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Quality Assurance of Voltage Measurement in Multifunction Calibrator as Measurement Standard in National Standardization Agency of Indonesia (SNSU – BSN)

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Abstract: Based on ISO 17025: 2017 clause 7.7, SNSU BSN as the peak of traceability must have quality assurance for measurement results, this is in line with the peer review result of Electrical Laboratory in 2017 and 2019 that suggest doing an intermediate check to support the quality of the measurement results issued by the Electrical Laboratory of SNSU – BSN. The method used method in this research is intermediate check including establishing the control line from the initial data and examining it every month over the year. The out-of-control measurement result will be analyzed more deeply using F-test and T-Test. The result of this test will be the basis of control line updating. The measurement points used are 100 mV, 1 V, 10 V, 100 V, and 1000 V. Over the year, there is no updating in the control line for 100 mV, 1 V, and 10 V because there is no out-of-control measurement result. Besides, there are 2 times control line updating for each 100 V and 1000 V because of artifact movement and drift. Even though it has been updated repeatedly, the last formed control line and the distribution of all data are still in the control line formed by the manufacturer's specifications.

Keywords: Quality assurance; Intermediate check; Control line; Measurement; Voltage.

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Introduction

The International Bureau of Weight and Measures (BIPM) stated that "Metrology is the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology" and metrology itself supports the manufacturing process too. (Brown, 2021; Morse, 2019). From the BIPM statement, metrology is a science of measurement that is indispensable at all levels of application of science and technology from basic to advanced. As a representative of BIPM Deputy of National Measurement Standard – National Standardization Agency of Indonesia (SNSU-BSN), has two main functions, the first function is maintaining traceability of physical quantities and the second function is disseminating their value in Indonesia where the method of disseminating this value is through calibration services. One of the laboratories that perform calibration services is the electrical laboratory of SNSU-BSN, where calibration services carried out within one year can reach 203 tools from electrical calibration laboratories and individuals. Meanwhile, in Indonesia, 246 calibration laboratories have been accredited and among them, 46 laboratories have electrical calibration services (Yayienda et al., 2019). Regarding the main function of SNSU-BSN and the number of electrical calibration laboratories in Indonesia, it shows that there is a large potential for these laboratories to calibrate the SNSU-BSN Electrical Laboratory considering that SNSU BSN is at the peak of traceability in Indonesia (Peraturan Presiden Republik Indonesia Nomor 4 Tahun 2018, 2018).

Based on the traceability status in Indonesia, SNSU-BSN must have quality assurance for measurement results to acquire consumer trust (Grasso Toro &

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Lehmann, 2021). This quality assurance for the measurement results is in line with 17025: 2017 clause 7.7 which states "Laboratory shall have a procedure for monitoring the validity result. The resulting data shall be recorded in such a way that trends are detectable and, where practicable, statistical techniques shall be applied to review the result. This monitoring shall be planned and reviewed and shall be included" (ISO/IEC, 2017). To acquire the data needed for measurement quality assurance and measurement result validation it needs the intermediate check (Gjengedal, 2019; Lynch, 2018). An intermediate check is taking the value of a reference standard by using a check standard between calibration intervals and analyzing the result with a statistical control process (Harris, 2019). Intermediate check is very important to decide the quality of standard, it also can be used to decide the recalibration interval for those standards (ILAC, 2007; ISO/IEC, 2017; OIML, 2004).

Moreover, in 2017 and 2019 peer review was carried out in SNSU-BSN Laboratory wherein 2017 was carried out on the DC voltage and current parameters and in 2019 was carried out on the AC voltage and current parameters. One of the results of the peer review is a suggestion to do an intermediate check to support the quality of the measurement results issued by the Electrical Laboratory of SNSU – BSN. Another result from peer reviews in 2017 and 2019 is that the uncertainty value of the drift dominates the overall uncertainty value caused by the reference standard which is calibrated every three years so the drift must be analyzed using the reference standard manual book. This can be avoided by doing an intermediate check on the reference standard. This phenomenon shows that intermediate checks are indispensable to improve measurement quality

Furthermore, in the process of the intermediate check, there are statistical process control procedures to acquire the quality of the standard. The statistical method that is generally used is the statistical control process, this method uses to test every intermediate check data in the defined limit and analyze the out-of-control value using F-test and T-test. However, the implementation of this method in metrology is commonly used in Mass Metrology(Harris, 2019; Kan, 2019; Pendrill, 2014). Still, there is research that implements this method in electrical metrology but only in the middle range of working standards (Yayienda et al., 2019).

The condition of the SNSU-BSN electrical laboratory needs quality assurance that has never been done before, in line with the result of peer review in 2017 and 2019, and because of the recommendation from ISO 17025:2017 the research will be conducted on quality assurance at the Electrical Laboratory of SNSU – BSN on the Voltage parameter. This research will use a brand new MFC 5730 as the reference standard and Multimeter K3458A as the check standard. The first step of the quality control process method is using the intermediate check to acquire data and proceed statistically, then the data will be updated each month. The result of this research can be used to validate the measurement result using this artifact.

Method

In this research, there are several steps, the first step is the preparation of reference standards and check standard. The schematic diagram for research can be seen in Figure 1.

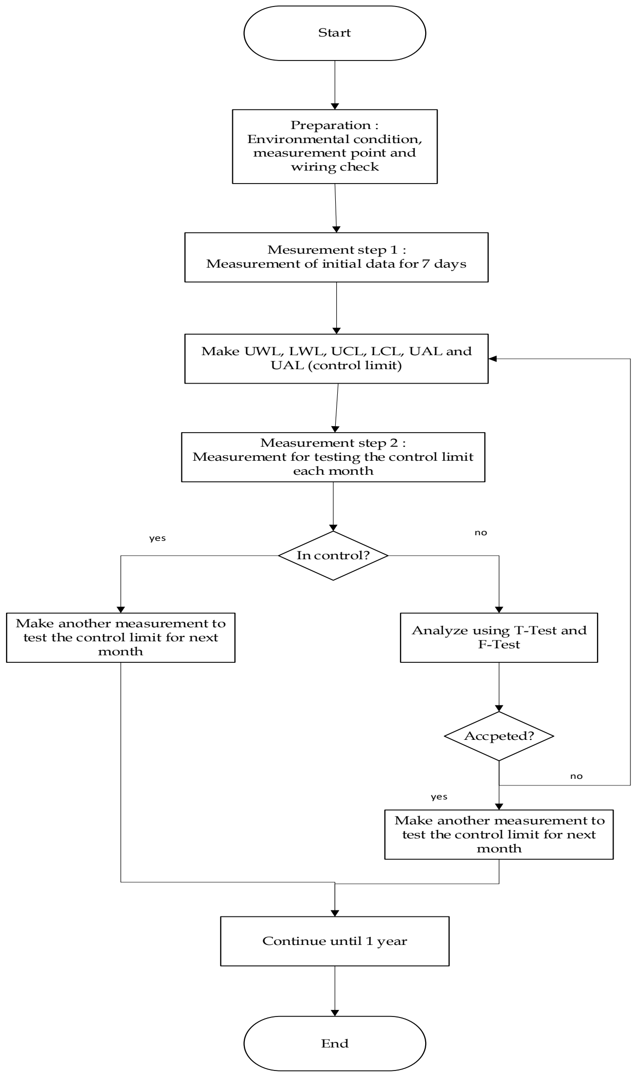

Figure 1. Schematic diagram for the research

Preparation Step

The reference standard used in this research is 7 ½ Multifunction Calibrator Fluke 5730A (MFC F5730A) and the check standard is 8 ½ digit Multimeter Keysight 3458A (Multimeter K3458A), both traceable to the secondary standard in SNSU BSN Reference Multimeter 8 ½ digit Fluke 8508 A (RMM 8508A). Apart from those two main artifacts, it needs calibrated Thermo-hygrometer to measure the temperature and humidity of the environment at the time of measurement.

The Voltage measurement uses the direct method with an environmental condition limit in temperature is (23,0 ± 3,0) ℃ and Humidity <75% (Amalia et al., 2021). This setup and environmental condition will hold the same until the end of the measurement. The measurement point of the DC Voltage measurement are 100 mV, 1 V, 10 V, 100 V, and 1000 V. This measurement point is taken according to the calibration certificate owned by the MFC Fluke 5730A(Fluke, 2015).

Here is the schematic drawing of the artifact set up in the voltage measurement using MFC F5730A and Multimeter K3458A can be seen in Figure 2.

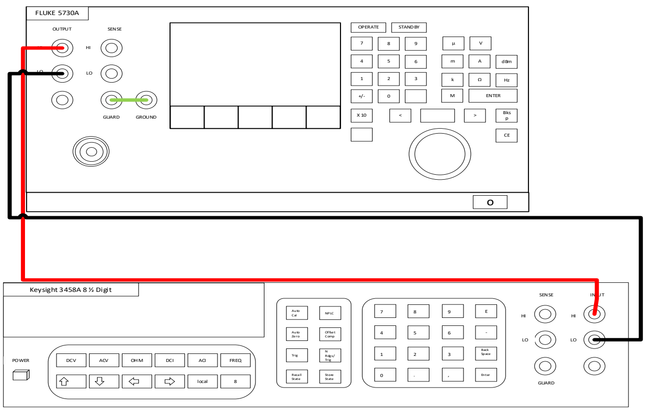

Figure 2. Schematic diagram of voltage measurement

Measurement

The measurement is ready to be done if the preparation is ready. The measurement is done in two steps. The first step is a measurement for obtaining the initial data. In this step, the measurement will be carried out at each measurement point for 7 days and there will be no more than one measurement in one day. The purpose of this measurement is to make the control line from the reference standard. There will be 4 control lines there were Upper Control Limit (UCL), Upper Warning Limit (UWL), Lower Control Limit (LCL), and Lower Warning Limit (LWL). The four control limits made by the mean and standard deviation of 7 days measurement of each measurement point; detailed formula can be seen in eq (1) – (2)

$$WL = \bar{x} \pm 2\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

$$CL = \bar{x} \pm 2\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (2)$$

Where WL is Warning Limit and CL is Control Limit.

After the initial data is carried out the second step is a measurement to obtain data in each month to test the control line. In this step, there will be a possibility that the measurement result will fall outside the control line (Out of control). If it happens, then it needs a further analysis using F-test and T-Test. Detailed equation of F-test in eq (3) and (4), meanwhile T-test can be seen in eq (5) and (6).

$$F_{Test} = \frac{s^2 new}{s^2 p} \quad (3)$$

$$F_{ciritical} = \begin{cases} F_{(1-\alpha/2, N_1-1, N_2-1)} \\ F_{(\alpha/2, N_1-1, N_2-1)} \end{cases} \quad (4)$$

$$T_{test} = \frac{\overline{Y_1} - \overline{Y_2}}{S_p\sqrt{1/N_1 + 1/N_2}} \quad (5)$$

Where,

$$S_p^2 = \frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1+N_2-2} \quad (6)$$

The test compares the behavior of the new and old data. F-test compares the equality of both data variance and T-Test compares the equality of both data means. In F-test, if

$$Ftest < F_{(1-\alpha/2, N_1-1, N_2-1)} \quad (7)$$

Or,

$$Ftest > F_{(\alpha/2, N_1-1, N_2-1)} \quad (8)$$

The variance of old and new data is considered to be unequal (Valcu & Călin, 2018). Meanwhile for T-Test, if

$$Ttest > F_{(\alpha/2, N_1-1, N_2-1)} \quad (9)$$

Then the mean of old and new data is considered to be unequal. If this happens, then the control line should be updated by pooling all the retrieved data. The data retrieving process takes 12 months by manual book of the reference standard. In the twelfth month, we can compare the updated control line with the specification given by the manufacturer

Result and Discussion

Based on the method above after the control line is made than it needs to have another measurement to test the control line. For the first two months, there is no measurement data that lay outside the control line. But in the third month, all the measurement result lays inside the control line except for the 1000 V. It lies far from all control lines as shown in Figure 3.

It can be caused by the different environmental conditions and increasing intensity of use of MFC F5730A. Based on the record of the use of MFC F5730A, there was a movement of this artifact from the AC DC transfer room (2.44b) to the DC Voltage room (2.46 and 244.c). And the condition of this room is slightly different especially on humidity although it is still on the environmental condition limit. The difference of humidity might be changing in electrical properties inside the artifact that caused the difference in the measurement result (Bhadra et al., 2019). Moreover, this brand new MFC F5730A started to be used to perform calibration services while the previous condition has never been used to perform calibration services because the artifact is a new standard purchased by SNSU-BSN. These sudden changes condition made the self-heating resistor inside the artifact called loading effect which can cause the difference of measurement result (Wang et al., 2015).

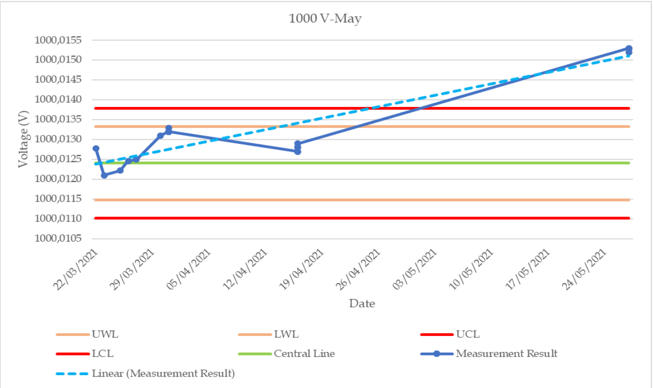

Figure 3. Measurement result for 1000 Volt in May 2021

So, because of that, it needs the T-Test and F-Test to analyze it. The result of the T-Test and F-Test can be seen below.

Table 2. F-Test and T-Test Result

Measurement Point	F-Test	T-Test
1000 V	H_0 Rejected	H_0 Accepted

From Table 2, the new data did not have equal variability although based on the T-test it still has an equal mean. So, it needs updating the control line to accommodate the variability of the new data by pooling all the data to make the new one. The updated control line in the fourth month (June 2021) can be seen in fig 4.

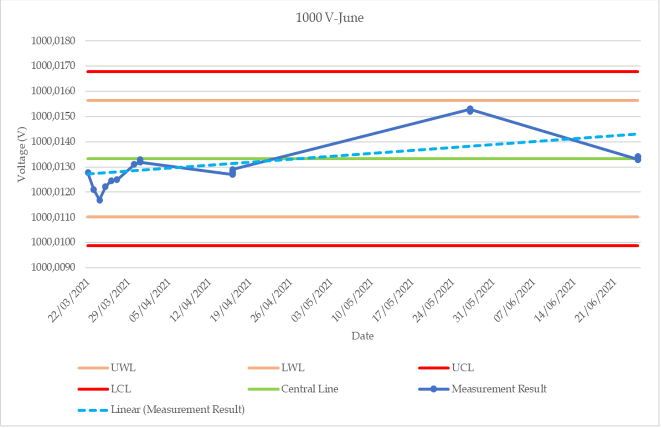

Figure 4. The measurement results in an updated control line for 1000 Volt in June 2021

Meanwhile, in the fourth month (June) no measurement result lies outside the control line for another measurement point. So, it did not need any Tests and updating.

In the next four-month, the measurement of all measurement points always lies between the control line. So, there is no updating control line in those months. But in the ninth month (November) the measurement result starts to drift outside the control line for 100 Volt and 1000 Volt. This behavior is predictable because the drifting trendline of the artifact itself can be seen every month through the measurement result recorded in the control line below.

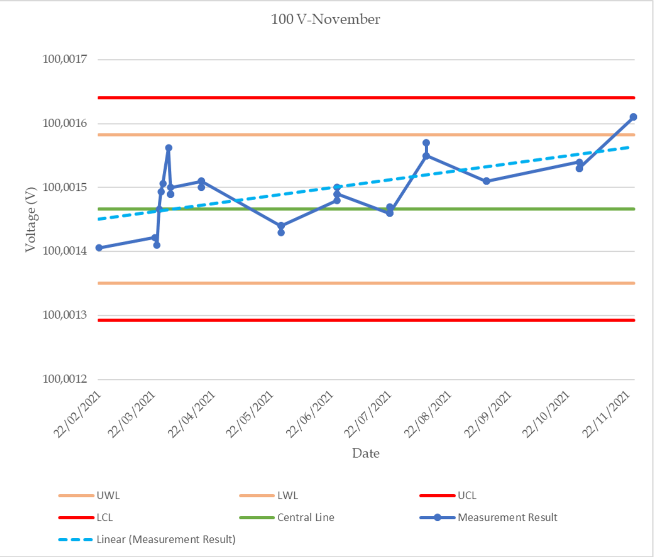

Figure 5. Measurement result for 100 Volt in November 2021

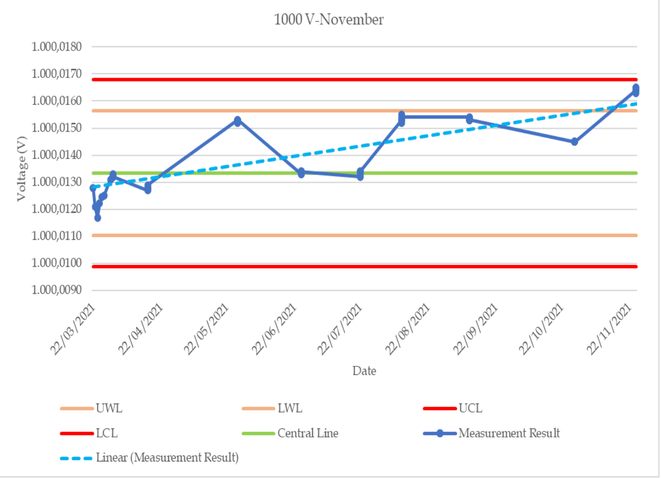

Figure 6. The measurement results in an updated control line for 1000 Volt in November 2021

From figure 5 and 6, measurement result recorded every month shows that every month the value of the artifact tends to drift against time. Although the value drifts by 2 ppm for 100 Volt and 4 ppm for 1000 Volt, this is a sign that the artifact value changed over time and it is something normal happened to the standard artifact, it can be shown in a lot of high precision artifact (Faisal et al., 2016, 2017; Khairiyati et al., 2019; Vernotte & Lantz, 2015). This drifting value is very small compared to the Calibration and Measurement Capability owned by SNSU BSN, it means that even though it drifts, the measurement quality is still valid and reliable in November. After all, the control line of 100 Volt and 1000 volt still need to be updated because of the out-of-control value. The F-test and T-test result for 100 Volt and 1000 Volt can be seen in table 3.

Table 3. The F-Test and T-Test result for 100 Volt and 1000 Volt in November

Measurement Point	F-Test	T-Test
100 V	H_0 Rejected	H_0 Accepted
1000 V	H_0 Rejected	H_0 Accepted

Based on Table 3, both 100 Volt and 1000 Volt new measurement result variability do not equal with the old one. So, it needs to update the control lines. The updated control line tested in the tenth month (December can be seen in Figures 7 and 8.

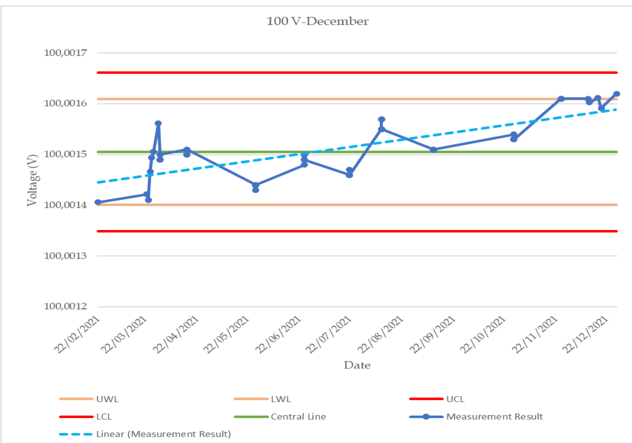

Figure 7. The measurement results in an updated control line for 100 Volt in December 2021

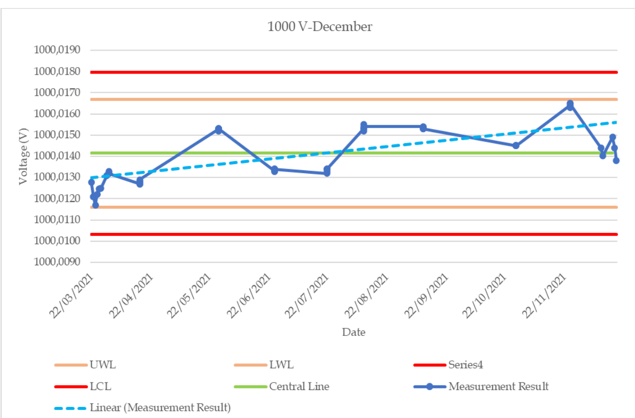

Figure 8. The measurement results in an updated control line for 1000 Volt in December 2021

For the tenth month (December), for 100 Volt the data was out-of-control, so it needs another F-test and T-test for this month. The result of the F-Test and T-Test can be seen in Table 4.

Table 4. The F-Test and T-Test result for 100 Volt in December

Measurement Point	F-Test	T-Test
100 V	H_0 Rejected	H_0 Accepted

Based on the table above, the control line needs to be updated. The updated control line can be seen in its implementation in the eleventh month in January (Figure 9)

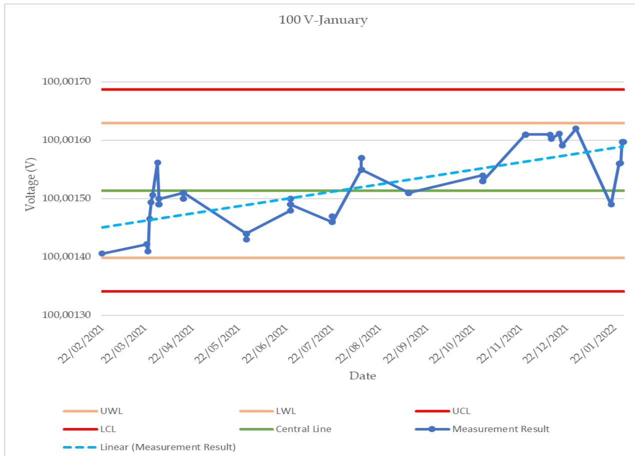

Figure 9. The measurement results in an updated control line for 100 Volt in December 2021

Because of the Covid-19 Issues, there is no measurement in the twelfth month. So, to compare the updated control line as quality assurance and manufacturer specification, it uses the last taken measurement result. The comparison result of each measurement point can be seen in the figures below

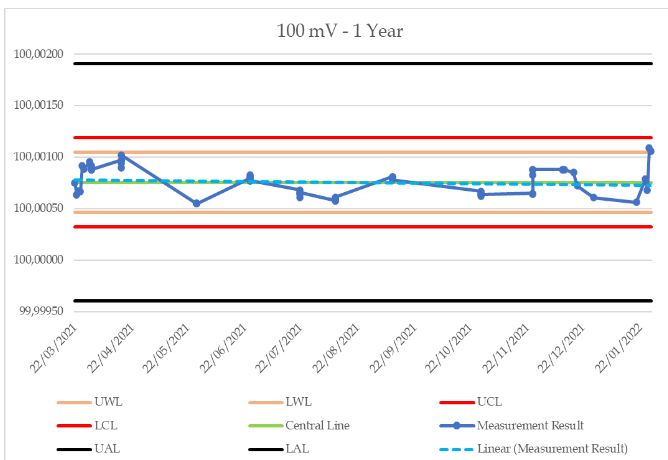

Figure 10. 1-year measurement result of 100 mV

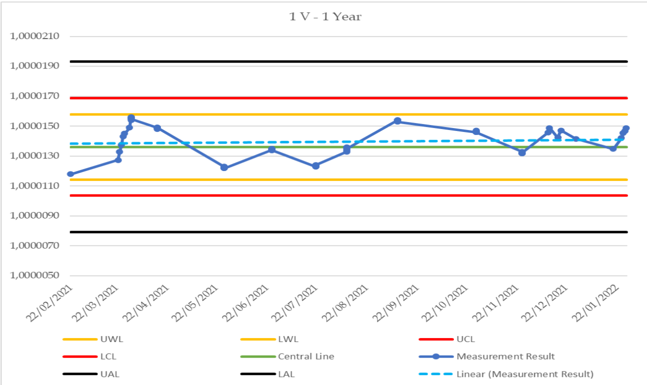

Figure 11. The 1-year measurement result of 1 V

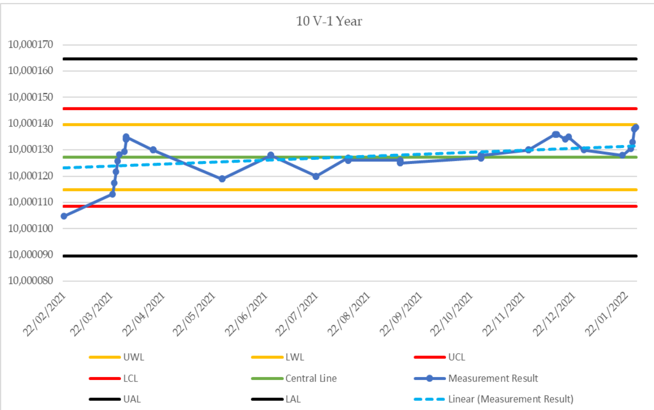

Figure 12. The 1-year measurement result of 10 V

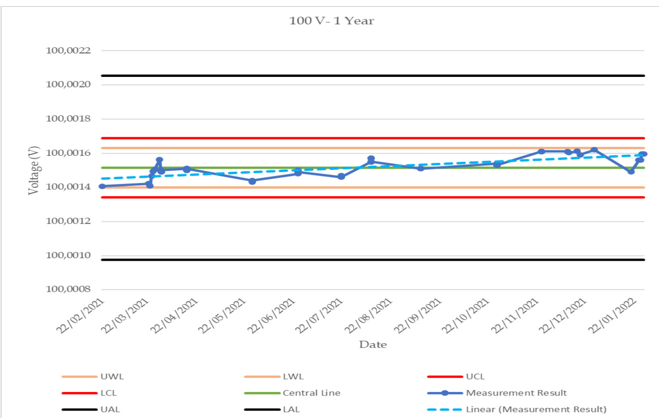

Figure 13. The 1-year measurement result of 100 V

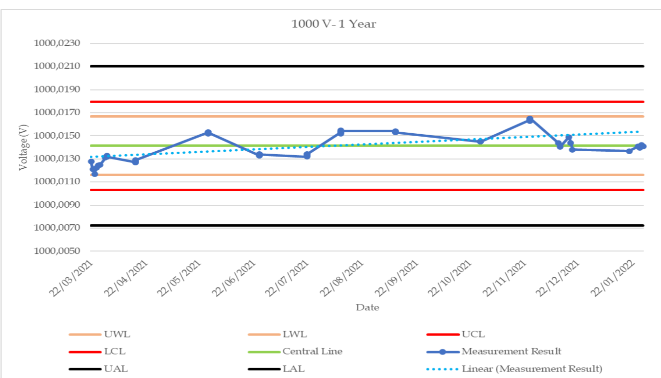

Figure 14. The 1-year measurement result of 1000 V

As shown in Figures 11 – 14, 2 additional lines are UAL and LAL. UAL is Upper Action Limit and LAL is the lower Action Limit. Unlike another control line, UAL and LAL are made by using specifications from the manufacturer, in this case, is a specification from MFC F5730A. There is a lot of selection values of specification in the manual book of the manufacturer but in this research, the user specification is a 1-year absolute specification. This value was taken because the measurement itself was carried out for almost 1 year. The comparison results of measurement taken as part of quality assurance and specification can be seen in the figure above that even though a lot of measurement results that out of line and for some measurement point the control line must be updated repeatedly the quality assurance of voltage measurement is still outstanding and all the measurement data in the whole year is valid (Valcu & Călin, 2018). This is because the latest control line is still far inside the specification line and all of the measurement results in the whole year are in control with or without using the artifact to perform calibration.

Conclusion

Control line has been established in the form of UWL, LWL, UCL, and LCL that made from the average and standard deviation of the initial data. The four control lines will be tested every month, if the measurement result is out of control, a deeper analysis is needed by conducting an F-test and T-test analysis which is then used as the basis for updating the control line. In one year at a nominal value of 100 mV, 1 Volt, and 10 Volt, there is no updating of the control line because there is no out-of-control data. Meanwhile, at the nominal 100 Volt and 1000 Volt, the control line is updated 2 times each, the causes of the measurement results are out of control are the displacement of the position which results in differences in environmental conditions, the loading effect of the tool because it is used for calibration and drifts. But even though it has been updated repeatedly, the last formed control line and the distribution of all data are still in the control line formed by the manufacturer's specifications. So, the conclusion is the measurement done by SNSU-BSN is valid and the quality assurance is outstanding

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