Smart panel design for renewable energy generation

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ABSTRACT

The aim of this study is to design and develop a smart panel module specifically for solar power generation, which includes three critical functions: the automatic transfer switch (ATS), the automatic main failure (AMF), and capabilities for remote monitoring and control. The ATS and AMF features employ Haiwell AT12MOT Ethernet PLC control equipment in conjunction with the Haiwell B7H Ethernet IoT cloud HMI, both designed for remote operation through an IoT system and integrated with the Haiwell cloud application. The developed PLC program interacts with HMI software that is created using NB designer. Inputs from the PLC are monitored and managed via the Haiwell cloud application, which connects with the relay designated as input for the Haiwell AT12MOT PLC. The resulting design interfaces with the PLC output located within an electrical panel specifically designed to handle industrial loads. This research results in a smart panel capable of operating in an industrial context with a power capacity of 2,200 VA. It is noteworthy that during automatic operations, load transfers between solar power systems and PLN (the national grid company of Indonesia) do not occur instantaneously; instead, there is a delay of 10 seconds as the system stabilizes back to normal conditions.

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1. INTRODUCTION

The implementation of solar power plants within industrial settings is increasingly promoted, particularly to enhance the efficiency of electrical energy by harnessing available energy sources in proximity to the industry. The transmission of electrical energy from the solar power plant to various loads occurs through an electrical panel, which serves as a hub for control and monitoring. The necessity for control and monitoring arises from the fact that operational conditions are not always stable or typical [1]. Control panels can be operated either manually or automatically, allowing operators to manage them from both nearby locations and remote distances. Consequently, the development of a smart panel is essential for the effective control and monitoring of the solar power plant system [2], [3].

The electrical energy generated by solar modules cannot be automatically monitored via the internet; rather, it can solely be controlled and observed through a system implemented within the solar power plant environment [4], [5]. The application of internet of things (IoT) technology is crucial for the remote control and monitoring of smart panels. There is a need for a tool that facilitates direct and remote management of electric power usage, particularly through an Android application utilizing the IoT framework [6]. It remains prevalent for this IoT system to incorporate a microcontroller, while in industrial applications, control systems typically employ programmable logic controllers (PLC) alongside human-machine interfaces (HMI) as control panels and display systems [7], [8]. This applies to both on-grid photovoltaic power systems [9] and off-grid photovoltaic power systems [10]. Various studies addressing the implementation of IoT in solar power plants through smart panel control and monitoring systems have been documented in research conducted by authors in [11]-[13].

While previous research has focused on the intelligent management and oversight of solar power plants through IoT methodologies, the specific approaches employed have varied significantly. One study developed a system that enables wireless monitoring of photovoltaic energy generation utilizing a Raspberry Pi 3 [14]. Another investigation addressed the challenges of real-time surveillance of photovoltaic systems and the regulation of electricity supply for smart microgrid-PV applications through IoT technology [15]. Furthermore, a different study implemented photovoltaic panels as sources of electrical energy by leveraging IoT-based solutions with a PLC [16].

This research is focused on fulfilling the requirements of our partner, CV. Cotindo Jaya [17], which specializes in designing and manufacturing IoT-based smart control panels. The objective is to develop an IoT-based smart control panel that effectively addresses the implementation needs of the partners while satisfying customer demands for such technology. The development process involves programming the PLC, which interacts with HMI software developed using NB designer [18]. Inputs from the PLC are managed and monitored through the Haiwell cloud application [19], which connects to the relay designated as input for the Haiwell AT12MOT PLC [20].

2. METHOD

By identifying the requirements and technical specifications necessary for the development of intelligent control panels designed to manage solar power plants, it will assess both the essential materials needed for constructing these smart panels and the IoT components required for their remote operation and monitoring within a solar energy framework.

The project includes the design and implementation of a Haiwell AT12MOT Ethernet smart panel PLC intended for use in solar power plant management. Additionally, it encompasses the creation of graphical user interfaces (GUIs) for the Haiwell B7H Ethernet IoT cloud [21] smart panels, which facilitate control over solar energy systems. An IoT application program will be developed for use with the Blynk platform [22], further enhancing the functionality of smart panel applications in solar power generation. Moreover, this research will involve designing the visual interface of the IoT application on the Blynk platform [23], specifically for solar power plants. The effectiveness of these intelligent control panels will be evaluated through rigorous testing procedures in an IoT-based environment. Finally, this investigation will culminate in a scientific article that addresses advancements in smart control panels tailored for IoT applications in solar energy systems.

The smart control panel system at a solar power plant consists of several components, as illustrated in the block diagram in Figure 1. The block diagram explains how the smart panel connects to both local operators (via HMI) and remote users (via IoT cloud through the internet) [24]. It illustrates the interaction between the solar power plant, the PLC control system, and the remote monitoring/operation platform.

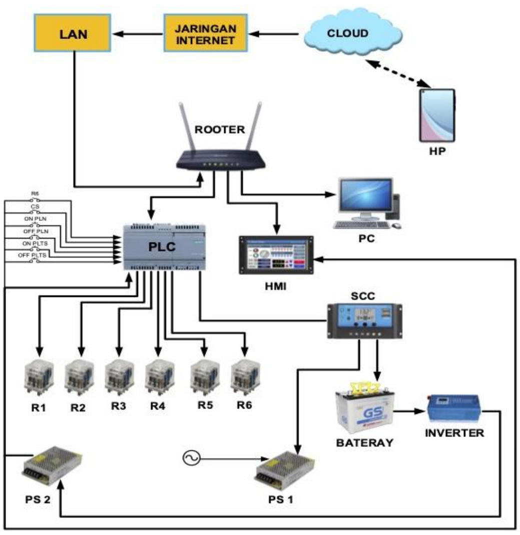

Figure 1. Block diagram of smart panel control

In order to facilitate the construction of an intelligent control panel, it is essential to establish a power circuit that serves as a reference for the wiring process involved in creating an IoT-based solar power plant smart control panel, as illustrated in Figure 2. It represents the electrical wiring concept inside the smart panel that manages the power flow between PLN (grid) and the solar power plant to supply the load. The PLC-controlled automatic transfer switch/automatic main failure (ATS/AMF) circuit and the load connection [25]. The circuit ensures stable, safe, and automatic switching between grid and solar power sources, either manually (push button/HMI) or automatically (PLC logic).

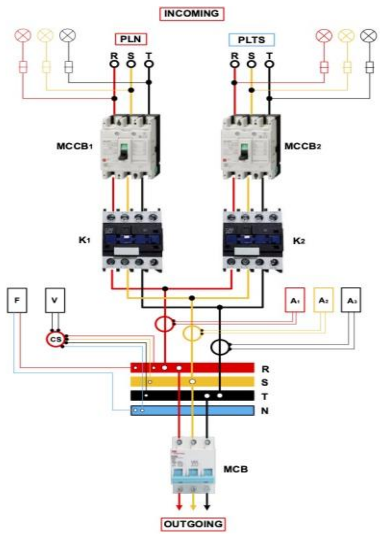

Figure 2. Wiring diagram of smart power circuit

3. RESULTS AND DISCUSSION

The physical and visual characteristics of the proposed smart panel are illustrated in Figure 3. In terms of its physical composition, the smart panel functions as an electrical enclosure that houses a PLC, relays, an HMI, an IoT module, contactors, switches, and indicators. Visually, it features a touchscreen HMI along with an IoT dashboard, enabling operators to oversee system status, modify settings, and manage operations either manually or automatically.

Figure 3. Physical appearance of the smart panel box

3.1. Design and create a Haiwell AT12MOT

The Haiwell AT12MOT PLC's input-output configuration is designed for ATS and AMF applications. The focus of the ladder diagram design for the Haiwell AT12MOT PLC is to establish a functional system that operates as an ATS/AMF. In this context, the ladder logic governs all components within the ATS/AMF circuit. The programming of the Haiwell AT12MOT PLC, which serves in the capacity of an ATS/AMF for solar power generation, adheres to the addressing conventions previously outlined.

Subsequently, a ladder diagram is developed, illustrating how the intelligent panel transitions automatically or manually between solar power and the PLN grid (ATS/AMF). Inputs such as grid status and control buttons dictate outputs like contactor relays, facilitating seamless power transfer and monitoring. Consequently, based on specific input conditions—such as grid availability, operational mode (automatic/manual), and solar energy availability—the ladder logic activates the appropriate relays to alternate between PLN and solar energy supply.

3.2. Display designs for HMI Haiwell B7H Ethernet IoT cloud smart panels

The design of the Haiwell B7H HMI display encompasses several stages, which are outlined as follows: i) The ATS/AMS monitoring stage is responsible for overseeing the automated operations of the system. This feature enables operators to easily track the status of the PLN interlock, identify which power source is active, and ascertain the condition of the utilized interlock. A key aspect of monitoring in this phase involves AMF functionality for automatic systems; ii) The ATS/AMF configuration allows for the adjustment of delay times tailored to both the generator and the existing electrical infrastructure; and iii) The ATS/AMF can function either through manual operation or automatically.

Figure 4 presents the design of the HMI developed for overseeing and managing the functionalities of smart panels within the solar–PLN system. This system encompasses capabilities for monitoring, configuration, and operation of ATS/AMF. It visually represents the operational status of the system, indicating whether it is drawing power from PLN or solar sources, provides options for modifying parameters such as delay times, and allows operators to toggle between manual and automatic modes. The graphical interface on the touchscreen serves as the primary interaction point for operators. The configuration of the Haiwell B7H HMI focuses on three essential functions: monitoring, settings, and operation of ATS/AMF. It features user-friendly graphical indicators, adjustable delay settings, and controls that support both manual and automated operations. Additionally, its integration with IoT technology facilitates local touch control alongside remote monitoring via a smartphone application linked to the smart panel in conjunction with the solar power plant.

Figure 4. HMI visual layout

The evaluation of current and voltage parameters in the smart panel utilizes incandescent lamps, each with a power rating of 200 watts. This load is structured into three phases consisting of five separate groups. Each phase accommodates a total load of 1,000 watts, with each group designated to handle a load of 200 watts. Measurements for current and voltage are carried out for both phase-to-phase and phase-to-neutral arrangements. Load increments are introduced according to the group distributions across all phases, specifically increasing by 200 watts per phase, culminating in a total addition of 600 watts for three-phase configurations. Assessments of current and voltage for the loads on the smart control panel are conducted through both manual and automated methods, which include: i) control via a push button situated on the door panel; ii) control using a touch interface on the HMI screen integrated within the panel; and iii) control through remote access facilitated by an IoT system operated via smartphone.

The assessment of the parameters related to the smart panel, which facilitates the management of solar power plant systems through push buttons. The findings obtained from the measurements and evaluations regarding the performance of the smart panel module in controlling the solar power plant system—specifically via the push button located on the panel door—are presented in Tables 1 and 2 for the manual and automatic methods, respectively.

Table 1. Measured parameters when smart panel is operated manually

Description	On	Off	Power			Voltage						Current		
			R (W)	S (W)	T (W)	RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	R (A)	S (A)	T (A)
PLN	X2=0	X3=1	0	0	0	0	0	0	0	0	0	0	0	0
			200	200	200	0	0	0	0	0	0	0	0	0
	X2=1	X3=0	0	0	0	385	391	386	220	225	229	0	0	0
			200	200	200	385	391	387	221	225	228	0,8	1	0,8
			400	400	400	384	390	386	220	224	228	1,7	2	1,6
			600	600	600	384	389	385	219	224	228	2,5	2	2,4
			800	800	800	383	389	384	219	223	227	3,4	3	3,3
			1000	1000	1000	382	388	384	219	223	227	4,2	4	4,1
Solar power plant	X8=0	X9=1	0	0	0	0	0	0	0	0	0	0	0	0
			200	200	200	0	0	0	0	0	0	0	0	0
	X8=1	X9=0	0	0	0	388	392	388	222	227	229	0	0	0
			200	200	200	387	392	389	222	226	229	0,8	1	0,8
			400	400	400	386	391	386	222	225	228	1,7	2	1,6
			600	600	600	386	390	386	221	225	228	2,4	2	2,3
			800	800	800	385	390	384	221	224	227	3,2	3	3,1
			1000	1000	1000	385	389	384	220	224	227	4	4	3,9

Table 2. Measured parameters when smart panel is operated automatically

Description	On	Off	Power			Voltage						Current			Information
			R (W)	S (W)	T (W)	RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	R (A)	S (A)	T (A)	
PLN	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when the solar power plant goes off
			200	200	200	0	0	0	0	0	0	0	0	0	
	1	0	0	0	0	385	391	386	220	225	229	0	0	0	Delay 10 seconds after the system returns to normal
			200	200	200	385	391	387	221	225	228	0,8	0,8	0,8	
			400	400	400	384	390	386	220	224	228	1,7	1,6	1,6	
			600	600	600	384	389	385	219	224	228	2,5	2,4	2,4	
			800	800	800	383	389	384	219	223	227	3,4	3,3	3,3	
			1000	1000	1000	382	388	384	219	223	227	4,2	4,1	4,1	
Solar power plant	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when PLN goes out
			200	200	200	0	0	0	0	0	0	0	0	0	
	1	0	0	0	0	388	392	388	222	227	229	0	0	0	Delay 10 seconds after the system returns to normal
			200	200	200	387	392	389	222	226	229	0,8	0,8	0,8	
			400	400	400	386	391	386	222	225	228	1,7	1,6	1,6	
			600	600	600	386	390	386	221	225	228	2,4	2,3	2,3	
			800	800	800	385	390	384	221	224	227	3,2	3,1	3,1	
			1000	1000	1000	385	389	384	220	224	227	4	3,9	3,9	

Table 1 demonstrates the effective operation of the manual mode of the smart panel. It verifies that both PLN and solar energy sources can reliably support loads of up to 1,000 W per phase, maintaining consistent voltage and proportional current when controlled through the push buttons on the panel. Table 2 confirms that the ATS/AMF automation system within the smart panel functions efficiently. This system is engineered to automatically switch between PLN and solar power in the event of a failure, incorporating a 10-second pause before resuming normal operation, while ensuring stable voltage and current performance across a range of load conditions. Next, the designed smart panel for managing the solar power plant system via touch interaction on the HMI screen located on the panel door is presented in Tables 3 and 4. The data indicates that the smart panel operates efficiently in both scenarios, whether controlled manually through the HMI or in an automatic ATS/AMF mode. The key difference between these operational modes lies in user convenience and dependability.

The system was managed via a smartphone using an IoT remote control, incorporating both manual and automatic approaches, as illustrated in Tables 5 and 6. These tables indicate that the reliability of the IoT remote control closely matches that of local control, evidenced by consistent voltage and current measurements. According to Table 5, there exists a minor delay of approximately five seconds attributable to network communication. Furthermore, Table 6 enhances the automation capabilities of the PLC's ATS/AMF, allowing for hands-free operation while still providing users with the option to monitor and assume manual control through smartphone applications.

Table 3. Measured parameters when HMI screen is touched manually

Description	On	Off	Power R (W)	S (W)	T (W)	Voltage RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	Current R (A)	S (A)	T (A)
PLN	M10=0	M11=1	0	0	0	0	0	0	0	0	0	0	0	0
			200	200	200	0	0	0	0	0	0	0	0	0
	M10=1	M11=10	0	0	0	385	391	386	220	225	229	0	0	0
			200	200	200	385	391	387	221	225	228	0,8	0,8	0,8
			400	400	400	384	390	386	220	224	228	1,7	1,6	1,6
			600	600	600	384	389	385	219	224	228	2,5	2,4	2,4
			800	800	800	383	389	384	219	223	227	3,4	3,3	3,3
			1000	1000	1000	382	388	384	219	223	227	4,2	4,1	4,1
Solar power plant	M20=0	M21=1	0	0	0	0	0	0	0	0	0	0	0	0
			200	200	200	0	0	0	0	0	0	0	0	0
	M20=1	M21=0	0	0	0	388	392	388	222	227	229	0	0	0
			200	200	200	387	392	389	222	226	229	0,78	0,78	0,78
			400	400	400	386	391	386	222	225	228	1,65	1,58	1,58
			600	600	600	386	390	386	221	225	228	2,35	2,25	2,25
			800	800	800	385	390	384	221	224	227	3,2	3,1	3,1
			1000	1000	1000	385	389	384	220	224	227	4	3,9	3,9

Table 4. Measured parameters when the HMI screen is touched automatically

Description	On	Off	Power R (W)	S (W)	T (W)	Voltage RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	Current R (A)	S (A)	T (A)	Information
PLN	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when the solar power plant goes off
			200	200	200	0	0	0	0	0	0	0	0	0	
	1	0	0	0	0	385	391	386	220	225	229	0	0	0	Delay 10 seconds after the system returns to normal
			200	200	200	385	391	387	221	225	228	1	1	1	
			400	400	400	384	390	386	220	224	228	2	2	2	
			600	600	600	384	389	385	219	224	228	3	2	2	
			800	800	800	383	389	384	219	223	227	3	3	3	
			1000	1000	1000	382	388	384	219	223	227	4	4	4	
Solar power plant	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when PLN goes out
			200	200	200	0	0	0	0	0	0	0	0	0	
	1	0	0	0	0	388	392	388	222	227	229	0	0	0	Delay 10 seconds after the system returns to normal
			200	200	200	387	392	389	222	226	229	1	1	1	
			400	400	400	386	391	386	222	225	228	2	2	2	
			600	600	600	386	390	386	221	225	228	2	2	2	
			800	800	800	385	390	384	221	224	227	3	3	3	
			1000	1000	1000	385	389	384	220	224	227	4	4	4	

Table 5. Measured parameters when using a smartphone

Description	On	Off	Power R (W)	S (W)	T (W)	Voltage RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	Current R (A)	S (A)	T (A)	Information
PLN	M10=0	M11=1	0	0	0	0	0	0	0	0	0	0	0	0	Delay 5 seconds after pressing the on/off button
			200	200	200	0	0	0	0	0	0	0	0	0	
	M10=1	M11=10	0	0	0	385	391	386	220	225	229	0	0	0	
			200	200	200	385	391	387	221	225	228	0,8	0,8	0,8	
			400	400	400	384	390	386	220	224	228	1,7	1,6	1,6	
			600	600	600	384	389	385	219	224	228	2,5	2,4	2,4	
			800	800	800	383	389	384	219	223	227	3,4	3,3	3,3	
			1000	1000	1000	382	388	384	219	223	227	4,2	4,1	4,1	
Solar power plant	M20=0	M21=1	0	0	0	0	0	0	0	0	0	0	0	0	Delay 5 seconds after pressing the on/off button
			200	200	200	0	0	0	0	0	0	0	0	0	
	M20=1	M21=0	0	0	0	388	392	388	222	227	229	0	0	0	
			200	200	200	387	392	389	222	226	229	0,8	0,8	0,8	
			400	400	400	386	391	386	222	225	228	1,7	1,6	1,6	
			600	600	600	386	390	386	221	225	228	2,4	2,3	2,3	
			800	800	800	385	390	384	221	224	227	3,2	3,1	3,1	
			1000	1000	1000	385	389	384	220	224	227	4	3,9	3,9	

Table 6. Measured parameters when remotely by IoT

Description	On	Off	Power			Voltage						Current			Information
			R (W)	S (W)	T (W)	RS (V)	ST (V)	TR (V)	RN (V)	TN (V)	SN (V)	R (A)	S (A)	T (A)	
PLN	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when
			200	200	200	0	0	0	0	0	0	0	0	0	the solar power plant goes off
	1	0	0	0	0	385	391	386	220	225	229	0	0	0	Delay 10 seconds
			200	200	200	385	391	387	221	225	228	0,8	0,8	0,8	after the system
			400	400	400	384	390	386	220	224	228	1,7	1,6	1,6	returns to normal
			600	600	600	384	389	385	219	224	228	2,5	2,4	2,4	
			800	800	800	383	389	384	219	223	227	3,4	3,3	3,3	
			1000	1000	1000	382	388	384	219	223	227	4,2	4,1	4,1	
Solar power	0	1	0	0	0	0	0	0	0	0	0	0	0	0	Auto switch when
plant			200	200	200	0	0	0	0	0	0	0	0	0	PLN goes out
	1	0	0	0	0	385	391	386	220	225	229	0	0	0	Delay 10 seconds
			200	200	200	385	391	387	221	225	228	0,8	0,8	0,8	after the system
			400	400	400	384	390	386	220	224	228	1,7	1,6	1,6	returns to normal
			600	600	600	384	389	385	219	224	228	2,5	2,4	2,4	
			800	800	800	383	389	384	219	223	227	3,4	3,3	3,3	
			1000	1000	1000	382	388	384	219	223	227	4,2	4,1	4,1	

In scenarios where the solar power plant is inactive, and the PLN system is functioning, power measurements across the phases—designated as R, S, and T—are recorded within a range of 0 to 1,000 W. The inter-phase voltage remains relatively constant, fluctuating between approximately 384 V and 390 V. Similarly, the phase-to-neutral voltage exhibits stability within a range of roughly 218 V to 224 V. Current in each phase shows a proportional increase in relation to the rising power levels, ranging from 0 to 4 A.

In contrast, when the solar power plant is operational, and PLN is not active, the additional power produced by the solar system also gradually increases from 0 to 1,000 W across all phases, reflecting conditions similar to those observed during PLN operation. The voltage measured between phases (R-S, S-T, and T-R) ranges from 388 V to 391 V; this value is slightly elevated compared to that recorded during PLN operations. The phase-to-neutral voltage (R-N, T-N, and S-N) varies from 219 V to 223 V. This rise in voltage within the solar power plant system can be attributed to minimal voltage losses encountered during electrical distribution. Such losses generally result from resistance found in conductors, connections, and equipment. Unlike PLN’s extensive distribution network that extends further away from generation sites to end-users, the solar power plant benefits from shorter distribution routes directly connecting its panels. It is important to note that during automated transitions between loads on the solar power plant and PLN or vice versa, these transfers do not occur instantaneously. Instead, a delay of ten seconds is implemented following system stabilization before normal operations can resume.

4. CONCLUSION

A sophisticated control panel for a solar power plant has been successfully designed and manufactured. Testing outcomes demonstrated that this advanced control panel functions efficiently as an ATS control system within an IoT framework. This intelligent control panel facilitates monitoring and operation through smartphones and laptops via the Haiwell cloud application. Assessments were conducted to evaluate both manual and automated measurements of current and voltage, which encompassed on/off pushbutton controls, in addition to manual and automatic readings managed through an HMI. Furthermore, both manual and automated methods were examined with remote control capabilities enabled by the IoT system.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state that no conflict of interest occurred when the research was conducted.

DATA AVAILABILITY

The authors of this article have provided the evidence supporting the available findings in https://drive.google.com/drive/folders/1_i-wA-Np8Xcqo7LL31fbxDhluD0A5Na9?usp=share_link.

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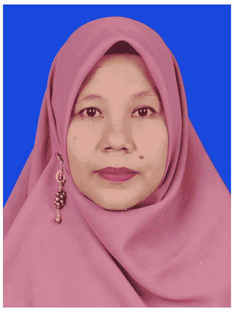

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