Rehabilitation of Bamberg Kit in the High-Voltage Lab at University of Technology- Iraq

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***Abstract*—High-Voltage (HV) labs are crucial for the power and energy sector, as they provide necessary testing for power equipment and devices at voltages significantly higher than their operating levels. The Department of Electrical Engineering at the University of Technology has one of the biggest HV labs in Iraq, and it was well-equipped at some point. Unfortunately, the lab has been out of operation and neglected for decades including the Bamberg kit. No catalog nor a manual existed when the rehabilitation process started. In addition, no internet-based documentation could be found regarding the Bamberg kit due to closing the production line by the manufacturer. Thus, over the recent years, the extensive repair works were carried out and guided by practical experience, detailed analysis, and innovative problem-solving. Remarkably, these efforts were achieved with minimal costs, far below initial departmental estimations. Currently, all the HV generators in the Bamberg kit are back to its normal operation. By the end of the project, most of the kit generator circuits and measurement systems were successfully restored, reaching 80% of a full rehabilitation with less than 1% of the estimated cost. Besides listing and detailing the variety of rehabilitation works that have been done, the paper serves the documentation process of the lab, and this contributes to similar labs that still utilizing Bamberg HV kit.**

***Index Terms*—breakdown voltage, generators, high-voltage techniques, laboratories, maintenance, voltage measurement**

I. Introduction

The fascinating development in power grid voltage levels from few to hundreds of kilovolts for the last century has required rapid development in the HV engineering field [1]. Experimental investigations are indispensable for HV engineering since it is still an empirical field of science [2, 3]. The reasons behind that are the unavoidable defects and imperfections in the processes of power equipment production and assembly [4]. Thus, inevitable verifications are required via experimental work, so HV labs are essential for industrial routine, type and commissioning power equipment testing. Different tests have been performed, and several measuring techniques have been used for power equipment testing due to the diversity of operating conditions and failure causes [5–7]. Accordingly, national and international standards, such as IEC, IEEE and CIGRE, have been developed and accepted over the years. Basically, the service voltage characteristic stresses shall be represented by HV testing stresses in the labs [8].

Nowadays, HV Labs have been upgraded significantly regarding control, digitization of measurements, and data acquisition [9]. However, the HV testing generators are being manufactured in the same way for decades, and their main design concepts have not changed a lot since a long time [10]. The old manufactured hardware is capable of generating the required testing voltages as good as modern HV kits. Thus, rehabilitating HV labs has never been a waste of time or effort since it can always perform the required essential experiments and power equipment tests properly [11]. Nevertheless, other different designs for HV generators also exist. Example of that is the rack mount Glassman HVDC supply with a low ripple voltage of only 0.01-0.1% and regulated discharge current [12]. Moreover, some modifications for the HV generators were made for special purposes, like Haefely lightning impulse (LI) portable generator for on-site testing [13]. In addition, HV measurement techniques developed, including non-contact methods [14, 15]. Furthermore, modification for HV lab can also be done, like the one in the Center for Advanced Power Systems, Florida State University, which offers the ability to perform HV measurements at cryogenic temperature since the gas under test dielectric strength changes with temperature [16–18].

The HV lab at the University of Technology has been out of service for decades due to lack of spare parts and fund, besides vandalism. The lab was abandoned for many years, with the absence of documentation. Inquiring about the manufacturer, Messwandler-Bau (MWB) GmbH, Bamberg, Germany, it was found that the company has stopped its production line of HV testing equipment, and it was sold to another company. Hence, it was useless trying to find any available documentation. Accordingly, rehabilitating the lab depended on our own expertise and critical thinking for proposing solutions, with touches of innovation. In addition, this paper serves as an important piece of documentation resource, and it provides invaluable information and guidance that are very useful for similar HV labs utilizing Bamberg kit.

A Bamberg Kit is a complete system for HV testing. It includes testing transformers, measuring instrumentation, control desk, and other components. It enables wide range of AC, DC, and impulse tests. These tests evaluate the dielectric strength, and long-term performance of HV power equipment. The Bamberg Kit were established in the HV lab in mid-70's. The testing space area for the Bamberg Kit in the HV lab occupies 4 m × 6 m.

With the first check for the lab, many issues were noticed, and it was obvious that rehabilitating the HV Bamberg kit, which includes AC, DC and impulse testing systems, requires a lot of work. There were many non-functioning and missing apparatus for the generators and the measuring systems. The rehabilitation involved fixing and replacing the circuit components and relays, fabricating some parts, applying maintenance for the driving motors, remaking wiring connections, and other related works. The paper details the rehabilitation/ maintenance process and the order of investigations, which would be helpful for similar works. The examination started by constructing and testing the generators circuits, then examining the measuring systems connections, electronic circuits and instrumentation. The paper also serves the documentation process for the lab main equipment and components since nothing is available regarding that. By the end of the work, the main generators circuits and measuring systems for Bamberg kit were revived successfully, achieving 80% of the original lab initial condition, with less than 1% of the estimated cost.

II. Historical Overview

As an educational institution, the Technical Educators Institution was founded in 1960 in compliance with a cooperation agreement between UNESCO and the Iraqi Ministry of Education. The name was soon changed to High Industrial Institute. Then, it became the College of Industrial Engineering and later modified to the College of Technological Engineering. Finally, in 1975, the college became a standalone university, the University of Technology (UOT) [19]. With insightful perspective and fund availability, the university departments started the foundation of high-tech labs. UOT built the biggest HV Lab in the country at that time, and it was well-equipped for the purpose of education, scientific research and power equipment testing. The lab was affiliated with the Department of Electrical Engineering. At that time, Iraq was on the right track regarding academia and industry aspects. The contracting and commissioning of the HV lab kits were established with German pioneer HV companies in mid-70's. Accordingly, the lab big hall was equipped with Messwandler-bau GmbH Bamberg kit and Siemens 6-stage impulse generator kit, with their Measuring and Control Desks. A wood-glass physical barrier forming the control room and separates the generators circuits.

The Bamberg kit consists of three 0.22/100 kV AC testing transformers with all the required ancillaries, including variety of resistors, capacitors, diodes, sphere gaps and gas vessels. Photos for the kit components and its control desk are shown in Fig. 1. The kit single stage testing capabilities are 100 kV power frequency, 140 kV HVDC, and 125 kV no load impulse (max impulse). In addition, the kit is capable of generating higher voltages when multistage is constructed. Table I lists the Bamberg kit components specifications with ratings. Symbols used in the table are TT for testing transformer, R for resistor, C for capacitor, and D for diode/rectifier.

(a)

(b)

Fig. 1. Bamberg kit: (a) Components and (b) Control desk.

TABLE I: COMPONENTS OF BAMBERG KIT WITH RATINGS AND SPECIFICATIONS

Component	Values	Count	Ratings/Specifications
TT	-	3	5 kVA
R	375 MΩ	2	60 W
R	140 MΩ	2	140 W
R	49 MΩ	5	60 W
R	10 MΩ	1	60 W
R	50 kΩ	1	125 W
R	6100 Ω	2	60 W
C	10000 PF	2	140 kV
C	1200 PF	2	140 kV
C	100 PF	2	100 kV
D	500 kΩ	4	8 W – 140 kV – 5 mA
Connecting Rod	-	4	-
Insulating Rod	-	8	-
Spark Gap	-	2	-
Measuring Spark Gap Device	-	2	-
Corona Tub	-	1	-
Control and Measuring Desk	-	1	-

The lab condition started deteriorating in the 80's of the last century, with the start of the war, when the lab foreign staff and faculty started departing the country. In 1990, a comprehensive embargo was placed on Iraq, and sanctions were imposed. Thus, the rest of lab staff could not fix the failures since no spare parts were allowed to be imported, and their price were very high due to the depreciation of Iraqi currency. Accordingly, the lab was abandoned for decades. In 2003, when the country was unstable, the lab was sabotaged by some individuals who broke into the lab intending to steal some of the valuables. This aggravated the lab condition.

Over the following years, there were several attempts by the Department of Electrical Engineering to revive the lab. However, the estimation for the rehabilitation cost always comes very high. This estimation was based on replacing most of the non-functioning parts in the lab. In addition, unfortunately, not a single catalogue was found in the lab. Consequently, the lab was in a bad shape with nothing working, and it was left in a retirement status for a long time.

III. Status and Rehabilitation

The HV test systems require two main functions, generation and measurement [10, 20]. Hence, the rehabilitation process extended to these two different parts. First, for each generator circuit, its components were investigated to examine the generator ability to produce sparks across the Measuring Spark Gap. Second, the measuring system is examined afterwards.

Upon the start of the HV lab rehabilitation, and with the absence of documentation, it was decided to investigate and work on each part one by one. The sequence of examinations and repairments is recommended to be followed for similar works, so each component can be examined logically in order one by one. Fig. 2 demonstrates a map for the main different issues found with the Bamberg Kit. In the following subsections, the status of each HV generator for the Bamberg kit is briefed before the rehabilitation process. Then, details for what was done to fix each issue with the generation circuit and measurement system are discussed.

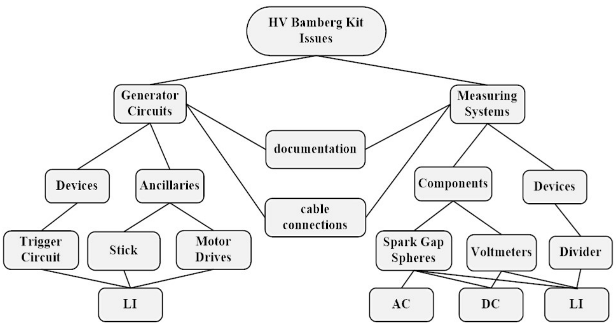


Fig. 2. Overview of key issues identified in the Bamberg Kit.

A. Generators Circuits

For the start, the regulating transformer was checked. It is built in the Control and Measuring Desk, and it supplied from the main. Connecting a voltmeter to its output showed that it is working properly. However, the connection of the handle with the regulating transformer axel was stiff, so the gears connection was lubricated with grease for smooth rotation.

Investigating the testing transformers was next since they are the essential component for the all types of HV generators. Therefore, the single stage AC generator circuit was connected. It simply comprises of a testing transformer. The circuit did not operate normally, with no sparkover across the spheres of the Measuring Spark Gap device. Accordingly, the focus was directed to the testing transformers. An oil change for them fixed the problem since it is usually the main issue for these types of transformers. The generator was back to its normal condition, and sparks were crossing over the Measuring Spark Gap when voltage was risen to the breakdown voltage (V_{BD}) level.

The Measuring Spark Gap for the Bamberg kit serves all the Bamberg kit generators, AC, DC and impulse. However, it had its own problems. One of its three supporting legs was missing, so its upper part was inclined. Being in this condition for a long time, the Measuring Spark Gap spheres were not aligned perfectly, and the device was definitely going to collapse. A support leg was found with the spare parts in the lab, but it was not threaded. The lathe workshop at the UOT Training and Workshops Center helped in making the thread, and the third support leg was installed. The Measuring Spark Gap device was straightened back, and consequently, the spheres are currently aligned

The other issue with the sphere gap was the electric drive system, which was not responding. It controls the rotation direction for the motor that moves the lower sphere to increase/decrease the gap distance. After failing conductivity test, the three-wire connection cable and the plug were replaced. Accordingly, the electric drive system was restored. However, the movement was stuck when reaching the distance limit, and it implied weak drive system torque. To solve this issue, the Measuring Spark Gap motor was checked, and nothing was found regarding its windings. Thus, it was decided to double the capacitor to increase the two-phase motor torque. Accordingly, the electric drive system is back to normal motion. Fig. 3 shows the above-mentioned rehabilitation works for the Measuring Spark Gap device.

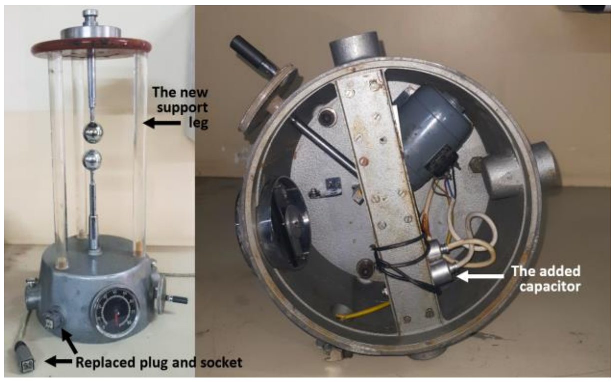
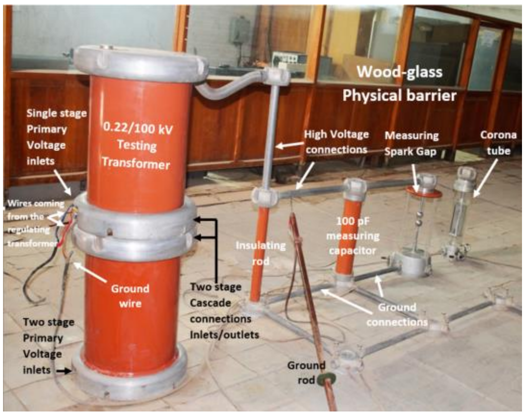


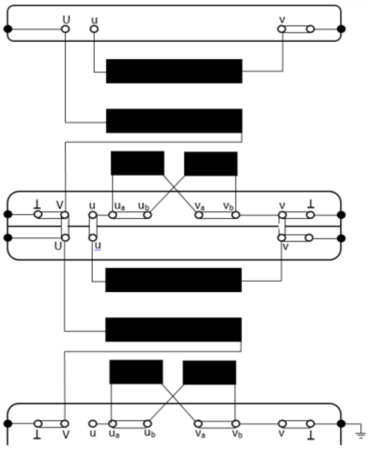
Fig. 3. Fixed and added components for the measuring spark gap device.

The last work done regarding the AC generator was constructing HVAC multistage by arranging the cascade connection of two testing transformers to reach 200 kV. This arrangement is done simply by topping one of the transformers on the other and aligning their inlets/outlets. This construction is kept unmovable since it serves both single and two stage HVAC generator in the lab. For single stage, the top transformer is used alone. For two stage cascaded transformers, the AC wires coming from the regulating transformer and the ground wire are connected to the bottom transformer while connecting their cascade inlets/outlets. Fig. 4 (a) shows the details for

HVAC single and two stage combined circuit, terminals connections and two-stage diagram while cascade diagram is shown in Fig. 4 (b).



(a)



(b)

Fig. 4. HV Bamberg combined circuit (a) HVAC generator with the Measuring Spark Gap and Corona tube. (b) The cascade connection diagram as shown on the testing transformer name plate.

Fig. 5. Sustained arc development on a piece of glass.

Furthermore, for the cascade arrangement, due to regulation, first transformer primary current is reduced, so arc is sustained without tripping the system protection, as shown in Fig. 5.

With absence of documentation, there was no guide for the construction of the DC and impulse generator circuits. Selecting the Bamberg kit components for the DC and LI generators circuits was not difficult, and sparks were obtained indicating the successful operation reaching the generators maximum limit. However, the components for the switching impulse generator were studied and compared to the other HV kits [21, 22].

TABLE II: SINGLE STAGE GENERATORS CIRCUIT COMPONENTS

Generator	Circuit components	Load/divider (measuring component)
AC	TT	100 pF
DC	TT + 2 D + 10000 pF (Cs)	140 MΩ
Lightning Impulse	TT + 2 D + 10000 pF (Cs) + SG + 6100 (Rt) + 375 Ω (Rf)	1200 pF
Switching Impulse	TT + 2 D + (10000 // 10000) pF (Cs) + SG + (49 + 49) kΩ (Rt) + 50 kΩ (Rf)	1200 pF

Table II lists the Bamberg components required to construct the single stage of each HV generator. Symbols used in the table are Cs for smoothing capacitor, SG for sphere gap, Rt for wave tail parallel resistor, and Rf for wave front series resistor.

Regarding the single stage impulse generator, many issues were found. Some of them still not solved, like the trigger control circuit, while others were addressed. The generator circuit was constructed and operated normally. This indicated that circuit components were performing properly. However, regarding the impulse sphere gap component, the stick that connects it to the motor drive could not be found in the lab. The stick transfers the rotating motion from the drive to change the gap distance. Couple of the sticks were handmade, as shown in Fig. 6 (a). Also, the drive motor for the impulse sphere gap was not responding, and it was in bad condition. Basic maintenance for the motor revived it back. In addition, replacing the three-wire connection cable and the plug and socket were also required. Finally, the drive system was restored. Fig. 6 (b) shows the maintenance work for the Bamberg kit lightning impulse drive motor.

(a)

(b)

Fig. 6. Maintenance of the Bamberg Kit Lightning Impulse Single Stage Drive Motor (a) The new stick (b) drive motor.

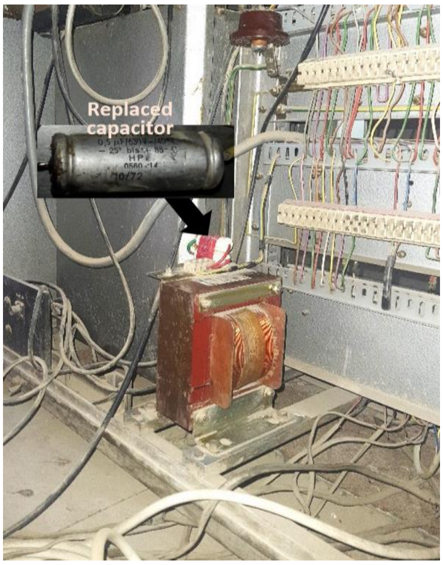


Fig. 7. Couple of 0.25 μF capacitors connected in parallel replacing the 0.5 μF at the back of the control and measuring desk.

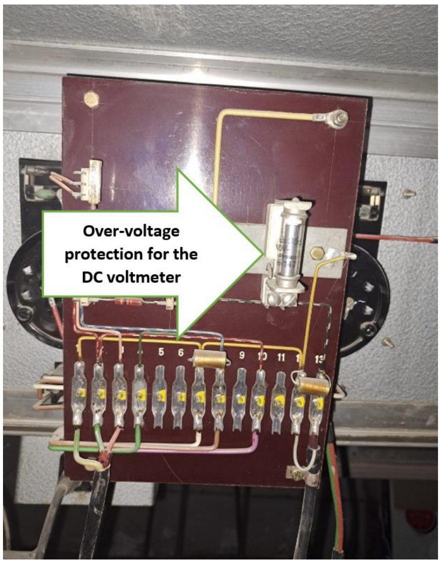


Fig. 8. Electronic board for DC voltmeter at the back of the control and measuring desk.

B. Measuring Systems

The second part was focused on investigating and repairing the measurement systems. Consequently, this part of work required tracing the connections and wiring one by one first before checking the measuring components and instrumentation. Rehabilitating the measurement systems has its issues with the fact that no documentation is available. The situation was challenging since measurement systems characteristics differ depending on the rated voltage, range of measurements, time of operation and environmental conditions [4].

The measuring components, 100 pF, 140 MΩ, and 1200 pF, for AC, DC and impulse HV generators respectively, were simply examined regarding oil level. That can easily be sensed by smoothly shaking the component while holding it horizontally. This examination was applied on all kit resistors and capacitors that contains oil. Accordingly, it was noticed that one of the circuit resistors needed an oil fill.

No measurements were obtained while operating the HVAC and HVDC generators. Thus, the second job was focused on the connections and checking the measuring components and devices in the Control and Measuring Desk. No issues were found when tracing the connections. However, a comprehensive examination for the electronic circuits components were performed, and many issues were discovered. For instance, the 0.5 μF capacitor, shown in Fig. 7, and few fuses were burned out, so these defected elements were replaced. In addition, some components were shortened while they should not be, like shorting the overvoltage protection for the DC voltmeter, as shown in Fig. 8. Removing that and fixing all the above-mentioned issues, voltmeters were back to provide HVAC and HVDC measurements.

A hissing sound was coming from AC voltmeter when rising the AC voltage. However, nothing was wrong with voltmeter itself. Surprisingly, it was found that a misconnection between the wire that connects the outer shield of the coaxial cable and the measuring 100 pF capacitor is the cause behind that, shown in Fig. 9. The broken connection base of the measuring capacitor caused the misconnection. Soldering the connection fixed the problem, and the sound was never heard again.

For the impulse generator, a 1.2 μF voltage divider is required to be at the bottom of measuring capacitor, 1200 pF. The voltage divider could not be found in the lab. The impulse voltameter has its own issues, including the overvoltage protection, shown in Fig. 10. Thus, the impulse voltage values were estimated according to gap distance of Measuring Spark Gap device.

Fig. 9. Misconnection issue in the measuring capacitor.

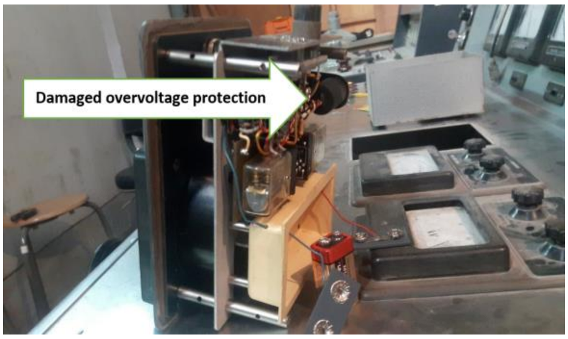


Fig. 10. Impulse voltameter.

Finally, several V_{BD} values were recorded for different standard gap distances at 18.7℃, 101.3 kPa and 57% humidity, with an air density correction factor of 1.05.

These values were validated using AC and DC voltmeters measurements, shown in Fig. 11. The peak impulse voltage values were also verified with their corresponding maximum AC testing voltage. The full load tolerance of front time (T_1) for the LI is ±15%, while for tail time (T_2) its ±2%. For switching impulse (SI), the tolerance of time to peak (T_p) is ±32%, while T_2 is ±14%.

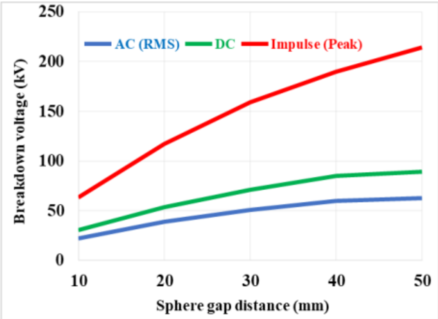


Fig. 11. AC, DC and impulse breakdown voltages for different gap distances.

IV. Conclusion

The rehabilitation of the HV lab affiliated with the Department of Electrical Engineering, University of Technology- Iraq, marks a significant achievement in restoring a critical facility for the benefit of Iraq's undergrad and higher education students and faculty. It also serves the future of power system and HV engineering research sectors. The Bamberg kit in the lab has been revived at a low cost, compared to the departmental estimates, depending on the rehabilitation team sole experience, old technology operation principles, and creative solutions. This paper not only chronicles the extensive repair efforts for the Bamberg HV Kit, detailing its various components and rehabilitation works, but it also serves as an important piece of documentation resource. The lack of such information on global-wise due to the closure of production line for the manufacturer makes it invaluable. The provided information and guidance are indispensable for similar HV labs that are still using the Bamberg Kit.

The generation and measuring systems were investigated and rehabilitated part by part. The paper provides a guide that could be followed in sequence for examining and repairing such issues in HV labs. The rehabilitation has extended to different generators circuits, then to the measuring systems and instrumentation.

For future work, it would be beneficial for the department to continue maintaining the other HV kit, Siemens six stage impulse generator, in the lab and invest in the latest digital measurement tools and instrumentation to enhance accuracy.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author A and B conceived the idea and conducted the practical and experimental work; Author A and B analyzed the results and measurements; all authors wrote the paper; all authors had approved the final version.

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