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DEVELOPMENT OF LOTO DEVICES FOR MINIATURE BREAKER ON CDU ELECTRICAL CONTROL PANEL BY USING 3D PRINTING TECHNOLOGY

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ABSTRACT

Lockout/tagout is a method employed to prevent equipment from moving and posing a risk to workers. The lockout/tagout standard is applicable to various industries and covers the servicing and maintenance of machines and equipment where unexpected start-up or release of stored energy could potentially result in severe damage or even fatalities. Insufficient control of hazardous energies can lead to grave injuries or fatalities for workers involved in servicing or maintaining machinery and equipment. Failure to properly control hazardous energies during maintenance tasks can result in serious or catastrophic injuries, including electrocution, burns, crushes, cuts, lacerations, amputations, or fractures. Furthermore, to properly control hazardous energies by implementing the lockout/tagout involves several steps. Before start, make sure familiar with the safety regulations and standards in working area, as well as the specifics of the equipment and always make sure to follow the specific instructions provided with the lockout/tagout procedures. In this study, the development of Lockout/Tagout (LOTO) devices for the miniature breaker on the CDU electrical control panel by using 3D printing technology was successful. The objective was to enhance safety measures during maintenance and repair work by preventing accidental activation.

1.0 Introduction

Workplace accidents cause disruptions that can have significant material and human consequences. It is crucial to exercise increased caution to minimize accidents in industrial settings. Manufacturing environments can present a wide range of accidents and risks, with maintenance workers being particularly vulnerable to injury and fatalities (Maria T Bulzacchelli et al., 2008). The National Institute for Occupational Safety and Health has issued guidelines for energy control during maintenance and servicing. These guidelines became necessary after the promotion of the Hazardous Energy Control (Lockout/Tagout) Standard by the Occupational Safety and Health Administration (OSHA) in 1989 (Occupational Safety and Health Administration, 1989). According to the regulation, employers are required to have an energy control strategy in place that includes locking out and disconnecting equipment.

Lockout/tagout is a method employed to prevent equipment from moving and posing a risk to workers. The lockout/tagout standard is applicable to various industries and covers the servicing and maintenance of machines and equipment where unexpected start-up or release of stored energy could potentially cause harm to employees. OSHA recognizes that machines and equipment present numerous hazards during regular production operations. In certain cases, the lockout/tagout rule may address specific hazards encountered during typical production processes

Lockout devices play a vital role in safeguarding machines or equipment by ensuring that the energy-isolating device remains in a safe state and prevents it from becoming energized. This is achieved by clearly identifying the energy-isolating device as a potential source of danger, thereby signalling that both the energy-isolating device and the controlled equipment should not be used until the tagout device is removed.

Additionally, periodic inspections must be conducted at least once a year to verify the correct implementation of energy control methods (locks and tags) and to ensure that personnel are knowledgeable about their responsibilities under such procedures (William F. Martin et al., 2001). In the case of lockout procedures, the periodic inspection should involve a discussion between the inspector and each authorized employee regarding their obligations under the energy control procedure being examined.

2.0 Methodology

The project aims to enhance safety during maintenance and repair work by developing Lockout/Tagout (LOTO) devices for the miniature breaker on the CDU electrical control panel. This will be achieved through the utilization of 3D printing technology. The project flowchart (refer with: Figure 1) will guide the project by defining the scope, conducting research and analysis, designing and prototyping, testing and evaluation, refining and optimizing, finalizing, and documenting, implementing, and providing training, and concluding with project evaluation and recommendations.

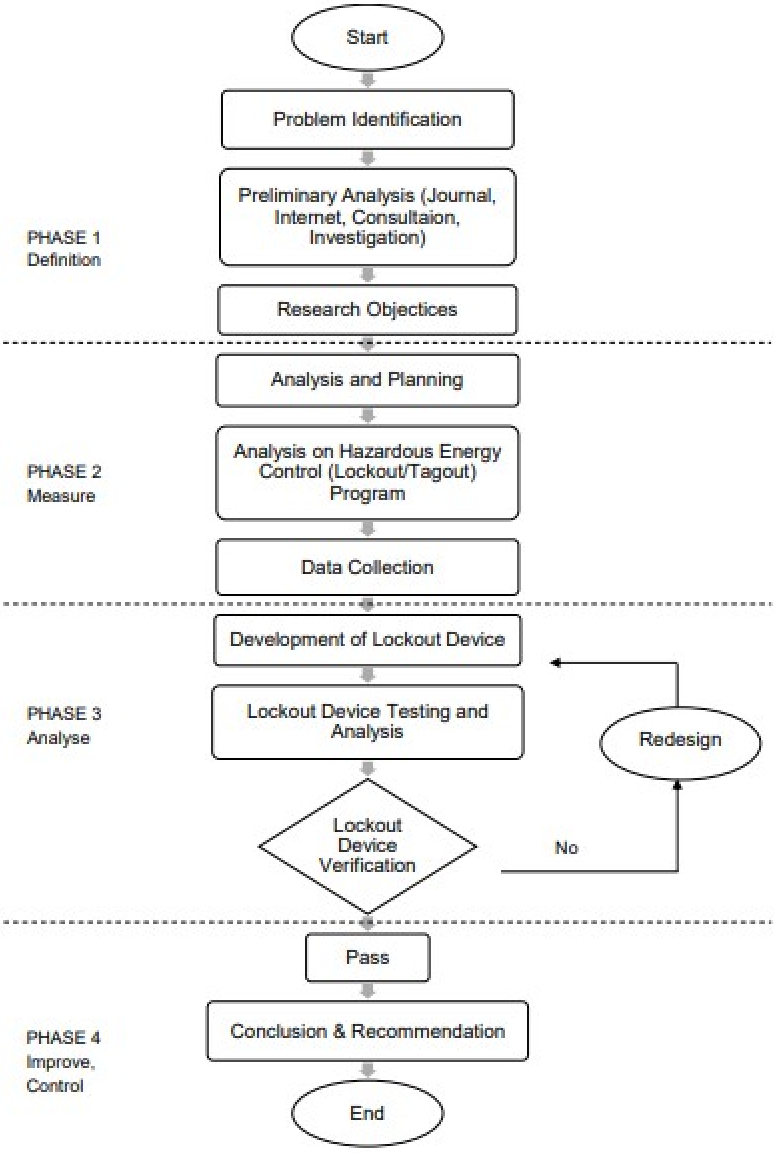


Figure 1. Project flowchart.

2.1 Planning Method

Before starting the project, it is crucial to determine the desired study output and the program required to ensure its availability. When developing new devices, there are various categories to consider, including design, current design evaluation, measurement techniques, material selection, effectiveness assessment, and adherence to standard procedures. These factors are essential for completing the project successfully.

2.2 Design Process

The design process enables researcher to learn from failure and emphasises open-ended problem solutions. This process develops researchers' abilities to devise creative solutions to problems in any subject. The design process ranges from identifying the problem that the design or product will solve, all the way to research, planning, prototyping, and more. There are 7 steps in the design process (refer with: Figure 2).

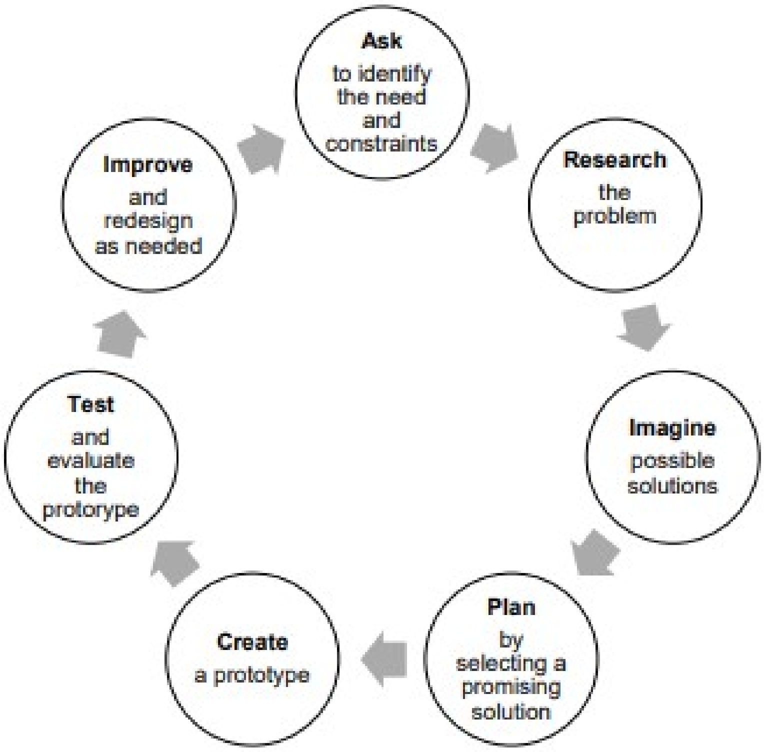


Figure 2. Design process.

2.3 AutoCAD

AutoCAD is a computer-aided design software program created by Autodesk (hence the name AutoCAD). It enables faster and easier drawing, design, and editing of digital 2D and 3D designs than by hand. The data can also be readily downloaded and kept on the cloud, where they can be accessed at any time and from any location. Here are a few more advantages of using AutoCAD in designing the product:

a) AutoCAD simplifies the design process by enabling **easy edits** and modifications, eliminating the need to start from scratch or deal with messy revisions. Designers can effortlessly update and manipulate their designs using this software.

b) AutoCAD facilitates **faster production** through the creation of a reusable block library. Design elements can be saved and reused, improving efficiency compared to manual processes. This feature is particularly useful for repetitive manufacturing components or utilizing existing window systems.

c) AutoCAD **enhances accuracy** by allowing precise design down to fractions, overcoming the limitations of hand-drawn sketches. The software enables the conversion of designs to 3D printers or machines for prototyping. Alternatively, the measurements from AutoCAD drawings can be utilized to construct various parts, such as structures or dwellings.

2.4 3D Printing Technology

In 3D printing technologies, the process begins with the creation of a CAD-based model, which is then transformed to a stereo-lithographic file (STL). This file deconstructs the surface into a logical set of triangles that represent a portion of a 3D model's surface and are then used by the slicing method. The STL file slices the model into thin cross-sectional layers, allowing for 3D printing of the desired model. Below (refer with: Figure 3) is the process flow in 3D printing.

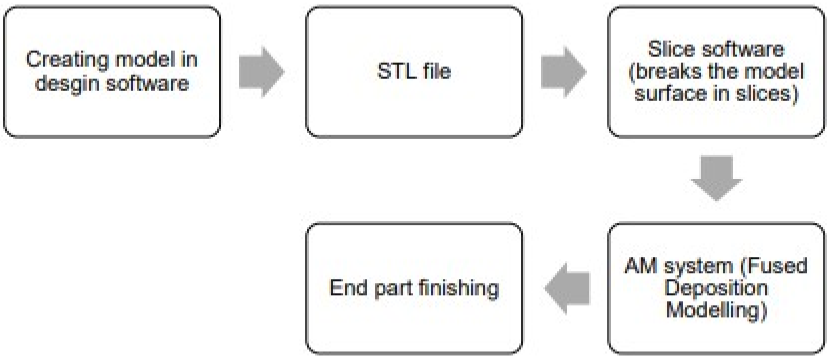


Figure 3. Process flow in 3D printing.

3.0 Result and Discussion

This chapter focuses on outlining the activities undertaken to fulfil the project requirements, making it a vital section of the research report. It presents a comprehensive overview of the study's findings and outcomes, serving the primary objective of delivering clear and organized results and discussions. This facilitates reader comprehension and interpretation of the study's outcomes.

3.1 Design Considerations

Designing a lockout circuit breaker involves incorporating a mechanism to ensure that power is effectively cut off and cannot be restored until certain conditions are met. Below is a step that need to be consider before beginning the product design:

1) Conduct **research to gather information** on available lockout circuit breakers at UniKL MITEC. Obtain technical specifications and design details from product manuals, manufacturer websites, and reliable sources.

2) Identify key **design parameters** for comparison, such as voltage rating, current rating, breaking capacity, number of poles, trip curves, physical dimensions, enclosure type, and mounting options.

3) Determine **specific requirements** for the lockout circuit breaker based on the circuit's nature, equipment being protected, and relevant safety regulations or standards.

4) Choose a suitable **lockout mechanism**, considering factors like reliability, accessibility, and ease of use. Options include mechanical locks, electrical interlocks, or combination locks.

5) Assess **physical dimensions and enclosure type**, particularly if space is limited during installation. Compare sizes, weights, and mounting options, and ensure the enclosure type meets environmental and safety requirements (e.g., moulded case, open frame).

6) Consider the **material used** in the production of lockout circuit breakers, which may vary among manufacturers and products.

3.2 Design Comparisons

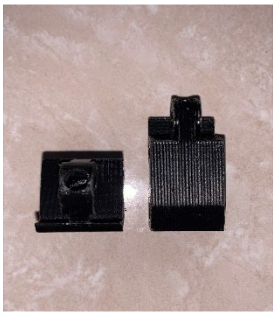
Design comparisons involves systematically analysing and comparing various aspects of each design, such as functionality, aesthetics, performance, cost, materials, and manufacturing processes. Table below (refer with: Table 1, Table 2) is a lockout breaker design that currently available in UniKL MITEC and updated 3D printed lockout breaker design that has been produced.

Table 1. Current lockout breaker design in UniKL MITEC.

No.	Lockout Design	Specifications	Brand	Price
1		• Pin-In Standard (PIS) • Glass-filled nylon, stainless steel • Suitable for single pole miniature breaker • To be used with single padlock • Padlock shackle diameter up to 7mm • 0.56 in x 0.95 in x 1.64 in (L x W x H) • 18 grams	Brady	RM70.44 each

2		• Pin-Out Standard (POS) • Glass-filled nylon, stainless steel • Suitable for single pole miniature breaker • To be used with single padlock • Padlock shackle diameter up to 7mm • 0.56 in x 0.95 in x 1.64 in (L x W x H) • 14 grams	Brady	RM71.61 each
3		• Pin-Out Wide (POW) • Glass-filled nylon, stainless steel • To be used with single padlock • Padlock shackle diameter up to 7mm • 0.56 in x 0.83 in x 1.64 in (L x W x H) • 20 grams	Brady	RM81.74 each
4		• Universal Multi-Pole Breaker Lockout • Nylon, ABS • Suitable for all kind of small circuit breaker • Padlock shackle diameter up to 7mm • 2.25 in x 2.45 in x 1.05 in (L x W x H) • 32 grams	Brady	RM62.32 each

Table 2. Updated 3D printed lockout breaker design.

No.	Lockout Design	Specifications	Brand	Price
1	 	• 3D Printed Lockout Breaker • ABS (Acrylonitrile Butadiene Styrene) • Suitable for 2-4 pole miniature breaker and mini size circuit breaker • To be used with single padlock • Padlock shackle diameter up to 7mm • 0.87 in x 0.87 in x 1.89 in (L x W x H) • 9.6 grams	-	RM10.00 each per print

The features and benefits of the updated 3D printed lockout breaker design showcased in (refer with: Table 2). This design is well-suited for the CDU electrical control panel's miniature breaker and outperforms other designs that are too small or limited to single-pole breakers. By accommodating 2-4 pole breakers, it reduces the number of required lockouts and saves UniKL MITEC from incurring additional expenses. The cost of producing this design using a 3D printer is cheaper, at only RM10.00 per print, compared to purchasing other designs.

Furthermore, UniKL MITEC's possession of a 3D printer offers an advantage, as it can produce these lockout devices and save costs. A comparison table in (refer with: Table 3) further highlights the distinctions between using a 3D printer and an injection moulding machine for producing lockout devices.

Table 3. The differences between 3D printer and injection moulding machine.

	3D Printer	Injection Moulding Machine
Speed	Slower production speed, especially for complex designs or large quantities	Faster production speed, especially for large quantities and standardized designs
Cost	Lower initial investment cost, especially for small-scale production	Higher initial investment cost due the need for moulds and setup
Design Flexibility	High design flexibility, enabling customization and iteration of designs	Limited design flexibility, as moulds are needed for each design iteration

Complexity	Suitable for producing complex geometries and intricate designs	Better suited for simpler designs and standard shapes
Material Selection	Wide range of materials available, including various plastics and some composites	Limited to materials compatible with the injection moulding process, such as plastics
Prototyping	Excellent for rapid prototyping and iterative design improvements	Additional time and cost may be required for prototyping due to mould fabrication
Production Volume	Better suited for small to medium production volumes	Ideal for large production volumes, cost-effective for mass production
Tooling	No need for expensive moulds or tooling, reducing setup time and costs	Requires moulds for each part, which can be costly and time-consuming to produce
Waste	Minimal material waste as parts is built layer by layer	Some material waste due to the trimming or excess material and sprues from the moulds
Maintenance	Regular maintenance and calibration required for optimal performance	Maintenance required for machine and moulds, with less frequent calibration

3.3 Design Process in AutoCAD

The lockout breaker design as in (refer with: Table 2) was designed by using AutoCAD software, resulting in a detailed and precise representation of the device. The design incorporated the necessary features and components to effectively lock out and tag a circuit breaker, ensuring the safety of maintenance personnel during servicing or repairs. The following figure (refer with: Figure 4, Figure 5, Figure 6) shows the design of lockout breaker.

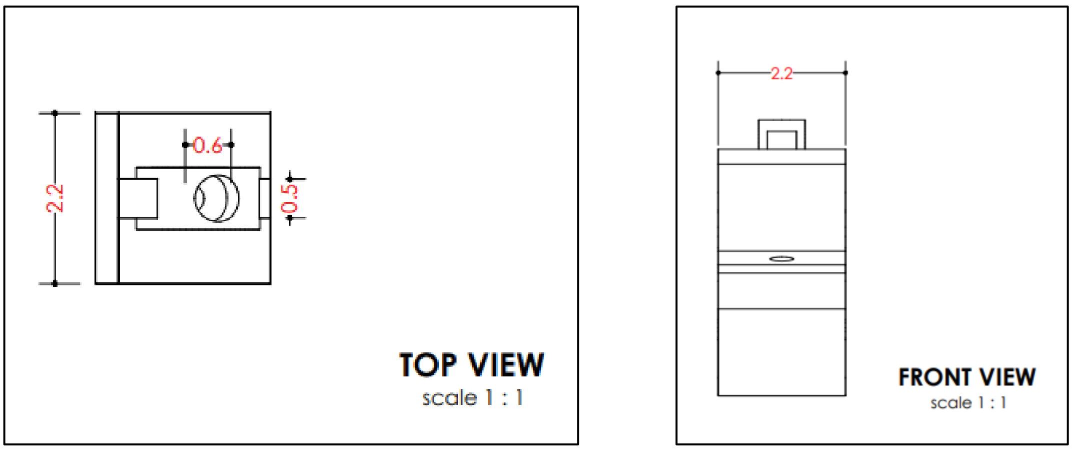


Figure 4. Figure of top view (a) on the left and front view (b) on the right of lockout breaker design.

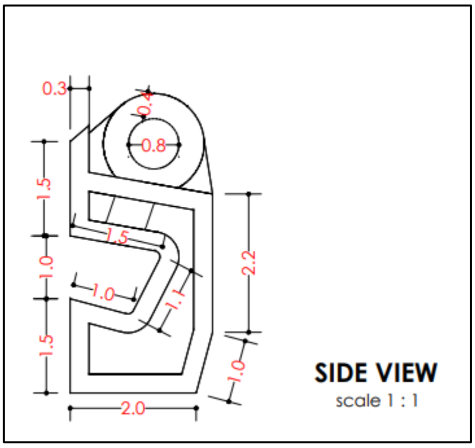


Figure 5. Side view of lockout breaker design.

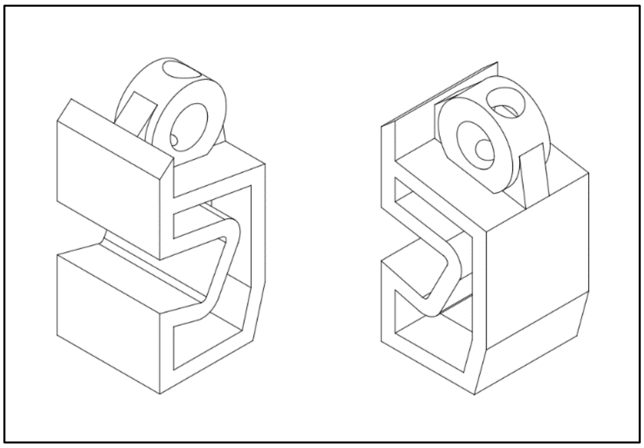


Figure 6. Lockout breaker design.

3.4 Design Process using 3D Printing Technology

The lockout breaker design as in (refer with: Table 2) was successfully produced by using 3D printing technology. The 3D printer utilized a durable thermoplastic material, such as ABS (Acrylonitrile Butadiene Styrene), to create a functional and robust lockout device. The printing process involved layer-by-layer deposition of the material based on a digital design file, resulting in an accurate representation of the lockout circuit breaker (refer with: Figure 7, Figure 8, Figure 9, Figure 10).

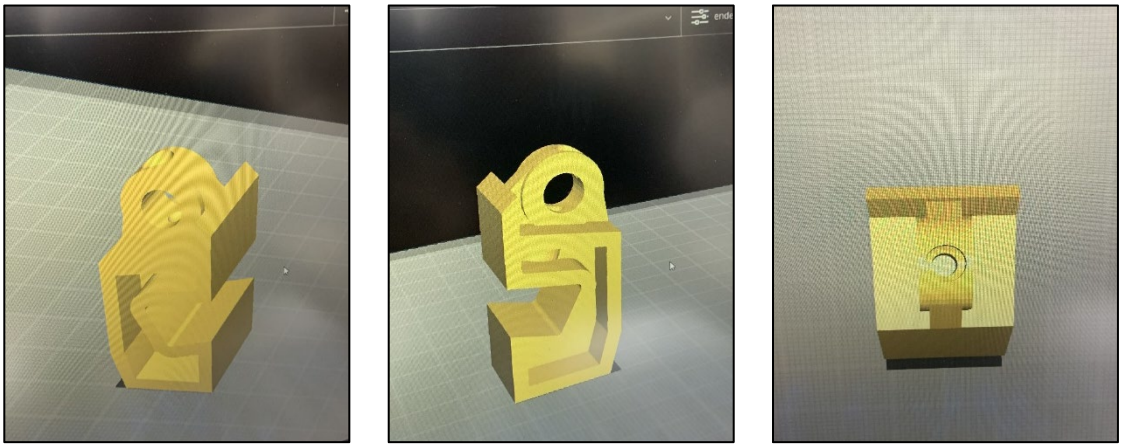


Figure 7. Lockout breaker design in the ultimaker cura software.

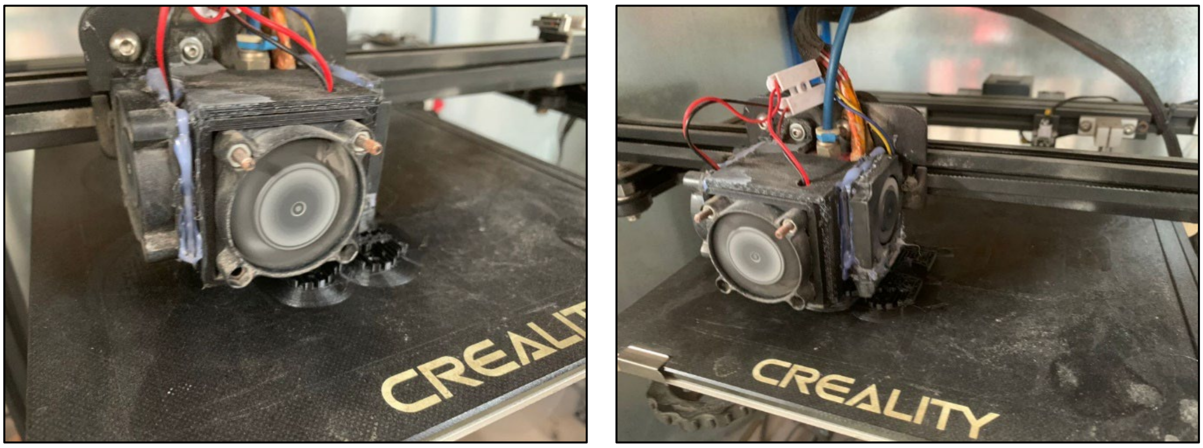


Figure 8. 3D printing process of lockout breaker design.

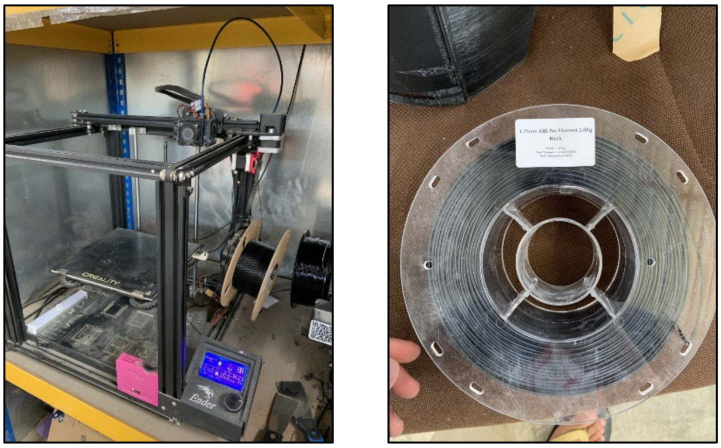


Figure 9. Figure of ender 5 pro 3D printer (a) on the left and 1.75mm ABS pro filament 1.0kg black (b) on the right.

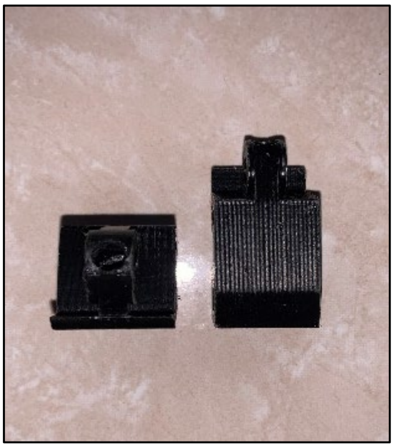



Figure 10. Updated 3D printed lockout breaker design.

3.5 The Effectiveness of Updated 3D Printed Lockout Breaker

The effectiveness of current lockout breaker design in UniKL MITEC was compared with the updated 3D printed lockout breaker design that has been produced, depending on several criteria as shown in (refer with: Table 4) below.

Table 4. The effectiveness of lockout circuit breaker.

Criteria	3D Printed Lockout Breaker	Design 1	Design 2	Design 3	Design 4
Ease Of Installation	High	High	High	High	Moderate
Compatibility With Systems	Very High	High	High	High	High
Versatility	Very High	Low	Moderate	Moderate	High
Safety Features	Very High	High	Very High	High	High
Durability	High	Moderate	Moderate	Moderate	High
Cost	Very Low	High	High	Very High	High
Maintenance Requirement	Low	High	High	High	Moderate
Size / Compactness	Very High	High	High	High	High

3.6 The Implementation of Updated 3D Printed Lockout Breaker

Implementing updated 3D printed lockout breaker involves several steps. Before start, make sure familiar with the safety regulations and standards in working area, as well as the specifics of the breaker. Here's a general guide (refer with: Figure 11, Figure 12, Figure 13) on how to implement it:

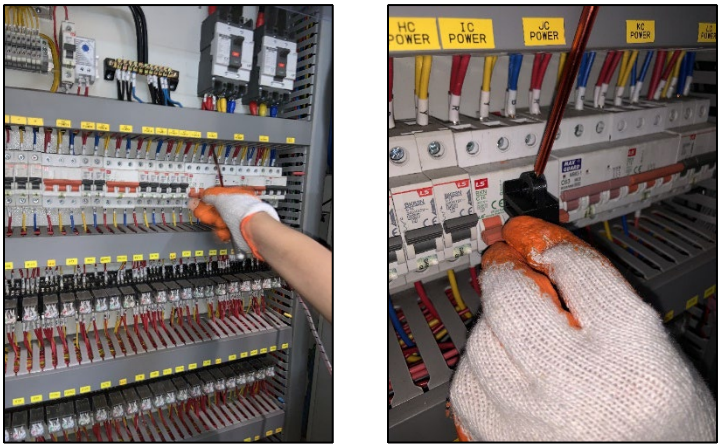


Figure 11. Figure of shut down the circuit (a) on the left and apply the lockout device (b) on the right.

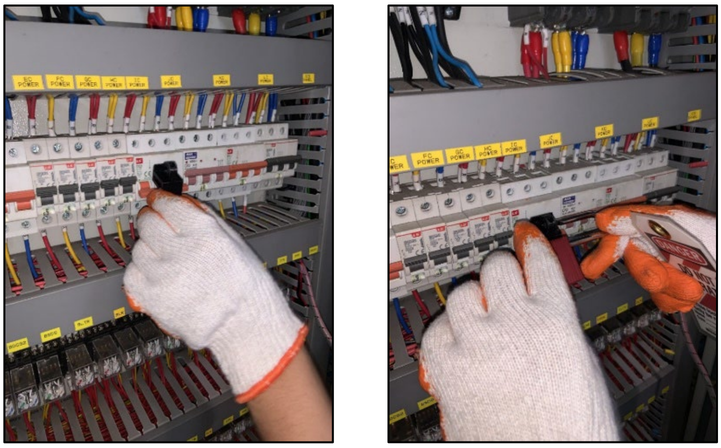


Figure 12. Figure of secure the lockout device (a) on the left and lock the lockout device (b) on the right.

Figure 13. Figure of tag the lockout device (a) on the left and verify, release the lockout device (b) on the right.

Always make sure to follow the specific instructions provided with the lockout device. This guide is intended as a general overview, and the exact steps may vary depending on the specific lockout device and the circuit breaker it's being applied to. The following figure shows the step to implement the updated 3D printed lockout breaker that has been produced.

4.0 Conclusion

The study successfully developed Lockout/Tagout (LOTO) devices for the miniature breaker on the CDU electrical control panel using 3D printing technology. The aim was to improve safety during maintenance and repair work by preventing accidental activation of the breaker. The study concluded that 3D printing technology was a viable and efficient method for manufacturing LOTO devices. It enabled customization, quick prototyping, and the production of specific LOTO devices for the CDU electrical control panel. The designed LOTO devices effectively enhanced safety by securely locking the breaker in the off position and incorporating visible tags for ongoing maintenance work, reducing the risk of accidents and injuries. Additionally, 3D printing technology offered cost and time efficiency compared to traditional manufacturing methods, allowing for rapid iteration and production. The adaptability and scalability of 3D printing were also evident as the LOTO device design could be easily modified and scaled to fit different sizes of breakers and control panels, making it suitable for various applications.

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