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Rehabilitation and Modernization of the Test Benches (IV, V, VI) of the Electrotechnical Laboratory: Challenges of Precision and Safety

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Abstract: This article presents a technical study dedicated to the rehabilitation of test benches IV, V and VI of the electrotechnical laboratory of ISPT-LikasiFaced with obsolete equipment and the requirements of the Competency-Based Approach (CBA), the rehabilitation of test benches IV, V, and VI in the electrical engineering laboratory has become an imperative necessity due to the degradation of legacy equipment. The initial assessment revealed structural obsolescence where mechanical wear of components and fragile wiring have become major risk factors. The main objective of this project is to restore operational reliability while adapting these tools to contemporary technological requirements. From a safety perspective, the absolute priority is bringing the installations into compliance with current electrical standards. This entails the systematic replacement of archaic protection systems with high-sensitivity residual current circuit breakers (RCCBs) and the installation of centralized emergency stop devices. These measures aim to eliminate any risk of electrocution for students and researchers, guaranteeing a safe and professional working environment. The modernization also aims to drastically improve metrological accuracy, often compromised by aging analog measuring instruments. The integration of modern sensors, capable of providing data with low uncertainty, is central to this transformation. The shift to digital instrumentation allows for greater accuracy in measurements, an essential condition for any rigorous scientific research. The project includes a transition to automated data acquisition systems. By replacing manual meter readings with interfaces connected to specialized software, the laboratory reduces human transcription errors. This digitalization facilitates real-time results analysis, transforming raw data into instantly usable graphs and reports. The pedagogical aspect of the modernization is equally crucial for enhancing practical experience. These renovated benches allow students to work with cutting-edge technologies, such as high-performance static converters and programmable control systems. This upgrade ensures a strong connection between the theoretical training received in the classroom and the realities of industrial fieldwork. The durability of the installations is ensured through the selection of robust and easily replaceable components. By structuring the wiring in a modular fashion and using standardized connectors, future maintenance operations will be easier and less expensive. This preventative approach significantly extends the service life of IV, V, and VI test benches. Automating startup and protection sequences is another modernization lever. By integrating programmable logic controllers (PLCs),The laboratory secures complex procedures, thus preventing overloads or mishandling during the power-up phases of rotating machines or transformers. Energy management within the laboratory will also benefit from this upgrade. Improved control of electrical parameters will allow for testing with optimized energy consumption and reduced heat loss. This eco-responsible approach modernizes the institution's image while reducing long-term operating costs. The implementation of this project requires rigorous planning, including strict testing phases before any commissioning. Each stage of the upgrade must be documented in a control report, ensuring that the accuracy of the results is validated by calibration in accordance with industry standards. Rigorous execution during this acceptance phase is the cornerstone of the project's sustainability. The modernization of test benches IV, V, and VI transforms an aging space into a center of excellence in electrical engineering. This project is not limited to a simple refurbishment but represents a true technological upgrade. Thanks to this intervention, the laboratory is equipped with the necessary means to meet the security and precision challenges required by modern research and teaching.

Keywords: *Rehabilitation, Renovation, Electrical Safety, Precision, Electrotechnics, Durability, Modularity, Preventive Maintenance, Pedagogy.*

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I. INTRODUCTION

In the current landscape of technical education and scientific research, the electrical engineering laboratory remains a fundamental infrastructure for the experimental validation of theoretical concepts. It is within this space that the transition between mathematical modeling and physical reality takes place, allowing future engineers and researchers to test their knowledge against the constraints of real machines.

Test benches IV, V, and VI form the cornerstone of this experimentation, having been used for many years to study rotating machines, static converters, and energy transformation systems. However, the passage of time has inevitably led to a degradation of their initial performance.

The obsolescence has become evident, not only through the mechanical wear of passive and active components, but especially through the technological gap with current measuring instruments. This situation seriously compromises the reliability of the data collected during practical work.

The issue of metrological accuracy is central to this challenge. In an environment where precision is synonymous with scientific rigor, the uncertainty associated with aging analog instruments no longer allows us to reach the standards required for in-depth studies or high-quality applied research.

At the same time, electrical safety is a critical issue that can no longer be ignored. Current standards impose levels of protection for people and equipment that, at the time of the initial design of these benches, were not yet standardized or integrated in such a rigorous manner.

The rehabilitation of these benches should therefore not be seen as mere corrective maintenance. It is a genuine modernization project, aiming to integrate cutting-edge technologies capable of guaranteeing sustainable, safe, and efficient operation for years to come.

This modernization project is also part of a broader effort to digitize learning. Interfacing the benches with computerized data acquisition systems is essential for real-time analysis, thus providing users with a more nuanced understanding of complex electromagnetic phenomena.

Beyond the technical aspects, this renovation fulfills a pedagogical requirement. By working with modern equipment, students become familiar with the instrumentation they will be using in their future professional careers within the industrial sector.

The economic stakes are also significant. A modernized installation drastically reduces downtime for maintenance and limits the risk of costly breakdowns, thus optimizing the investment made by the institution in its laboratory equipment.

This report aims to detail the process of this transformation, from the initial audit of the situation to the technical choices made for upgrading benches IV, V and VI, including the analysis of risks and the security solutions deployed.

Finally, through these eleven points, we will demonstrate that the rehabilitation and modernization of test benches IV, V and VI are not only a technical need, but an essential strategy to maintain the academic and scientific excellence of the electrotechnical laboratory in the face of the technological challenges of the 21st century.

- *Problem Statement*

The current state of test benches IV, V, and VI in the electrotechnical laboratory of the Higher Pedagogical and Technical Institute (ISPT) of Likasi reveals a worrying level of obsolescence. These devices, once essential to knowledge dissemination, are now in a state of advanced disrepair, characterized by outdated connectors, faulty analog measuring instruments, and a glaring lack of modern safety features.

This technical shortcoming creates a digital and technological gap between the theoretical training provided at the Institute and the practical requirements of the surrounding industrial sector. Leading mining companies, such as Gécamines and TFM, now operate with high-precision systems and advanced automation, rendering current laboratory tools inadequate for effectively preparing students.

The central problem lies in the inability of these test benches, given their current state of disrepair, to fulfill their fundamental mission of providing educational and research support. The impossibility of conducting reliable tests on rotating machines, converters, and transformers deprives students of practical experience essential for their future careers.

Furthermore, the lack of thermal-magnetic protection conforming to international standards poses a major safety problem. In a laboratory environment where the handling of high-power currents is frequent, this deficiency exposes users to the risk of serious electrical accidents and threatens the very integrity of the machines during attempts to power them up.

From a scientific perspective, this situation also hinders applied research. Researchers and graduate students, faced with the inaccuracy of measurements provided by malfunctioning sensors, are unable to validate their hypotheses or optimize the performance of the electrical systems they are studying.

It therefore becomes legitimate to ask: how can we transform these obsolete test benches into modern and secure work platforms, capable of simulating the real conditions of industrial networks while respecting current safety standards? This question underlines the urgency of a profound intervention to rehabilitate these working tools.

Ultimately, resolving this issue is not merely a technical fix, but a strategic challenge for ISPT-Likasi. It involves rethinking the overall architecture of these benches to integrate acquisition and protection technologies that will reposition the institution at the heart of the technological challenges facing the Haut-Katanga region.

➢ *Assumption*

To address the issue raised, we formulate the following working hypotheses, which will guide our rehabilitation approach:

- *Technical Modernization as a Driver of Reliability*

We assume that replacing the analog measuring devices with a digital data acquisition chain and installing precision sensors will significantly reduce measurement uncertainty. This technical upgrade is a prerequisite for aligning the laboratory's experimental results with the high-precision standards required by local mining industries.

- *Improving Safety Through Regulatory Compliance*

We assume that a complete overhaul of the electrical protection system—incorporating modern thermal-magnetic circuit breakers, high-sensitivity residual current devices, and centralized emergency shutdown systems—will eliminate the risk of electrical accidents. This safety measure is essential to bring benches IV, V, and VI into compliance with international standards and to guarantee the physical safety of users.

- *Automation as a Lever for Educational Performance*

We assume that integrating programmable logic controllers (PLCs) to control startup and protection sequences will facilitate students' understanding of industrial processes. This automation will transform the test benches from simple demonstration devices into interactive simulation tools, thus bringing practical work closer to real-world situations (such as those encountered at Gécamines or TFM).

- *Modularity for Sustainable Maintenance*

We hypothesize that a modular cabling architecture and the use of standardized components will facilitate future preventive maintenance. By simplifying access to critical components and streamlining rigid cabling with standardized flexible connectors, it is possible to sustainably increase the lifespan of test benches and reduce long-term maintenance costs.

- *The Impact on Applied Research and Innovation*

We anticipate that once rehabilitated and modernized, these test benches will no longer be used solely for teaching, but will constitute a viable platform for applied research. The availability of usable digital data will allow researchers to conduct studies on energy optimization and the dynamic behavior of machines, thus contributing to the scientific reputation of ISPT-Likasi.

These hypotheses postulate that a systemic approach — combining security, digital precision and technological modernity — is the key to restoring the full educational and scientific utility of test benches IV, V and VI, while meeting the needs of high-level technical training.

II. REHABILITATION METHODOLOGY

The methodology adopted for the rehabilitation of benches IV, V and VI is based on a rigorous approach in four successive phases: technical audit, design of the protection system, choice of measurement components (metrology) and, finally, validation tests under load.

➢ *Audit and Dismantling Phase*

The first step involves a comprehensive assessment. We dismantle obsolete components while mapping the existing wiring diagram. This phase allows us to isolate reusable mechanical elements (chassis, motors, transformers) from electrical elements that need replacing (wiring, contactors, measuring devices).

➢ *Sizing of protective devices (Calculations)*

To ensure safety, each bench must be protected by a thermal-magnetic circuit breaker sized according to the nominal current (In) of the machines. The calculation rule for choosing the current rating (Icb) is:

$$I_n \leq I_{cb} \leq I_z$$

Where Iz is the permissible current of the conductors. For a motor, we must also consider the starting current (Idem), often equal to 5 to 8 times In. The magnetic trip unit must be adjusted so as not to trip during current inrush.

$$I_{mg} \approx 1.2 \cdot I_{dem}$$

➢ *Modernization of the Measurement Chain (Metrology)*

We replace analog voltmeters and ammeters with precision sensors. The accuracy of a measurement depends on the sensor uncertainty (x). If a current transformer (CT) is used, the actual measurement (Imes) is:Δ

$$I_{mes} = I_{secondaire} \cdot K$$

Where K is the transformation ratio of the TI. The relative error (Er) is calculated by:

$$E_r = \left| \frac{I_m - I_{theorique}}{I_{theorique}} \right| \cdot 100$$

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The goal is to achieve an error rate of less than 1% for laboratory tests.

➤ *Integration of Automated Systems (APIs)*

For automation, we program start-up sequences (e.g., star-delta start for motors). The calculation of the switching time (t) depends on the inertia of the load:

$$j_{to} = j_{moteur} + I_{Charge}$$

The acceleration time (ta) is given by:

$$t_a = \frac{j_{to} \cdot \omega}{c_m \cdot c_m}$$

Where Cm is the driving torque, Cr the resisting torque, and the angular velocity.ω

➤ *Continuity and Isolation Check*

Before restoring power, an insulation test is mandatory. The insulation resistance must comply with standard NF EN 60204-1, generally:R_{i50}

$$R_{i50} \geq 1M\Omega(sous\ 500\ DC)$$

➤ *Testing and Acceptance Phase*

The final step is to perform no-load and then load tests. For transformers (Bench VI), we validate the transformation ratio (m or K):

$$m = \frac{U_2}{U_1} \approx \frac{N_2}{N_1}$$

$$K = \frac{U_1}{U_2} \approx \frac{N_1}{N_2}$$

Any significant deviation from nominal data indicates a fault in the magnetic circuit or windings.

III. ANALYSIS AND CONDITION OF THE BENCHES

This section presents the technical examination of benches IV, V and VI. Each bench is analyzed not only by its current physical state, but also by its specific role in the laboratory's energy chain.

➤ *Bench Analysis*

The benches that support the study are dedicated to:

- The study of DC and asynchronous motors revealed significant wear on the connection terminals, causing intermittent faulty contacts. Furthermore, the mechanical braking systems for torque testing were seized, preventing any accurate measurement of the mechanical characteristics.
- For the study of power electronics, there is a major obsolescence issue with control boards. Power components (IGBTs/Thyristors) no longer have transient overvoltage protection (snubbers), making them extremely vulnerable during rapid switching. Displaying signals on older oscilloscopes prevents accurate harmonic analysis.
- They suffer primarily from degraded winding insulation, detected by high leakage current measurements. Passive cooling systems are obstructed, leading to premature heating. High-voltage connections are also deemed non-compliant, posing a risk of electrical arcing if handled by untrained students.

➤ *Summary of the Current Situation*

To visualize the urgency of the interventions, the table below summarizes the critical state by type of failure:

Table 1 Summary of the Current Situation

Component	Bench IV Status	Bench V Condition	State of Bench VI
Connectivity	Defective	Obsolete	Dangerous
Protection	Non-existent	Inadequate	Absent
Measure	Analog (Imprecise)	Analog (Unsuitable)	Analog (HS)
Risk Level	AVERAGE	Pupil	Very high

➤ *Interpretation of the Analysis Data*

Cross-analysis demonstrates that the blockage is not solely mechanical. The major problem is the break in the continuity of the measurement chain. Without reliable digital instrumentation, the results obtained do not allow for the plotting of the characteristic curves necessary for validating theoretical models (torque-speed, efficiency, etc.).

➤ *Upgrade Prospects*

For each bench, the analysis dictates a differentiated strategy:

- Bench IV:Complete overhaul of the coupling components and installation of a modern eddy current brake.
- Bench V:Complete replacement of the control stage with a programmable digital system (DSP/FPGA).
- Bench VI:Redesign of high-voltage terminal blocks and installation of digital temperature and current sensors.

IV. SCIENTIFIC CONTRIBUTION OF THE PROJECT

The scientific contribution of this rehabilitation goes beyond simple restoration. It is structured around three fundamental axes:

➢ *Improving the Reliability of the Metrological Measurement Chain:*

The integration of low-uncertainty digital instrumentation allows us to move from a qualitative approach (observation) to a quantitative approach (model validation). The key benefit lies in the ability to statistically process experimental data, thus guaranteeing a level of precision that meets the requirements of applied research.

➢ *Modeling and Simulation of Complex Systems*

By modernizing benches IV, V, and VI, we enable researchers to observe dynamic phenomena (transient regimes, harmonics, non-linear behavior) that were previously invisible on analog instruments. This transforms the benches into true simulators of industrial networks.

➢ *Methodological Contribution to Predictive Maintenance:*

The automation of startup and monitoring sequences (via API) represents a major pedagogical advancement. It allows students to be introduced to the concepts of predictive maintenance and automated diagnostics, preparing them for the technological standards encountered at mining companies (Gécamines, TFM).

V. EXPECTED RESULTS AND IMPACTS

The implementation of this modernization project must generate tangible results, measurable by the following indicators:

- Increased security:Electrical incident rate reduced to zero thanks to compliance of differential and magnetothermal protections (NF C 15-100).
- Data quality:Reduction of measurement uncertainty to less than 1% for machine characterization tests.
- Equipment availability:Increase in the operational availability rate of benches IV, V and VI, estimated at +80% thanks to modularity and ease of maintenance.
- Training-Employment Match:A better job placement rate for students, now familiar with API systems and high-performance digital instrumentation.
- Practical effectiveness:Reduction in the time required to set up and configure practical exercises, allowing more time to be devoted to the analysis and interpretation of physical phenomena.

Fig 1 Expected Results and Impacts

➢ *Strategic Impact for ISPT-Likasi*

- Academic influence:The laboratory is once again becoming a credible platform for basic and applied research in electrical engineering in the Haut-Katanga region.
- Eco-responsibility:Reduction of overall energy consumption of test benches, through better management of machine operating regimes.

➢ *Summary of Validation Through Results*

The success of the rehabilitation will be validated by comparing the measured characteristic curves (e.g., torque-speed, efficiency) with the theoretical curves provided by the manufacturers. A correlation greater than 95% will confirm the validity of the new measurement system and the effectiveness of the modernization performed.

VI. CONCLUSION

The rehabilitation and modernization of test benches IV, V, and VI in the electrotechnical laboratory of the Higher Pedagogical and Technical Institute (ISPT) of Likasi is not simply a corrective maintenance operation. This study has demonstrated that this approach represents a strategic necessity to ensure that academic training is aligned with the technological requirements of the modern industrial sector.

The initial state of the equipment, characterized by material obsolescence and obvious electrical insecurity, constituted a real obstacle to the development of students'

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skills. By structuring our methodology around three fundamental pillars—normative safety, digital metrological precision, and automation using programmable logic controllers (PLCs)—we laid the foundations for a new generation laboratory.

The expected results of this modernization extend far beyond the technical realm. In terms of safety, compliance with international standards now guarantees a protected learning environment. Regarding pedagogical effectiveness, the integration of digital learning tools allows students to become familiar with tools they will encounter in the mining industry, thus facilitating their transition to the job market. Finally, the modularity of the installations ensures the longevity of the equipment, providing ISPT-Likasi with an infrastructure capable of evolving with future advancements in electrical engineering.

This project demonstrates that methodological rigor and the application of fundamental electrical engineering principles can transform aging facilities into centers of scientific excellence. It paves the way for new avenues of applied research, particularly in the areas of energy optimization and the dynamic behavior of electrical machines, thereby enhancing the academic standing of our institution.

In conclusion, this investment in modernizing the laboratory is a direct response to the challenges of technical education in the Haut-Katanga region. By rehabilitating these test benches, we are not simply maintaining machines; we are investing in the quality of training for the engineers and technicians of tomorrow, essential players in the sustainable industrial development of the Democratic Republic of Congo.

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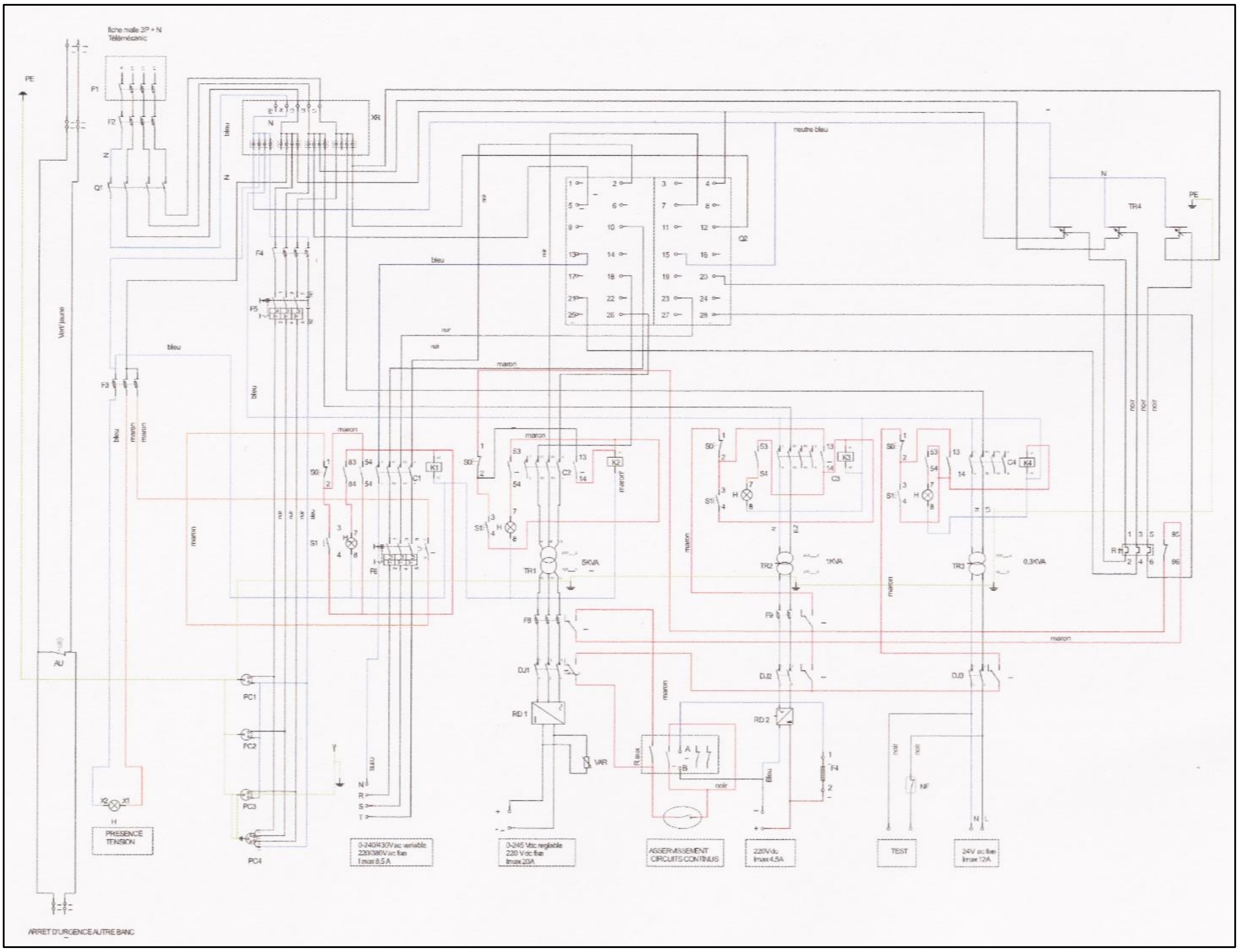
APPENDIX I THE OVERALL ARCHITECTURAL DIAGRAM OF THE BENCHES



- *Legend*

- ✓ AU = Emergency stop □ C1, C2, C3, C4 = Contactors
- ✓ DJ1 = 20A circuit breaker
- ✓ DJ2 = 10A Circuit Breaker
- ✓ DJ3 = 4A circuit breaker
- ✓ F1 = 20A fuse (plug)
- ✓ F2 = 20A fuse
- ✓ F3 = 3P fuse holder
- ✓ F4 = Single-phase 4A fuse holder □ F5 = Duruptor 22A contactor
- ✓ F6 = BBC Disconnector
- ✓ F7 = 40A, 3P fuse
- ✓ F8 = 40A, 2P fuse
- ✓ H = indicator lamp
- ✓ K = thermal relay
- ✓ K1, K2, K3, K4: contactor coils □ N= (Neutral in blue) □ NF= NF sealed contact.
- ✓ PC1, PC2, PC3 = Single-phase power outlets
- ✓ PC4 = Three-phase power outlet □ Q1 = On/off switch
- ✓ Q2 = Switch (voltage type selector)
- ✓ S0 = NC push button
- ✓ S1 = NO push button
- ✓ TR 1 = 5kVA three-phase transformer □ TR 2 = 1kVA single-phase transformer
- ✓ TR 3 = Single-phase transformer 300VA

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- ✓ TR 4 = 6.25 kVA Autotransformer
- ✓ VAR = Varistor
- ✓ XR = Distribution terminal
- ✓ R AUX = Auxiliary Relay

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APPENDIX II BENCHES AFTER REHABILITATION

Powering on Bench IV

Powering on Bench IV

Measurements on the Adjustable DC Circuit

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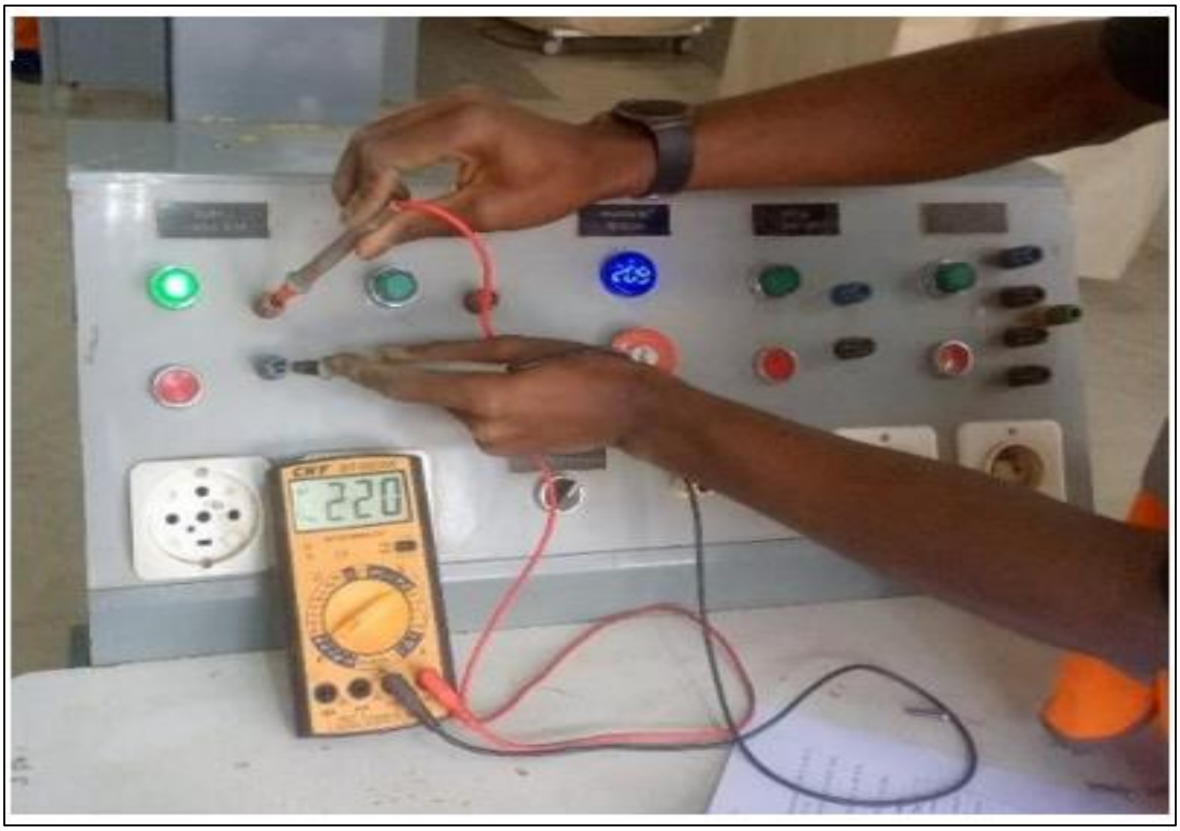
Voltage Measurement in the Socket Circuits



Voltage Measurement in the Circuit of the Replaced Rectifier: 220V DC

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APPENDIX III. RESULTS FROM BENCHES IV AND V

No.	Circuit	Result		Observation
1	Adjustable 0-240V/430V AC power supply 220V/380V AC fixed I max 8A	Good After intervention	OUR	Expected values
2	Fixed 24V AC power supply, Imax 12A	Good After intervention	OUR	Expected value
3	Voltage presence blade	Good After intervention	OUR	Expected values
4	Adjustable 0-245V DC power supply 220V DC fixed I max 20A	Good After intervention	OUR	Expected values
5	Fixed 220V power supply, max current 4.5A	Good After intervention	OUR	Expected value
6	Single-phase power outlet 1	Good After intervention	OUR	Expected value
7	Single-phase power outlet 2	Good After intervention	OUR	Expected value
8	Single-phase power outlet 3	Good After intervention	OUR	Expected value
9	Three-phase power outlet 1	Good After intervention	OUR	Expected values
10	Emergency Stop Button	-		Test not performed
11	Test 24V AC fixed I max 0.5 A	Good After intervention	OUR	Functioning correctly

Source: Ourselves

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APPENDIX IV RESULTS BENCH VI

No.	Circuit	Result		Observation
1	Adjustable 0-240V/430V AC power supply 220V/380V AC fixed I max 8A	Good After intervention	OUR	Expected values
2	Fixed 24V AC power supply, Imax 12A	Good After intervention	OUR	Expected value
3	Presence of tension	Good After intervention	OUR	Expected values
4	Adjustable 0-245V DC power supply 220V DC fixed I max 20A	Good After intervention	OUR	Expected values
5	Fixed 220V power supply, max current 4.5A	Good After intervention	OUR	Expected value
6	Single-phase power outlet 1	Good After intervention	OUR	Expected value
7	Single-phase power outlet 2	Good After intervention	OUR	Expected value
8	Single-phase power outlet 3	Good After intervention	OUR	Expected value
9	Three-phase power outlet 1	Good After intervention	OUR	Expected values
10	Emergency stop button	Good After intervention	OUR	Test not performed
11	Test 24V AC fixed I max 0.5 A	Good After intervention	OUR	Functioning correctly

Source: Ourselves