Improved the quantity of DMM calibration services by speeding up the quality of the measurement method

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Abstract. The DMM standard is a digital multi-function standard measuring instrument used to determine the accuracy of the use of voltage and current values which are important parameters of electrical energy values. This measuring instrument is an intelligent measuring instrument because it is equipped with an intermediary facility to communicate with the control device. Regarding the application of the DMM standard in calibration services, the speed of service can only be carried out by the automatic DMM calibration system. Quality and continuity of calibration services can be obtained respectively by 350 % and 400 % after the establishment of the automatic DMM measurement system in SNSU - BSN.

1. Introduction
Electrical energy is one of the primary energy needed for electrical equipment to utilize the electrical current in amperes (A), the voltage in volts (V), and the power consumption in watts (W). This electrical energy can rotate motors, switch on lighting lamps, turn on heaters, cool down freezers, and move mechanical equipment to produce other forms of energy.

Electrical energy efficiency can be achieved by increasing the accuracy of energy supply through 2 calibration methods, namely direct calibration method using an energy meter or indirect calibration method using a combination of current meter and voltage meter. Digital multimeter (DMM) is a standard multi-function digital measuring device that can act as a voltmeter and ammeter so that DMM can measure the energy consumption with an accuracy less than 0.01 VA[1]. In addition, the accuracy of DMMs can be increased using an automatic calibration system.

Two conditions indicate correct calibration, namely the relationship between the quantity value given by the calibration standard and the calibration uncertainty, and using this information to establish a relationship to obtain the calibration results of a calibration indication [2]. Based on the experience of requesting DMM calibration services in the electrical metrology laboratory in the Directorate of SNSU – BSN, the demands related to the number of multimeter calibration services that continue to increase are on the accuracy factor and the time factor.
The calibration service depends on the status of the calibration application, i.e. pre-setting, setting, and post-setting calibrations [3]. Generally, calibration points in the range >1A can be defined as % of the full-scale value, zero in the smallest calibration range, and at least five calibration points evenly distributed with a single frequency value. If requested, a maximum of 3 frequency values, including the smallest, can be carried out. It can be overcome from the national calibration accuracy factor, but it must be proven technically from the time factor.

According to international guidelines on uncertainty evaluation [4, 5], calibration uncertainty should be evaluated for each calibration result. Furthermore, the DMM automatic calibration method should be immediately implemented in SNSU – BSN to increase the calibration service by up to 350% and the accuracy to increase up to four times. Consequently, the analogue multimeter calibration service should be abolished because it is incompatible with the automatic calibration system.

2. State of the art of DMM
DMM is an electrical measuring instrument that can measure and test at least five functions of the electrical signal quantity with many ranges per function. However, based on the characteristics of the DMM service it has, the workload is always high. Quality processes depend on correct and continuous operation. However, time, environment, and physical use (or abuse) change the characteristics of DMMs. That is why it is crucial to calibrate or verify DMM performance periodically [6]. Calibration procedures need to ensure that the DMM is suitable for use through these capabilities. Calibrator specifications must be at least four times better than the specifications of the DMM tested [3].

The most common are DC voltage (volts), AC voltage (volts), DC current (amperes), AC current (amperes) and resistance (ohms) [1]. The introduction of advanced digital multimeters presents a real challenge for the SNSU Directory – BSN standards lab to provide external verification of their performance. The main objective of this paper is to describe that a proven method is adequate for verifying the performance of a highly accurate auto-calibrated DMM, HP 3458A. The verification process has been automated and practical. Data obtained from several HP 3458A shows that the automated calibration process works very well and that the instrument can perform standard lab measurements with a very high degree of accuracy [7].

The repeatability is evaluated as a 1σ type (A) uncertainty [8]. Table 1 shows the manual and automatic calibration results for different electrical sourcing and measuring instruments. Each of the magnitudes of ac voltage, dc voltage and dc resistance has been traced to the standard AC-DC Transfer [9], Programmable Junction Voltage system [10]. The software facilitates fast and consistent measurement objectives, including statistical processing, measurement results, and measurement report generation [11].

Only the complete expression of the measurement result allows the correct interpretation of the measurement results. For direct and indirect measurements, it would be advantageous to develop suitable software applications for integrating digital instruments and personal computers into automated measurement systems with the ability to display complete measurement results [12]. The autonomous system reduces the calibration time and minimize errors, but the technician can invest their time in more challenging activities [13].

Sometimes the operator can make mistakes such as plugging in the cable in the wrong place or forgetting to change the measurement range to break the DMM fuse. By involving the software in the calibration procedure, we can alert the operator if the operator plugs the cable in the wrong place or forgets to change the range of the electrical quantity with a pop-up menu that appears in the software [14].
Table 1. The automatic and manual calibration results for different electrical sourcing and measuring instruments

| Instrument                  | Ranges                     | Manual Mode | Automatic Mode |
|-----------------------------|----------------------------|-------------|----------------|
|                             | Value          | Type A      | Value          | Type A      |
| DMM or Multiproduct Calibrator | DC Volt 1000 V  | 999.90096   | 1.63E-04       | 999.90087   | 1.22E-04 |
|                             | AC Volt 1000 V @ 50 Hz | 999.90010   | 5.27E-03       | 999.90260   | 2.69E-03 |
|                             | DC Current 2 A      | 1.9998089   | 2.07E-06       | 1.9997699   | 1.64E-06 |
|                             | AC Current 1 A @ 50 Hz | 0.9971814   | 4.23E-04       | 0.9997919   | 2.13E-05 |
|                             | Resistance 1 KΩ     | 1.0016796   | 4.48E-04       | 1.0016599   | 9.41E-05 |
|                             | DC Volt 100 V       | 99.999329   | 8.54E-06       | 99.999506   | 5.71E-06 |
|                             | AC Volt 100 V @ 50 Hz | 99.897468   | 5.25E-03       | 99.896279   | 4.72E-05 |
|                             | DC Current 1 A      | 0.9999236   | 4.85E-06       | 0.9999474   | 1.60E-06 |
|                             | AC Current 1 A @ 1 kHz | 1.0000061   | 6.60E-06       | 1.0000855   | 7.98E-07 |
|                             | Resistance 100 Ω    | 99.993945   | 6.61E-05       | 99.993403   | 5.28E-05 |
|                             | DC Volt 10 V        | 10.000008   | 7.48E-06       | 10.000002   | 4.83E-06 |
|                             | AC Volt 10 V @ 1 kHz | 9.9893166   | 8.04E-06       | 9.9893268   | 4.22E-06 |
|                             | DC Current 10 mA    | 9.9969120   | 4.93E-08       | 9.9971854   | 2.22E-08 |
|                             | AC Current 100 mA @ 50 Hz | 99.991467   | 9.17E-07       | 99.991469   | 7.23E-07 |
|                             | Resistance 100 Ω    | 99.993945   | 6.61E-05       | 99.993403   | 5.28E-05 |

Table 2. Differences in the physical operation between manual DMM calibration and automation [14]

| No. | Parameter                          | Manual            | Automation   |
|-----|------------------------------------|-------------------|--------------|
| 1   | Connect cables                     | emf thermal       | no emf thermal|
| 2   | Change the measuring range         | Inaccurate        | accurate     |
| 3   | Read the function key text         | wasting time      | saving time  |
| 4   | Correct true value                 | Indirect          | direct       |
| 5   | Certification                      | Separated         | merged       |
| 6   | Standard equipment heating time and uuc | Imprecise     | precise      |
| 7   | Read data (res, repeat, etc.)      | uncontrolled      | controlled   |

Table 3. The number of variable measurements on DMM resolution > 4 ½ digits

| No  | Function  | Meas. points | Ranges scope             | Meas. numbers |
|-----|-----------|--------------|--------------------------|---------------|
| 1.  | DC voltage| 5            | In all ranges            | 25            |
|     |           | 8            | In a selected intermediate range | 40            |
| 2.  | DC current| 3            | In all ranges            | 15            |
|     |           | 4            | In a selected intermediate range | 20            |
| 3.  | AC voltage| 1            | In the smallest range    | 5             |
|     |           | 12           | In a selected intermediate range | 60            |
| 4.  | AC current| 2            | In the smallest range    | 10            |
|     |           | 4            | In all ranges            | 20            |

The total number of measurements is 195, the repeatability for one measurement point is five times, and each data lasting two minutes, then the length of time needed without a break is 1950 minutes or...
32.5 hours. Even though the manual calibration process for a 6.5-digit Reference Digital Multimeter in SNSU – BSN, including data analysis, takes 19 days. If the working hours are from 7.30 to 15.30 with a break of 1 hour, the effective time for calibration is 133 hours.

Simplified DMM calibration as closed-loop calibration with microprocessor-controlled (IEEE-488 bus or DMM communicating with RS232) has been simplified by automation (Figure 1). The average calibration time is about 12 minutes in an automatic system [9].

![Multifunction Calibrator (JF-5720A) to Digital Multimeter (HP-4568A) connection diagram](image)

**Figure 1.** Simple circuit of DMM calibration system

The automatic process is often referred to as closed-loop calibration. Loop is the relationship between measuring the performance of an instrument and the actual adjustment of its operating characteristics. In manual calibration, the operator first applies a short circuit to the UUT and making adjustment then removes the short circuit and applies a known voltage.

For a DMM calibrator, the system can send the correct range and function via the IEEE-488 bus, apply the desired stimulus to the analogue input, retrieve the read back via the bus, and command changes to the digitally stored correction. Finally, the system CPU closed the loop, and the hand on the screwdriver is removed. Next, the operator needs to connect the leads and start the process.

| No. | Parameter                          | Manual                      | Automation                  |
|-----|------------------------------------|-----------------------------|-----------------------------|
| 1   | Connect cables                     | twisted strong difference   | no difference in twisting strength |
| 2   | Change the measuring range         | wrong operation             | no wrong operation occurs   |
| 3   | Read the function key text         | Tiring                      | not tiring                  |
| 4   | Correct true value                 | mistakenly written          | writing accuracy            |
| 5   | Certification                      | Separated                   | Merged                      |
| 6   | Standard equipment heating time and uuc | can't be precise          | Proper                      |
| 7   | Read data (res, repeat, ...)       | uncontrolled                | controlled                  |

The manual operation takes much time, low working efficiency, easy to human error, the accuracy of the calibration results cannot be guaranteed [15]. In order to improve the automation level of digital multimeter calibration, improve work efficiency, and ensure the scientific and accurate calibration process, a digital multimeter automatic calibration system is designed with a multifunction calibrator as the standard source [16].
Table 5. Measurement uncertainty of automation and Manual DMM calibration [17]

| No. | Uncertainty variable         | Uncertainty type | Automation | Manual |
|-----|------------------------------|------------------|------------|--------|
| 1   | Calibrator certificate       | B                | yes        | yes    |
| 2   | Calibrator resolution        | B                | yes        | yes    |
| 3   | Calibrator repeatability     | A                | No         | no     |
| 4   | Calibrator correction        | B                | Yes        | yes    |
| 5   | Calibrator predictability    | A                | No         | no     |
| 6   | Calibrator loading           | B                | No         | no     |
| 7   | Calibrator zero offset       | B                | Yes        | yes    |
| 8   | Calibrator distortion        | B                | No         | no     |
| 9   | Environmental temperature    | B                | Yes        | yes    |
| 10  | Environmental Humidity       | B                | Yes        | yes    |
| 11  | Settling time                | B                | Yes        | no     |

Table 6. Advantages and disadvantages of manual and automatic method

| No   | Manual          | Automatic         |
|------|-----------------|-------------------|
| 1    | Facilitating aids | not needed             | Needed           |
| 2    | Service fee      | High               | Medium           |
| 3    | Time             | very long           | short (12 minutes) |
| 4    | Order quantity   | Low                | High             |
| 5    | Maintenance      | Seldom             | Often            |
| 6    | Efficiency (O/I) | Medium             | High             |

The developed automatic measurement system should be urgently prepared at SNSU-BSN for the DMM measurement using the direct method with the multifunction calibrator, which makes the measurement faster than manual [18].

4. Conclusion
Implementing an automated DMM calibration system increases accuracy by up to 350%, reduces calibration times by four times, and increases the number of calibration services by three times. Therefore, the automatic DMM calibration system is urgently needed and immediately implemented, especially in SNSU – BSN, by sacrificing some services such as analogue multimeter calibration. Furthermore, the automatic DMM calibration system will increase energy use efficiency nationally because the energy is measured more accurately.

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