Electronic Process Equipment Compatibility Evaluation Project for Power Quality Enhancement – A Malaysian Experience

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Abstract:

This paper will highlight a Malaysian experience in power quality enhancement work with respect to utility side and customers side mitigation analysis. One of main driving forces that help to accelerate industrialization process in a country like Malaysia is direct foreign investment in manufacturing and this has somewhat contributed to the rapid growth in electricity consumption. In majority of cases, the manufacturers are establishing or refurbishing plants with high-tech equipment for increased productivity that requires high quality power. Therefore, one particular luring attribute is the ability of the country's utilities to provide the power quality demanded by these customers. The proliferation of electronic equipment in manufacturing industries has made power quality related problem an important consideration in planning and design of a power supply system and its utilization. Variations in the supply voltage waveform even for a very short period that were not a concern before can now become very expensive in terms of process shut-downs and equipment malfunctions. In Peninsular Malaysia, more than 80% of electricity consumers are residential. However, the major users of electric power are the industrial customers. In terms of total number of consumers (TNB) of slightly above four millions, industrial customers constitute only 0.4% although the consumption is more than 51%. With such a high usage of electricity coupled with introduction of many automated processes aided by sensitive electronic devices, power quality problems have become main issues in the Malaysian industries.

In view of the importance of understanding power quality problems and its effect on the manufacturing industries, the IRPA (Intensified Research Priority Area), a Malaysian government agency, has sponsored an 18-month project on the customer-side power quality mitigation work. The participants of this project are Tenaga Nasional Berhad (a utility in Malaysia), University of Malaya and a multi-national semiconductor manufacturing. In general, the main objectives of this project are to achieve the followings.

- To address the issue of electronic process equipment compatibility towards voltage sag vis-à-vis the currently connected power system of TNB using selected factory's process equipment.
- To address in ***general***, the issue of the reliability and quality of the supply system of TNB so as to minimize the effect and occurrence of voltage sags that could lead to interruption of processes (ITP) within the factory's manufacturing facility.

The methodology that is used for this project is generally based on the guideline as published in the IEEE Std 1346-1998 entitled " IEEE Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment". The issues addressed in this paper encompass in general financial evaluation, power system performance evaluation, equipment performance evaluation, and power quality monitoring as derived from the project. Findings and observations achieved through this project will also be highlighted in this paper.

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1. INTRODUCTION

One of main driving forces that helps accelerate industrialization process in a country like Malaysia is direct foreign investment in manufacturing and this has somewhat contributed to the rapid growth in electricity consumption. In majority of cases, the manufacturers are establishing or refurbishing plants with high-tech equipment for increased productivity that requires high quality power. Therefore, one particular luring attribute is the ability of the country's utilities to provide the power quality demanded by these customers. The proliferation of electronic equipment in manufacturing industries has made power quality related problem an important consideration in planning and design of a power supply system and its utilization. Variations in the supply voltage waveform even for a very short period that were not a concern before can now become very expensive in terms of process shut-downs and equipment malfunctions. In Malaysia, more than 80% of electricity consumers are residential class. However, the major users of electric power are the industries as shown in table 1. In terms of total number of consumers (TNB) of more 4.5 millions, industrial customers constitute only 0.4% of this figure although the consumption is more than 51%. With such a high usage of electricity coupled with introduction of many automated processes aided by sensitive electronic devices, power quality problems have become a main issues in the Malaysian industries.

Table 1: Energy Consumption and Customer Class

Class	Customers	Consumption
Domestic	83.7%	18.6%
Commercial	15.3%	28.4%
Public Lighting	0.5%	0.8%
Industry	0.4%	51.9%
Mining/Export	0.1%	0.3%

In view of the importance of understanding power quality problems and its effect on the manufacturing industries, the Malaysian government through its ministry of science has initiated a project to carry out a study on electronic process equipment sensitivity towards voltage sag. The project is headed by the University of Malaya involving local utility Tenaga Nasional Berhad, Texas Instruments Malaysia Sdn. Bhd., a semiconductor industry located in Kuala Lumpur.

2. PROJECT SCOPE AND OBJECTIVE

The project is scheduled for 1.5 years and has several objectives to achieve. Most importantly, the project is to address the issue of electronic process equipment compatibility towards voltage sag vis-a-vis the currently connected power system of TNB using selected TIM's most sensitive process equipment. This is done through identifying process equipment at TIM facility that is most prone to voltage sag mal-operation. Subsequently, evaluations in terms of the identified equipment ride through capability against voltage sag using programmable AC voltage source is carried out. This process is categorized as load side analysis.

In addition, the analysis of the reliability and quality of the supply system of TNB transmission system, connecting TIM's facility to the rest of TNB system are also carried out. This process is essentially a voltage sag stochastic analysis using full TNB network data comprising of the transmission and the distribution system. The analysis provides information on the prediction of voltage sag occurrence in the TNB system that would have any impact on TIM's processes.

The project is also aimed to develop a guideline and a case study of how a to improve electronic process equipment compatibility performance subjected to the Malaysian infrastructure and economic condition.

3. METHODOLOGY

The methodology that was used in the project is generally based on the guideline as published in the IEEE Std 1346-1998 [7]. The issues addressed in the guideline as far as evaluating the compatibility of sensitive equipment to voltage sag is concerned cover essentially five important elements which include financial evaluation, power system performance evaluation, equipment performance evaluation, development of voltage sag coordination charts and power quality monitoring issues. However in this paper, only result from the power system performance and equipment performance evaluation will be discussed since the completion of the overall project is expected only in June 2001.

4. BACKGROUND OF SYSTEMS UNDER STUDY

Tenaga Nasional Berhad electric power system comprises of an integrated transmission system of voltages 500/275/132kV/66kV and radial distribution system of voltages 33/22/11and 0.415 kV. It is synchronously connected to Singapore Power Grid System in the South via 2X200 MVA, 230kV submarine cables between Pasir Gudang and Senoko power stations. In the northern part of the peninsular Malaysia, TNB power system is connected to Electricity Generating Authority of Thailand (EGAT) system via 1X141 MVA, 132kV line asynchronously operated. TNB power system is consisting of more than 14,000-circuit kilometer of line, which comprises of 96% of overhead line and 4% underground cables. The current maximum demand as of year 2000 is 9682 MW.

Texas Instrument (M) is a is a semiconductor manufacturing industry located in Kuala Lumpur and currently being fed by the TNB's 33kV system. The existing facility maximum load is approximately ~~8~~ 12 MVA. Due to the rapid growth in computer application, many of semiconductor industries such as TIM are intensifying their daily productions to meet increasing demand not only locally but also globally. Proliferation of sensitive electronic equipment in these facilities has resulted in the demand for ultra-pure sine wave from the TNB supply systems. Some of this equipment can only tolerate minimum voltage variation to operate without interruption even with very short duration. The traditional n-1 planning criteria to secure for high reliability level for this type of customers is almost non-applicable since their concern are more on avoiding the voltage sag rather than having a spare supply when the other connecting feeders or transmission line is taken out of service.

In year 2000, TIM has experienced 12 voltage sag events that resulted in either minor or major process interruption due to faults on the TNB transmission and distribution systems. Causes of the fault range from equipment failures to inclement weather and most of them were transient in nature and did not cause permanent supply loss. There are basically two types of interruption due to voltage sag observed at TIM and can be classified as follows.

i. Major Process Interruption - Most Plant processes totally interrupted

ii. Single Component/Equipment Shutdown - Minor Interruption

Major process interruptions in TIM are normally associated with supply interruptions or severe faults occurred very close to the receiving facility. These types of process interruption require resetting of many electronic equipment, such as the wire-bonders, before full production speed pre-shutdown can be achieved back. There are roughly around 500 wire-bonders in TIM and if all machines are interrupted simultaneously, it will take few hours to restart the process gain. The losses that will have to be incurred by TIM due to the downtime are costs as a result of lost work, idled labor, lost production, cost to repair damaged equipment and cost of recovery as well as opportunity loss. As such, it is imperative to estimate the probability of voltage sag occurrence at TIM that will result in process interruption so that proper mechanism to avoid the interruption such as putting mitigation measures can be carried out with justified cost.

5. POWER SYSTEM MODELS AND STOCHASTIC ANALYSIS

Analytical approaches towards understanding voltage sag characteristics and behavior were developed systematically towards the beginning of 1990's. Many papers published by middle of 1990's begin to address voltage sag impact on electronic equipment from reliability standpoint beside reinforcing and reconfirming findings on deterministic approach found previously. In [1], Becker et. al. presented an excellent paper describing the mechanics of voltage sag analysis and how to predict voltage sag performance of electric supply systems by combining a new voltage sag analysis method with reliability data. The method was later incorporated into Chapter 9 of the IEEE Std. 493 or better known as the Gold Book. The paper introduced the concept of limits of vulnerability of equipment sensitivity towards voltage sag. Limits of vulnerability define the distance from a fault point in a power network to the point of which sensitive equipment or a studied node is connected. The plot of different coverage area as defined by the limits of vulnerability will result in sag contour lines and by combining these lines with equipment sensitivity curve, one can estimate total number of disruption due to voltage sag with different duration.

Perhaps the three most important data required to accurately performing the voltage sag stochastic analysis as proposed by IEEE Std. 493 are as follows.

i. Statistics of short-circuit data of the studied system which comprises of Single Line to ground fault (LG), phase to phase fault (L-

L), phase to phase to ground (L-L-G) fault and three phase fault (3L).

ii. Estimated Fault Impedance data (for all faults with impedance)

iii. Network Models (transmission and distribution system model connecting the studied node.

6. STUDY METHODOLOGY

Analysis of voltage sag expected frequency and depth is carried out via the method as proposed by the IEEE Std. 493. Voltage sag probability analysis, calculation of depth and annual frequency of sag, is performed on Ampang 132kV bus, which is the source of the 33kV cable supplying the TIM's facility. The 33kV cable is essentially a dedicated radial cable to the TIM facility connecting it to the rest of the TNB system. The voltage sag as seen on the analyzed bus is taken as the voltage sag experienced by TIM's own electrical distribution system irrespective of attenuation or amplifying effect caused by the transformer winding arrangements within the TIM facility. Using PSS/E's Interactive Programming Language (IPLAN) package, two IPLAN routines were developed to facilitate the analysis. The routines and their functions are tabulated as follows.

Table 2: IPLAN Routine for Voltage Sag Analysis

Routine Name	Functions
SCRUN.IPL	-Performs Single Line to Ground Fault (LG), Line-Line to Ground (L-L-G), Line to Line (L-L) and Three-Phase Fault (3L) on all 132kV & 275kV Buses while monitoring studied bus voltage. -Calculate the change of Voltage (delta V) in percentage at studied bus with respect to the fault applied. -Rank the Buses with the largest (delta V) to identify area of vulnerability to Voltage Sag.
SCANAL.IPL	-Use the ranked output from SCRUN.IPL routine to calculate the expected annual frequency of Voltage Sag.

7. SHORT-CIRCUIT STOCHASTIC DATA

The fault data (event/year/100km) used in the analysis is based on actual TNB transmission fault statistic on regional basis (area) as shown in Table 2. In the voltage sag reliability calculation, the number of voltage sag event at a particular bus will be the sum of the remote voltage sag occurrences caused by L-G, L-L-G, L-L and 3L faults on the transmission system only.

Table 2 gives the area-by-area short circuit statistic used for the study and Table 3 gives the fault impedance used in all line to ground faults (L-G, L-L-G).

Table 3: Short Circuit Statistics in Event/100KM/Yr

		CCT-KM	LG	3L	LLG	LL
C	132	2144	1.791	0.168	0.728	0.000
	275	1618	0.890	0.000	0.297	0.074
E	132	1799	0.534	0.067	0.133	0.133
	275	2237	0.483	0.054	0.268	0.054
N	132	2215	1.517	0.108	0.271	0.163
	275	2178	0.771	0.165	0.055	0.000
S	132	2314	0.778	0.156	0.207	0.104
	275	1143	0.630	0.105	0.000	0.000

Table 4: Fault Impedance Data in PU Measurement

Voltage Level	Average		Median		Minimum	
	Rpu	Xpu	Rpu	Xpu	Rpu	Xpu
132Kv	0.1977	0.3088	0.1326	0.1571	0.0075	0.0129
275kV	0.0455	0.0711	0.0304	0.0362	0.0017	0.0029

The fault impedance data as shown in Table 4 are derived from actual events as captured by disturbance recorders installed in the TNB transmission system. Minimum value of the fault impedance is used in all of the line to ground faults calculations. Fault impedance data is important in short circuit calculation since from practical experiences a short circuit event in the transmission system is rarely with zero impedance except for a solid three phase fault condition.

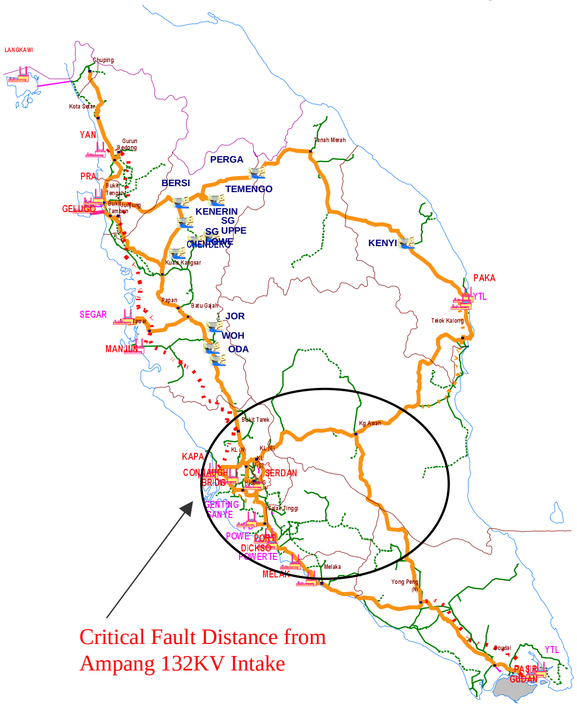
8. RESULT OF VOLTAGE SAG STOCHASTIC ANALYSIS

The following table shows the result of the annual expected voltage sag frequency and depth as seen by the studied 132kV bus connecting TIM's 33kV radial feed.

Table 4: TIM"S Expected Annual Voltage Sag Frequency due to Transmission Faults

Percent Sag (%)	L-G	L-L-G	L-L	L-L-L	Expected Annual Events
30.-100	11	1	5	1	17
40.-100	9	0	4	1	14
50.-100	6	0	3	0	10
60.-100	1	0	3	0	5
70.-100	1	0	2	0	3
80.-100	0	0	0	0	0
90.-100	0	0	0	0	0

The expected annual frequency of voltage sag is defined as the number of voltage sag occurrence within certain magnitude (30% or higher) per year at a studied bus subjected to faults applied (LG, LLG, LL and LLL) on all the TNB transmission system buses. The critical area of exposure to voltage sag refers to the area whereby if a fault occurs on any transmission line within the system, voltage sag of certain magnitude is seen by a particular bus would cause at least a minor equipment interruption. For the TIM's analysis, SEMI F47 curve is used as the guide to determine whether a magnitude of voltage sag is critical to TIM or not. In this respect, the sensitivity towards voltage sag of a studied bus can be geographically understood. In Figure 1, the area of critical exposure to voltage sag is given as seen by the studied bus. The circuit-km coverage of this



area is more than 1000 km in electrical distance.

Figure 1: Voltage Sag Critical (> 30% in magnitude) Area of Exposure to TIM

In the analysis, sag depth of 30% to 70% is used to represent the annual frequency of voltage sag at the studied bus. The reason for using these values (30%-70 % expected annual frequency) is to gauge in broader perspective of how the studied bus will be affected by change in the network configuration not limited to the SEMI F47 curve. Voltage sag of less than 30% is not considered since this value is not critical to most equipment installed at TIM.

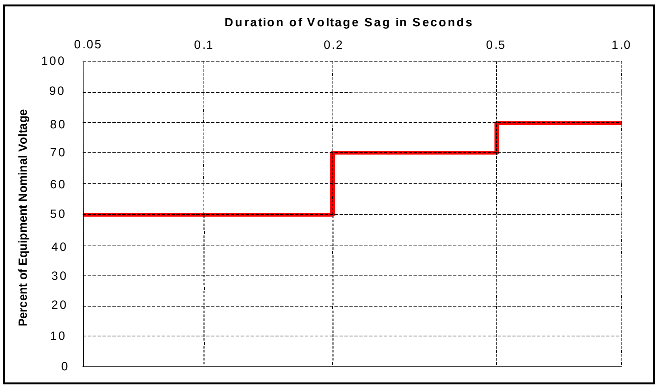


Figure 2: The SEMI-F47 Curve

9. Equipment Performance Evaluation

It must be mentioned that the best source for voltage sag information is the equipment manufacturer itself. However, some independent sources such as the EPRI have tested and collected data on various devices under voltage sag conditions. Nevertheless, in view of the Malaysian power supply system of 50Hz and 240 V at user end, information of electronic process equipment ride-through capability under voltage sag situation in Malaysia is very much desired. As such, under this project scope, the following work on selected TIM's sensitive electronics process equipment has been carried out. The work includes the identification of electronic process equipment (single and three phases) at TIM that need to be tested in terms of ride-through capability against voltage sag. From the identification process, it was determined that the wire-bonders and its controller (Manufacturing Area Controller-MAC), the devices that are used in the semiconductor assembly process, are the most critical device due to two main reasons. Firstly, majority of these devices which totaling close to five hundred units, are not protected by mitigation equipment such as the UPS or others. Secondly, on any mal-operation due to voltage disturbance, it requires several minutes for each device to be put on-line. Major power disturbances or severe voltage events can result in several hours downtime before the wire-bonders can be put on line back. There are essentially five types of wire-bonders currently being utilized in TIM. The wire-bonders were designed and built as far back as in 1984 and as late as 1999.

To test the ride-through capability of the wire-bonders and the controller, number of experiments were conducted to establish the minimum single-phase hold-in voltage during a simulated voltage sag events based on the SEMI-F47 ride-through curve using a device called programmable AC source. This device is capable to generate single-phase voltage sag of any magnitude and test duration for voltages of between 0 to 400 volt. Using a programmable ac source (voltage sag generator), the minimum ride-through voltage for the wire-bonders were determined by reducing the rms voltage (with specified magnitude and duration) until the devices fail to operate properly.

Figure 3 Below describes the result of the ride-through test of the different type of wire-bonders and the controller.

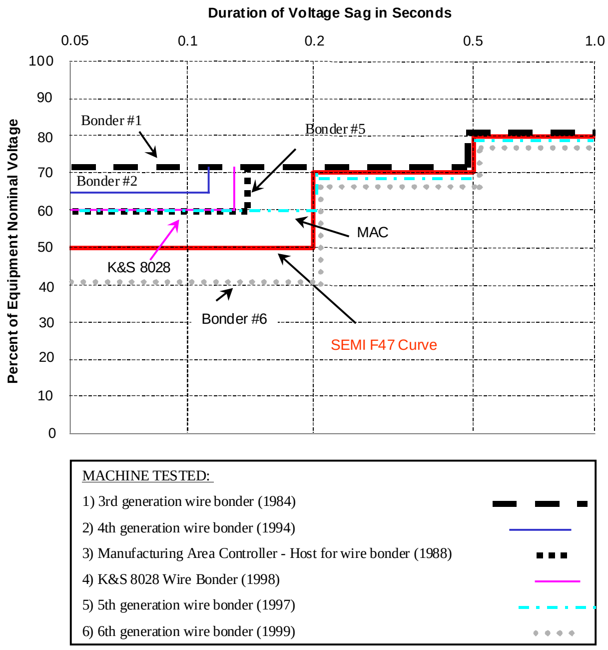


Figure 3: Test Result of Wire-Bonders and Area Controller Ride-Through Capability

10. DISCUSSION

The result obtained from the short circuit analysis presented in this paper only reflects the transmission-related fault of the TNB system. Nevertheless, this does not necessarily negate the obtained result since the TIM facility is directly connected to the TNB 33kV system through a direct radial cable. Plan has been made to incorporate distribution related fault analysis in the very near future. This will incorporate the impact on fault at adjacent 33kV feeders connecting the studied 132kV bus as well as the impact of transformer winding arrangement at TIM facility using the same methodology described in this paper. The preliminary result from the voltage sag stochastic analysis at TIM shows that critical area of exposure to voltage sag related to TIM's equipment mal-operation is essentially concentrated within the Klang-Valley region. This is relatively good since other facilities (other semiconductor facilities such as INTEL, KOMAG) in peninsular Malaysia shows greater critical area of overage i.e., 2000 cct-km. This can be explained by the fact that the short circuit level within the Klang Valley region is high due to the highly meshed network supported by many power generating plants operating nearby. Therefore, increase the level of voltage support at the studied 132kV bus against faults due to the transmission system.

The result of equipment performance tests shows dramatic improvement of the wire-bonders ride-through capability from the 1984 design to the 1999 model is which still under evaluation by the TIM's engineers. This shows that the awareness and understanding of the need to protect equipment from mal-operation due to voltage sag have been translated into better design of critical process equipment. Perhaps the best defense against voltage sag is some sort of mitigation device such as UPS, SMES, Flywheel or STATCOM. However, for a ever-growing company like TIM, space is a constraint for expansion and any mitigation device with big-footprint is almost impossible to be deployed. Understanding the behavior of the currently deployed process equipment may trigger more robust equipment designs that can ride-through most voltage sag without the need of large energy storage.

11. CONCLUSION

This paper has described preliminary results obtained from the joint project conducted by the University Malaya, Tenaga Nasional Berhad and Texas Instrument of Malaysia (TIM). Although the project is not yet completed, it has managed to reveal several important considerations useful for the Malaysian government in understanding the impact of voltage sag to the industries. The next phase of the project will be in terms of evaluating suitable mitigation measures for TIM by balancing the level of equipment sensitivity toward voltage sag, the probability of voltage sag frequency as well as the cost benefit that can be derived from it. The overall work towards this achievement is targeted by the end of year 2001.

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