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EXPERIENCES AND CHALLENGES OF INTELLIGENT REMOTE CONTROL BREAKER (IRCB) DEVELOPMENT

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Abstract:

The growing adoption of digital technologies in power distribution networks has highlighted limitations in traditional substation circuit breaker (CB) control methods, particularly their dependence on dedicated hardware and complex installations. This study addresses these challenges by proposing an alternative solution for Remote Circuit Breaker (RCB) control using mobile devices. The primary objective is to simplify and enhance the operational flexibility of circuit breaker control without requiring extensive infrastructure modifications. The proposed method utilizes mobile devices equipped with a Human-Machine Interface (HMI) that connect directly to network ports located outside power distribution substation buildings. This approach minimizes the need for additional hardware installations and reduces operational complexity. Preliminary findings demonstrate that this solution provides reliable control capabilities while maintaining ease of deployment and cost-effectiveness. The results suggest that adopting mobile-device-based RCB control can significantly streamline substation operations and contribute to the modernization of power distribution systems.

Keywords:

Digitalization, HMI, iRCB, Mobile Device Control, RCB

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Introduction – Intelligent Remote Control Box (iRCB)

The transition towards digital technology has significantly transformed the operation of Power Distribution Substations, particularly in the remote control of circuit breakers. This shift is driven by the need for greater efficiency, reliability, and sustainability. According to the MyDigital Report 2021, the digitalisation of Malaysia's energy sector prioritises several key areas. Smart Grid Implementation (45%) spearheads efforts to improve electricity distribution and integrate renewable energy sources. Advanced Metering Infrastructure (30%) facilitates efficient energy monitoring through the deployment of smart meters. Renewable Energy Management (20%) employs digital platforms to balance and forecast renewable energy production. Challenges include Data Centres (15%), which increase energy demand and the Digital Divide (10%), highlighting unequal access to digital technologies. These initiatives demonstrate Malaysia's dedication to modernising its energy infrastructure while addressing challenges to ensure a sustainable and inclusive digital transformation.

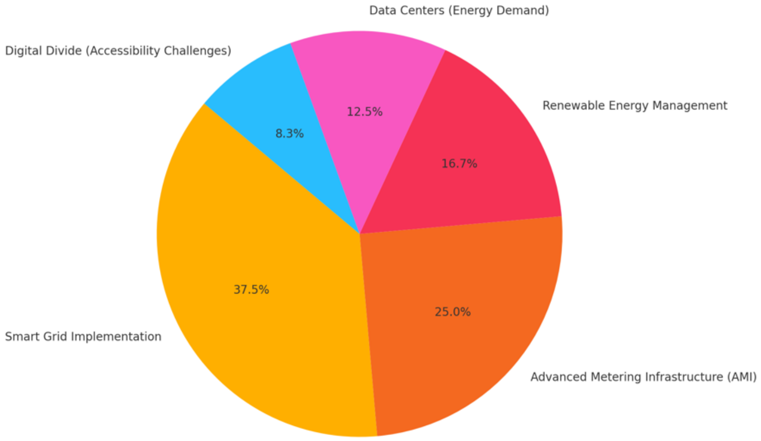

Figure 1: Summary Of Digitalization Of Malaysia's Energy Sector

In Malaysia, Tenaga Nasional Berhad (TNB) has implemented several digitalisation initiatives, including the nationwide deployment of smart meters and service automation. However, upgrading legacy infrastructure poses significant challenges due to the high costs associated with advanced digital technologies, particularly when replacing existing systems with fully digital solutions (Ahmad et al., 2022; Lee, 2022; Patel, 2022). These challenges highlight the need for innovative strategies to modernise systems while effectively managing costs.

This issue is particularly pertinent to Power Distribution systems, such as traditional Remote Circuit Breaker (RCB) systems. Transitioning entirely to digital solutions complicates modernisation efforts. For instance, substations often require additional physical space to accommodate new hardware and upgrading communication systems can be prohibitively expensive. Moreover, many existing systems depend on proprietary communication protocols, which add complexity and increase maintenance costs when fully replaced (Chen et al., 2021). As a result, scalability, interoperability and cost-efficiency remain critical challenges in the modernisation of substations.

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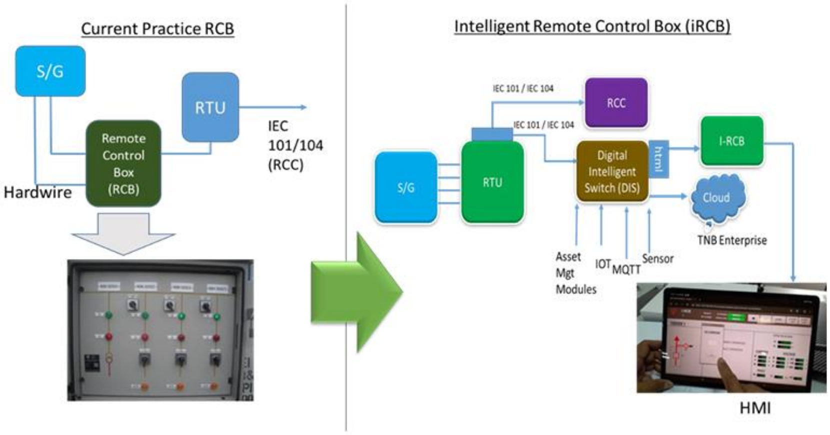

Figure 2: iRCB Architecture vs RCB

This paper focusses on advancing Remote Circuit Breaker (RCB) systems through the development of the Intelligent Remote-Control Breaker (iRCB), as illustrated in Figure 2. The iRCB serves as a digital and innovative alternative to traditional RCBs, designed to enhance connectivity, enable real-time monitoring and optimise power distribution operations within a test-bed environment.

This initiative represents a collaboration between TNB Research (TNBR) and DEC-TNB Distribution Network (TNB DN) to support the digital transformation of substations and improve operational efficiency. As part of TNB's efforts to integrate Industry 4.0 principles into energy systems, the iRCB leverages Internet of Things (IoT) technology (Patel, 2020) to facilitate predictive maintenance and energy optimisation. This paper further explores the findings from the iRCB development and its practical applications within the project's test-bed environment.

Literature Review

The adoption of digital technologies in TNB Distribution Network (TNB DN) substations has grown significantly in recent years, addressing longstanding challenges in traditional substation operations. Conventional systems often require extensive infrastructure and specialised hardware, resulting in high operational costs and increased safety risks, particularly for Authorised Person (AP) personnel during switching operations. Digitalisation through Remote-Control Breakers (RCBs) offers a promising alternative, improving cost efficiency, operational flexibility and user safety.

Despite these advancements, current RCB installations still face challenges related to cost and safety. For instance, substantial cabling is required for each substation, adding complexity and expense. Furthermore, the lack of efficient methods for tracing past switching activities complicates operational analysis. Gathering critical substation information, such as maintenance status, is time-consuming, delaying decision-making. Authorised Person (AP) personnel also require immediate access to detailed information to make timely decisions, which traditional systems are ill-equipped to provide. These limitations underscore the need for innovative solutions to modernise substation operations (Li, 2022; Huang, 2023).

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The development of the intelligent Remote-Control Breaker (iRCB) is a new initiative within TNB DN aimed at addressing these challenges. Conducted in a test-bed environment, the project seeks to enhance circuit breaker (CB) control, a critical substation function, by reducing reliance on complex hardware installations. While traditional setups prioritise safety, they often limit scalability, flexibility and cost-effectiveness.

Research into advanced RCB technologies provides valuable insights into potential solutions. Studies have highlighted the benefits of mobile-based Human-Machine Interface (HMI) systems for real-time monitoring and control of substation equipment, which can integrate with existing systems with minimal modifications (Naik, 2022; Patel, 2023). Similarly, mobile device integration has been shown to simplify operations and improve the user experience through intuitive interfaces for field operators (Javed, 2021; Xia et al., 2021; Li et al., 2022).

Cost-effective and scalable solutions are critical for modern substation operations. Research by Zhao et al. (2023) demonstrates that mobile devices and software-driven controls reduce dependency on proprietary hardware, aligning with industry trends toward commercial off-the-shelf (COTS) technologies (Kim et al., 2020). Advancements in network protocols and HMI systems (Das, 2021) also enable seamless integration of mobile devices with supervisory control and data acquisition (SCADA) systems, enhancing interoperability and enabling reliable remote operations (Gupta & Rana, 2021; Zhang & Wang, 2022). Real-time data analytics and automation have been identified as essential for meeting the evolving needs of the power grid (Zhang & Wang, 2022), while Kumar and Singh (2022) highlight the role of HMIs in improving user interaction and system reliability. Additionally, SCADA systems have been shown to enhance safety and provide real-time insights, supporting efficient remote operations (Tan & Lim, 2020; Chen et al., 2022).

Table 1: Summary of Key Literature Findings

Study	Key Findings
Adam & Hussein (2014)	Challenges in physical RCB infrastructure integration
Gupta & Rana (2021)	Importance of real-time data analytics
Kumar & Singh (2022)	Benefits of mobile-enabled HMI systems
Tan & Lim (2020)	Advancements in SCADA for remote substation control

The iRCB system builds on key findings from previous research by incorporating advanced Human-Machine Interface (HMI) features and supporting a range of Remote Terminal Unit (RTU) brands, making it well-suited to modern smart grid infrastructures. Its development marks a significant advancement in addressing the challenges identified in earlier studies.

By ensuring compatibility with multiple RTUs, the iRCB reduces dependence on proprietary systems, facilitating seamless integration across diverse infrastructure configurations. The system effectively addresses operational challenges by minimising the need for extensive cabling, enhancing access to historical data and enabling real-time monitoring and improved decision-making. Aligned with the objectives of grid modernisation, the iRCB delivers a cost-

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effective, reliable and efficient solution, laying the groundwork for substantial improvements in substation operations.

iRCB Test Bed Methodology

This study utilised a qualitative research methodology to assess the integration, functional performance and user acceptance of the intelligent Remote-Control Breaker (iRCB) based on the results of Functional Test Logs. The test-bed methodology adhered to a structured approach, as depicted in Figure 3.

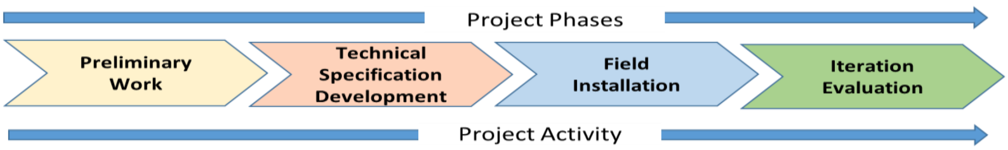

Figure 3: Test Bed Methodology

Key components of the study included:

- Qualitative Metrics: Observational data and test logs were reviewed to evaluate system behaviour under various operational conditions.
- User Feedback: Insights from substation operators were analysed to identify opportunities for refining interface design and enhancing functionality.

The process began with initial consultations with subject matter experts in SCADA systems, focusing on the workflow of remotely switching breakers within substations. These discussions informed the development of the iRCB Technical Specification document, outlining the critical functional features required for the system's development.
Functional tests using the iRCB Human-Machine Interface (HMI) were systematically conducted to evaluate key operational parameters, including:

- Point Status Monitoring: Assessment of the system's capability to provide real-time updates and accurate status reporting for single- and double-point indicators.
- Interlocking Conditions: Validation of safety mechanisms under predefined operational scenarios, ensuring adherence to safety standards and clear differentiation between "remote" and "local" control states.
- Command Execution: Evaluation of the precision and reliability of responses to remote commands, including successful execution of breaker ON/OFF operations.

These tests were conducted in a laboratory test-bed environment using RTUs (ABB 560, DF 1725, DF 1725 IED and SAE FW5-Gate). Comprehensive logs were meticulously maintained for each test to ensure repeatability and consistency in the evaluation process.

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Figure 4: Functional Test via HMI

The development of the iRCB's Human-Machine Interface (HMI) integrated features commonly utilised in Substation Control Systems (SCS), as illustrated in Figure 4. These features included real-time data visualisation through a Single Line Diagram (SLD), alarm management and sequence-of-events recording. The functionalities were designed to provide operators with seamless remote access and control via both computer and mobile devices.

Comparative assessments were conducted against traditional RCB systems to evaluate performance enhancements. The analysis specifically highlighted improvements in reliability, safety measures and operational efficiency.

Findings

The results demonstrated reliable functionality across all test scenarios, confirming the iRCB's ability to effectively manage remote operations within distribution network substations via its HMI features. The findings also verified the iRCB's compatibility and interoperability with various RTU systems.

To assess the performance of the Human-Machine Interface (HMI) developed for the Intelligent Remote-Control Breaker (iRCB), critical operations were rigorously tested. These tests focused on Functional Test Point Status Monitoring, Interlocking Conditions, Command Interlock and Control Functionality and Command Execution, utilising multiple RTUs (ABB 560, DF 1725, DF 1725 IED and SAE FW5-Gate).

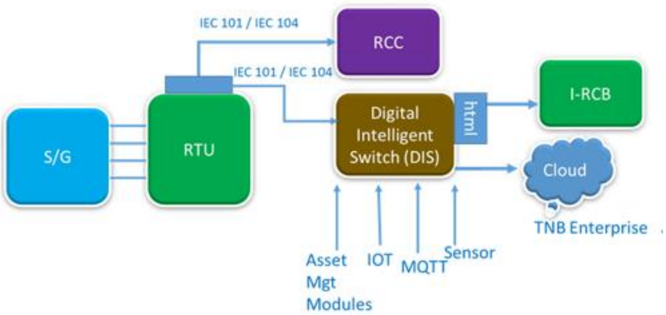

Figure 5: General Test-Bed Functional Testing Diagram

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Point Status Monitoring

Functional tests for single-point and double-point status monitoring demonstrated accurate representation of breaker statuses across all RTUs tested. The iRCB reliably displayed the states of breakers without any discrepancies. All RTUs (ABB 560, DF 1725, DF 1725 IED, and SAE FW5-Gate) successfully passed the status monitoring tests with no errors, ensuring dependable operation.

No	Signal Name			Result				
		0	1	Detail Bay	AML		CEL	
					Alarm	Time	Event	Time
1	FD1 OVERCURRENT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]
2	FD1 EARTH FAULT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]
3	FD2 OVERCURRENT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]
4	FD2 EARTH FAULT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]
5	TX1 OVERCURRENT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]
6	TX1 EARTH FAULT	NORMAL	OPERATE	[ ]	[ ]	[ ]	[ ]	[ ]

Figure 6: iRCB User Acceptance Test for Point Status Format

RTU	Functional Test – Point Status		
	Single Point	Double Point	Note
ABB 560	Pass	Pass	Able to show status of breaker with required setting parameters.
DF 1725	Pass	Pass	
DF 1725 IED	Pass	Pass	
SAE FW5-Gate	Pass	Pass	

Figure 7: Summary of iRCB Test Log Result for Point Status

Interlocking Condition Testing

Testing of interlocking conditions using an HMI tablet confirmed that all RTU brands correctly implemented interlocking logic. The iRCB effectively distinguished between "remote" and "local" control states, permitting only authorised actions in accordance with the configuration. The RTUs consistently passed the interlocking tests, demonstrating their capability to prevent unauthorised operations and uphold substation safety.

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RTU	Functional Test – Interlocking condition (HMI-Tablet)				
	Remote / Remote	Local / Remote	Local / Supervisory	Remote / Supervisory	Result
ABB 560	/	x	x	x	Pass
DF 1725	/	x	x	x	Pass
DF 1725 IED	/	x	x	x	Pass
SAE FW5-Gate	/	x	x	x	Pass

Figure 8: Summary of iRCB Test Log Result for Interlocking

Command Interlock and Control Functionality

Tests conducted to verify the iRCB's ability to issue control command on switching breakers ON or OFF, have produced successful results across all RTUs. Commands issued by the iRCB were accurately transmitted and executed by the RTUs (ABB 560, DF 1725, DF 1725 IED, and SAE FW5-Gate) without any failures, demonstrating its effective functionality through the developed HMI. These results confirmed the seamless integration and interoperability of the system for remote control operations.

RTU	Functional Test – Command Interlock		
	ON	OFF	Note
ABB 560	Pass	Pass	Successfully Control from iRCB-HMI
DF 1725	Pass	Pass	
DF 1725 IED	Pass	Pass	
SAE FW5-Gate	Pass	Pass	

Figure 9: Summary of iRCB Test Log Result for Control Functionality

The findings highlight the iRCB's effectiveness in improving substation operations as the following key outcomes:

Functional Test	Main Findings
Point Status Monitoring	The iRCB achieved 100% accuracy across all tested RTUs
Interlocking Conditions	All tested scenarios successfully maintained safety logic, effectively preventing unauthorized actions
Command Interlock and Control Functionality	The iRCB controlled breaker operations with zero errors across all tests

Figure 10: Summary of Functional Tests

The successful completion of these functional tests confirms the iRCB's potential as a dependable tool for remote monitoring and control, as demonstrated within the test-bed environment. By achieving compatibility with multiple RTUs, the iRCB exhibited its

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versatility and adaptability, making it well-suited for deployment across diverse substation settings. Its capability to enforce interlocking conditions and execute remote commands without errors further highlights its effectiveness in enhancing the reliability and efficiency of substation operations.

These results underscore the system's reliability and seamless integration with existing infrastructure. Additionally, the iRCB's advanced Human-Machine Interface (HMI) features provided operators with real-time insights, enabling improved decision-making during critical operations and reinforcing its role in modernising substation management.

Conclusion

The project successfully demonstrated the iRCB's potential to revolutionise substation operations by transitioning from traditional RCB systems to iRCB (remote breaker switching) through the completion of the required functional tests. The transformation from RCB to the digitalised iRCB addressed the limitations of conventional RCBs, offering enhanced functionality such as the elimination of space constraints. The iRCB is also scalable and compatible with multiple RTUs currently in use within power distribution substations, while its capabilities ensure improved safety for Authorised Persons (AP) during switching operations.

Looking ahead, future enhancements of the iRCB could include the integration of AI capabilities for predictive maintenance and machine learning algorithms. This would enable proactive management of power distribution networks, further advancing the modernisation and efficiency of substation operations.

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