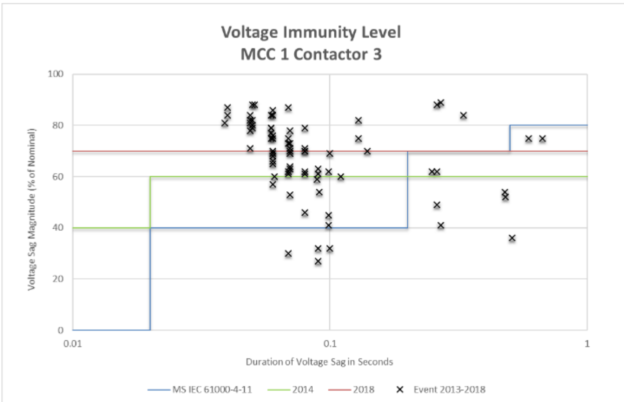

Fig. 9: Voltage Sags vs. Immunity Level of Contactor 3

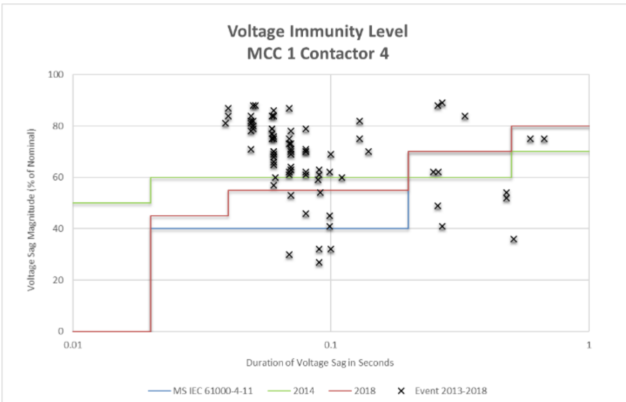

Fig. 10: Voltage Sags vs. Immunity Level of Contactor 4

AC Contactor	2014 Exposure Level	2018 Exposure Level
C1	3.0	2.7
C2	2.3	3.0
C3	3.0	6.2
C4	3.0	3.3
C5	5.2	6.2

Table 3: Summary of Exposure Levels

Comparison to Standards

From the test result, it is observed that the immunity levels of the EUT does not comply with the MS IEC 61000-4-11. It is evident that there is a challenge for the industry and manufacturer to comply with the guidelines proposed by utility companies or regulators.

Proposal for Improvement

To ensure high ride-through during voltage sag event, two options are available for the plant consideration. The first option is to perform an upgrade to the MCC and replace the contactors which conforms to the IEC 61000-4-11/34 standard. However it is very costly and complex process thus centralized mitigation of control circuits is proposed. Each of the Main Switchboard (MSB) in the MCC have a centralized control circuit which supply the 230Vac to contactor's coil on each of its motor starter. If this circuit is protected with a sag corrector, it will ensure a high ride through capability during a voltage sag event.

The sag corrector proposed for this plant is an ultra-capacitor based corrector capable to support single-phase 0% voltage sag up to 200ms. The ride through protection scheme could be seen in Fig. 11. It will able to ride-through all but one event based on the historical data gathered.

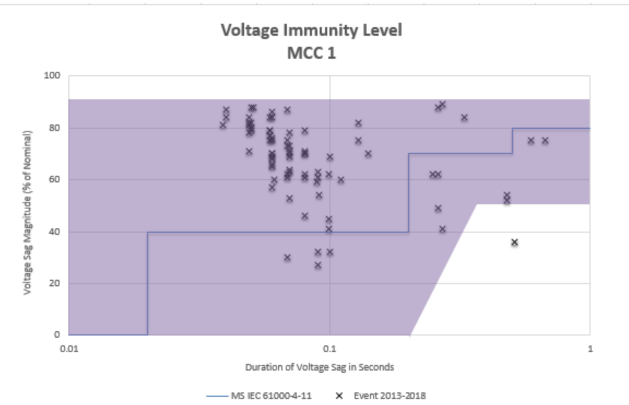

Fig 11: Ride Through Capability vs. Recorded Voltage Sags

CONCLUSION

AC contactors used in industrial environment are usually robust and could be used for a long time. However, the study presented in this paper shows some effect to the immunity levels of the contactors over period of time. Three out of five AC contactors show weakening immunity levels while the other two produces mixed results. Moreover, four out of five contactors exhibit an increase of exposure level when it was evaluated based on historical PQ events nearby. The knowledge of voltage sag performance of AC contactor in industrial environment is still insufficient. Therefore, it is recommended for the industry to continuously evaluate the contactor's immunity level at pre-determined period to assess the performance over time. It is also a challenge for industry and manufacturer to comply with the available proposed PQ guidelines.

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