Development of Integrated Assessment System for Underground Power Cable Performance: A Case Study

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Abstract. The basic operation of any electrical machines that is catered to serve needs of civilization involves electrical power which is the main source to trigger the internal mechanism in the machines then transfer the power to other form of energy such as mechanical, light, sound and etc. The supplies of electrical does not happen just by providing the source itself, it has load carrying agent which in many cases, user would refer to it as cable. Specifically, it is the power cable which its ampacity depends significantly on the operation temperature and load stress on it. Apart from having to focus on providing improvement on improving efficiency on the source itself, power cable plays and important role because without it, current ranging from low to high could not be transmitted and hence a failure of the power system generally. Studies have conducted to discuss whether which factor contributes relatively more to the causes of power cable failure or breakdown. Such factors can be narrowed down to the three major causes which are over temperature, over voltage and stress caused by over current. Over current is one of the factor which is depends on the usage of the power system itself. The higher the usage of the power system, higher the chances of over current to take place. This will then produce load stress on the cable which eventually destroy the insulator of the cable and slowly reach the core of the cable. It is believed that an assessment method should be implemented in order to predict the performance and failure rate of the power cable and use this prediction as reference rather than just letting power failure to happen anytime unpredictable which cause huge inconvenience to users and industries. Not only do a method should be implemented, it should be as easy to be used and understood by large range of users and integrated by a graphical user interface to be used. Therefore, this research will further narrow down on the approaches to do so and the location of studies involve Company M which is an agriculture industries which has higher usage on their own underground power cable. Moreover, in the past history the company experienced electrical power failure and this studies and findings will definitely come in hand to provide them necessary help and benefits.

1. Introduction

In the era of rapid growth of every field in the industries and as well as civilization, electricity power has become a necessity and it serves as the source for electrical machines operation which then helps
to execute task which was desired for different purposes [1]. Therefore, the performance of power distribution is a significant aspect to be taken into studies and finding ways to enhance the performance [2]. The general system of power distribution consists of a main power stations which transmit electrical currents to the other sub power stations and then directly to appliances locations such as factories, shop lots, households and etc [3-4]. The electrical currents are transmitted through a load carrying cable which is capable to carry load with 500kV depending on the type of conductor of the cable itself.

During the early days of power distribution, overhead lines cable was the method to install those loads carrying cable between power stations and appliances. Studies shows that overhead cable do come with few major disadvantages such as damage from severe weather conditions, constant relatively high electromagnetic field which causes power loss, geographically unfriendly to environment and disrupt aircraft or even wildlife [5]. Therefore, undergrounding power cable method was then begun to be applied as early as in 1870 where there was a high demand and urgency for power cable to be installed in the urban and industrial areas so that every piece of lands in the country is a power supplied area.

Underground power cable was widely spread and used because of its major advantages that gives the maximized performance of a power distribution system [6]. The electric magnetic field are comparatively lower than using overhead cable but it is depending on the depth of the cable being buried underground because those that buried lower due to insufficient space and rooms for the installation of power cable have similar amount of electric magnetic field produced. However, its advantages still outweigh the disadvantages because the disadvantages are mainly because of the cost, high maintenance and the inconveniences to fix the cable in case of power failure or any error occurred.

This led to many researchers to do study and come out with method to first analyse the load increase effect so that the power flow can be monitored and to make amendable changes to avoid any harm before it happens [7]. However, it is found that all the methods are precise analysis using mathematical approaches and it can find out every characteristic at the instant of the power cable but it is does not come with a proper user-friendly system for front user to directly predict the future outcome of the performance of the cable depending on the frequency of usages or power dissipation. Overcurrent is one of the very main factor that damages the power cable internally which sometimes causes short circuit breakdown and permanent damage to the cable and this comes very unhandy for underground power cable where the installation takes much more complexity and time than overhead cable. Furthermore, overcurrent can lead to over temperature (overheat) which also damage the cable permanently. Lastly, overvoltage which is due to the over supplied voltage that the specified voltage of the cable can also damage the cable. However, preventives method has been implemented to lessen the chances of these factors such employing sensor to associate with the circuit so that the supply is disabled once it exceeds the specific value and while associated circuits to disable the supply if its operating temperature exceeds a specific value. Overcurrent in this case still remains a quite high chance to happen compared to over temperature and over voltage because it is dependable on the output itself at the instant and the system cannot limit usage of power by the users, else it will become very unfriendly and large usage like factories can never be efficient.

Therefore, in this research, its purpose is to design an integrated assessment method for the underground power cable. This means it could be used by front user and directly enough for them to understand their usages of power cable as well as performance in the time to come so that they can readjust their usages frequencies or maybe considering a round-up maintenance. Specifically, this studies of research is carried out at location of Company M in Selangor.

It is ideal for an underground cable to be able to have high load carrying capacity and supply power efficiency and without extended outage. However, even though there is a means of effort to highlight about the limit of the power cable capacity, in other words its limitation, the frequency and capacity of usages is often hard to be controlled and monitored which then led to power breakdown or permanent damage to the cable. This is very relevant to the location of studies which is at Company M because of
the problem of circuit breakdown which led to delay in work progress and also cost spent on maintenance. Indeed, this is even relevant to most of the industries which has no proper method in assessing the power cable except the highly in depth and complicated analysis done by researchers which is difficult to put in practice by industries. Thus, to solve this problem, solution is proposed by designing an integrated assessment method for underground power cable performance to serve as a user-friendly monitoring system. Using the data that can be obtained from the meter gauge of the power cable, a suitable mathematical approach will be used to compute the data and then to monitor the performance and predict future condition of the power cable. Graphical user interface is necessarily to be implemented as well to be very approachable to users to use it.

The objectives of the project are:
(a) To develop an integrated assessment method as monitoring system using MATLAB with Graphical User Interface.
(b) To improve performance and sustainability analysis of underground power cable.
(c) To be able to predict the condition or performance of power cable in order to improve sustainability and practicality of underground power cable usage.

Throughout the review of few researches on journals, these studies or even studies that are still ongoing are focused to investigate the root cause of possible failures in power cable but many have directly and indirectly implying that it often occurs because of the load stress on the power cable itself that caused by the electrical current in the core over time, or over current. Overvoltage is proven that it can be corrected using attenuation method but whereas overcurrent is dependable on the output, which is usage of the users. Besides, throughout these reviews, it is noticeable that researchers use high complexity method to compute data for analysis purposes and very less to touch on how to building a monitoring system which is usable by front users and at the same time have simplified method of computing average number of data. Linking back to the problem stated by this research where user could not have a simplified and accurate assessment or monitoring system to analyse the performance and predict future condition of the power cable. As a solution, this research aimed to design an enhanced friendly-user software that can process simplified analysis to assess performance of the power cable. This studies will also help Company M and many industries who face similar problems.

2. Methodology

2.1. Research Design
The analysis used to determine the performance of the power cable at Company M will be using load analysis since electrical stress happens when the power cable is carrying the load. The data measured for this analysis will be the electrical current of the power cable and as for this case, Company M uses 3 phase power cable where it consists three cores in the power cable. The research design consists of the following:
(a) Method of assessment in the software.
(b) GUI of the software for data inputs.
(c) Assessment results of power cable performance in a specified time.

Whereas the methodology to design such system stated above is as follows:
(a) Identify the location which involved this study.
(b) Identify type of power cable used by Company M.
(c) Identify voltage supplied to the power cable.
(d) Collect data on a fixed regular schedule.
(e) Identify the suitable method of computation/analysis.
(f) Build a software base on the chosen method of computation/analysis and integrate it with a user-friendly GUI.
(g) Use the software and analyze the critical power cable in years to come.
(h) Record all the information about the research and recommendation for future work.
2.2. Power Cable Specification

It is crucial to determine the type of power cable used by the targeted research field location such in this case Company M. This characteristic is able to let us determine the maximum capability of current load on the cable so that the software can be catered to find its period of time before current overload risk. It is found out that Company M is currently using total of two types of cable which are PILC/SWA/PVC and PVC/SWA/PVC. The age of each cable is also different due to different year of installation. Table 1 depicts the specification of Company M underground power cable.

| Location of Power Cable | Size | Length | Type of Insulator & Conductor | Year Installed | Current Carrying Capability |
|-------------------------|------|--------|--------------------------------|----------------|-----------------------------|
| Block A                 | 1 X 4C X 150mm | 100m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Block B                 | 1 X 4C X 185mm | 100m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Block C                 | 1 X 4C X 185mm | 120m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Block D                 | 1 X 4C X 185mm | 180m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Block E                 | 1 X 4C X 185mm | 180m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Block F                 | 1 X 4C X 120mm | 150m   | PVC/SWA/PVC                       | 2008            | 348A                        |
| Block G                 | 1 X 4C X 95mm  | 220m   | PILC/SWA/PVC                      | 1989            | 348A                        |
| Perintis Lab            | 1 X 4C X 185mm | 220m   | PVC/SWA/PVC                       | 2002            | 348A                        |

2.3. Method of Data Collection

Since current on the power cable core is what is needed to measure to be used as data for analysis later, it is important to know the methods/setups that can be used to measure current on the power cable during data collection. Electrical current can be measured by:

(a) Using clamp-on ammeter (Digital)

(b) Sub switch board (SSB) current meter reading. (Analog)

These measurements are carried out to determine the current load on underground power cables. The measurement current underground cables are taken by clamp for each phase wire 3 phase cables (red, yellow blue).

It is also important to know how much data is needed in order to compute an accurate prediction or analysis. The higher number of data used, the more accurate the analysis will be. In this research, it is recommendable to record 3 times per week and total of four months of data needs to be collected.

2.4. Method of Assessment

Before the software desired to be developed, a method of assessment has to be implemented in order to analyze and predict the future behavior of the underground power cable performance. The method chosen for this research is from a statistical approach to use current usage behavior for predicament analysis. The significant parameters that involves in the method are such as mean and standard deviation.

Using the statistic parameter such as mean and standard deviation, it could be used to implement on graphical analysis method. Firstly, the graph will be linearized by distributing the mean value according to each frequency. Secondly, the percentage of standard deviation will then be used as the
gradient of the graph where the negative standard deviation is negligible. This is because the method is catered for predicting the overload risk of power cable at soonest possible time that it could happen. The graph is then plotted to the maximum point which is 80% of the current carrying capability of the power cable and the period of time to overload risk of power cable will be determined.

2.5. Software Development Tool
The main platform to perform all the analysis is the MATLAB software. Through this MATLAB software all of the data are going to be analyzed by a software with GUI in MATLAB. Based on the graph the behavior of the performance of the underground power cable can be determined. The software is also able to be exported as a standalone software that is compatible to be used by any Windows and Linux operating computer. The software will still consist of MATLAB compiler in order to run the software code and functions to compute data and also plot desired graph for analysis.

3. Results and Discussion

3.1. Calculated Mean and Standard Deviation
The data that collected for the past 18 weeks at Company M will be analysed. Each week the data is collected three time at three different days. The data is then being used to calculated the mean and standard deviation. The data recorded is the measurement of current across different colour coded wire inside each power cable with its respective location/building. Table 2 depicts the mean and standard deviation value of each location.

| Location   | Mean Current [A] | Standard Deviation Current [A] |
|------------|------------------|-------------------------------|
|            | Red              | Yellow                        | Blue             |
| Block A    | 155.833          | 144.167                       | 138.056          | 23.530 | 18.649 | 20.661 |
| Block B    | 206.111          | 203.889                       | 191.111          | 18.195 | 25.237 | 21.933 |
| Block C    | 337.222          | 332.500                       | 327.500          | 20.236 | 23.530 | 37.661 |
| Block D    | 142.056          | 125.722                       | 116.389          | 40.112 | 42.057 | 36.332 |
| Block E    | 141.389          | 138.056                       | 135.833          | 20.991 | 24.683 | 29.218 |
| Block F    | 85.000           | 82.722                        | 77.500           | 12.127 | 11.636 | 18.570 |
| Block G    | 66.944           | 60.833                        | 65.000           | 20.374 | 16.472 | 13.612 |
| Perintis   | 127.778          | 117.778                       | 121.111          | 18.960 | 20.452 | 24.707 |
| Lab        |                  |                               |                  |        |        |       |

3.2. Integrated Assessment Software
The software has successfully been developed according to the GUI design that has previously drafted. The software is compatible with any Windows and Linux operating system and it is exported as a standalone application software where it can be used by users without MATLAB software because the standalone application contained a MATLAB compiler within. It software is capable of providing user the selection of location and specific cable to be assessed. Radio button is used for the selection of cable while pop up option is used for the selection of location/building. The software in total has two display of graphical results, one represent the current data and one as prediction to current overload risk which is 80% of 348 amperes. Figure 1 depicts the sample of assessment execution of the software.
3.3. Linearized Load Measurement Graph
The first phase of the assessment where the load measurement graph is being linearized using the mean value and also the standard deviation as the increasing gradient of the graph. In this research, there are total of 18 weeks of data collected from September 2016 until January 2017 for 8 different building of Company M. Example of the result is shown in the GUI as per Figure 2, the graph on the right graphical display of the GUI.

3.4. Prediction of Load Measurement Graph
After acquiring the linearized graph, the graph is further plotted to the maximum point of current overload risk which in this case 80% current carrying capability which is 348A. Reason of doing so is because the graph characteristic is plotted based on standard deviation behaviour and therefore it might deviate more out of chances of probability. In short, it also serves as a safety measure. Therefore 80% of 348A is 278.4A. This value is coded in the software rather to serve as input by the user.
because the software is only focuses on this targeted assessment for underground power cable performance of Company M. Figure 3 depicts example of prediction graph of load measurement.

![Block B Prediction Graph](image)

**Figure 3.** Example of Prediction Graph of Load Measurement

### 3.5. Assessment Results

From the whole process of assessment from raw data of current usage/measurement to generating the prediction graph, a quantified amount of time as shown in Table 3 is able to be recorded as a source of analysis reference for further action that is needed to be taken by the user. In this case, the time is in the unit of number of weeks taken for current overload risk to happen which is at 278.4A.

| Location/building | No. of Weeks to Current Overload Risk |
|-------------------|---------------------------------------|
|                   | Red | Yellow | Blue |
| Block A           | 76  | 112    | 104  |
| Block B           | 54  | 35     | 54   |
| Block C           | -70 | -59    | -41  |
| Block D           | 45  | 47     | 62   |
| Block E           | 99  | 84     | 70   |
| Block F           | 269 | 285    | 177  |
| Block G           | 169 | 220    | 264  |
| Perintis Lab      | 125 | 123    | 97   |

From the results, it can be scaled accordingly to rate their condition. In this research, condition/performance scale rating is based on Table 4 shown below.

| Time Taken to Current Overload Risk | Condition/Performance |
|-------------------------------------|------------------------|
| (-ve) value                         | Critical               |
| < 1 year                            | Average                |
| 1 - 2 years                         | Good                   |
| > 2 years                           | Excellent              |
Therefore, using this scale, performance of each power cable can then be rated. Table 5 depicts underground power cable performance of Company M.

| Location of Power Cable | Condition/Performance | Recommended Action                |
|-------------------------|------------------------|----------------------------------|
| Block A                 | Good                   | Continue Monitoring              |
| Block B                 | Average                | Close Monitoring                 |
| Block C                 | Critical               | Re-plan production or execute maintenance |
| Block D                 | Average                | Close Monitoring                 |
| Block E                 | Good                   | Continue Monitoring              |
| Block F                 | Excellent              | Continue Monitoring              |
| Block G                 | Excellent              | Continue Monitoring              |
| Perintis Lab            | Good                   | Continue Monitoring              |

4. Conclusion
The scale of condition/performance rating of power cable is not fixed and can be changes according to the user themselves and further action is also depending on the user or industry. If the performance is in critical stage such as the one in Block C in Company M, earlier action can be taken such as relocation of machines among the buildings or change of power cable if the power cable has been used for a long time. It also can be used. All the three project objectives are achieved such as a software with GUI is developed using MATLAB, system is able to predict the performance of underground power cable and lastly it improves the performance and sustainability analysis.

There are recommendations that could be useful in order to further improve the system and further develop or maybe further commercialize to assess any data in a form of usage and frequencies. Current carrying capability can be set as an input from user rather than implementing in the software itself so that it become a software that can be used by other users who has difference specification of power cable.

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