EMITOR: Jurnal Teknik Elektro

Design of a Solar Power System for a Four-Way Intersection Traffic Light Based on Time Scheduling Using PLC

Abil Huda*, Abdul Muis Prasetia, Linda Sartika, Obbie Ramdan
Department of Electrical Engineering – Universitas Borneo Tarakan
Tarakan, Indonesia
*abil@borneo.ac.id

Abstract – *Indonesia possesses significant potential for renewable energy utilization, particularly solar energy, with an average daily solar irradiance of 1,200 W/m². This condition is ideal for the development of Solar Power Plants (PLTS). On the other hand, traffic light systems, although critical for regulating vehicle flows, often rely on fixed time cycles that are inefficient under varying traffic volumes. This research addresses the gap in adaptive traffic signal systems by proposing a solar-powered traffic light configuration integrated with time-based scheduling and programmable control. To address this issue, an adaptive control system based on a Programmable Logic Controller (PLC) is proposed, utilizing a time scheduling method. The objective of this study is to develop and implement a PLC-based control system synchronized with PLTS infrastructure to optimize signal timing in response to real-time traffic flow variations. During the evening rush hour from 16:00 to 17:00, the total traffic light cycle duration is 199 seconds, distributed as follows: the South direction experiences a 147-second wait with 48 seconds of green light, the North waits for 165 seconds with 30 seconds of green light, the East waits for 166 seconds with 29 seconds of green light, and the West waits for 120 seconds with 75 seconds of green light. The yellow light is active for 3 seconds in all directions, and there is a 1-second red light buffer before transitioning between intersections. The findings confirm that the integration of PLTS and PLC with dynamic time scheduling enhances energy efficiency and improves traffic flow responsiveness at urban intersections.*

Keywords – *Renewable energy; PLTS; PLC; Traffic light; Time scheduling.*

I. Introduction

INDONESIA holds significant potential in renewable energy sources, with solar energy being one of the most abundant and widely utilized, particularly for power generation [1–3]. Traffic lights are generally used to regulate vehicle flow, prevent congestion at intersections, provide opportunities for pedestrians or other vehicles, and reduce the risk of vehicle conflicts. However, existing traffic light control systems typically rely on standalone methods, where the durations of green and red lights are fixed and constant. This approach is less effective for managing traffic conditions with varying vehicle volumes at different times [4].

With advancements in electronics technology, we are witnessing rapid progress in control systems. While earlier controller technology was based on analog systems with complex operations, current technology has evolved towards digital systems that are more practical and user-friendly. To enhance the performance and development of existing control systems, the Programmable Logic Controller (PLC) has emerged as a practical and intelligent solution for modern digital control needs [5].

Despite the critical role of traffic light systems, limited research has focused on integrating renewable energy and smart control to create adaptive systems that respond to real-time traffic conditions. Most existing systems still operate under fixed time cycles regardless of vehicle density. This presents an opportunity to develop a more efficient solution using solar power and programmable scheduling.

As urban motor vehicle numbers and population continue to grow, traffic management at critical intersections becomes increasingly important. Urban traffic management at critical intersections is becoming increasingly important as vehicle numbers and populations grow. Recent studies have focused on assessing traffic characteristics at major intersections [6] and developing intelligent traffic management systems [7]. Various approaches have been proposed, including self-

The manuscript was received on March 14, 2025, revised on May 8, 2025, and published online on July 25, 2025. Emitor is a Journal of Electrical Engineering at Universitas Muhammadiyah Surakarta with ISSN (Print) 1411 – 8890 and ISSN (Online) 2541 – 4518, holding Sinta 3 accreditation. It is accessible at https://journals2.ums.ac.id/index.php/emitor/index.

organized intersection control for both motorized and non-motorized traffic [8], autonomous vehicle management [9], and adaptive traffic light control systems [10]. The integration of emerging technologies such as IoT, RFID, and connected/autonomous vehicles has shown promise in improving traffic flow and reducing congestion [11, 12]. Researchers have also emphasized the need for comprehensive traffic management systems that address data collection, signal optimization, and vehicle trajectory planning [13]. These advancements aim to enhance intersection efficiency, reduce travel times, and mitigate environmental impacts in urban areas.

Conventional energy resources are becoming more limited and expensive, whereas Solar Power Plants (PLTS) offer an environmentally friendly solution for power supply. Implementing PLTS in traffic light systems can reduce reliance on conventional energy sources. Effective time management in traffic light control is crucial to avoid congestion and ensure smooth traffic flow. By integrating time scheduling into the system, vehicles can pass through intersections more efficiently, minimizing wait times.

PLC, as a highly flexible electronic device, can be used to control various automated systems. In this context, PLCs can manage traffic lights based on predefined time schedules. The implementation of PLTS can reduce the operational costs of traffic light systems by lowering grid electricity consumption. This step also reduces maintenance costs associated with traffic management devices.

This research proposes an innovative combination of PLTS and PLC-based scheduling to address both energy sustainability and dynamic traffic control. By introducing ladder diagrams as the implementation method, the system can be customized to optimize signal timing for varying traffic densities.

This research is expected to provide a positive contribution by improving traffic light control at four-way intersections, thereby enhancing the quality of urban transportation [14].

Therefore, the objectives of this study are to: (1) design a solar-powered traffic light system with integrated PLC control, (2) implement a time-scheduled ladder diagram on the PLC, and (3) evaluate the system's effectiveness in real-world traffic flow scenarios.

Based on the background described, the problem statements of this research are as follows: designing a PLTS-integrated traffic light system, developing a PLC for time-scheduled traffic light operation, and designing a ladder diagram using PLC to implement a time-scheduling-based traffic light control system for four-way intersections.

II. Research Methods

The capacity of photovoltaic (PV) systems to convert solar radiation into electrical energy is influenced by several factors, including system requirements, the level of solar insolation, and the DC/AC ratio, which is typically within the range of 1.1 to 1.3 in solar power plant (PLTS) installations [15–17]. To calculate the power required (P_{req}) by the system, Equation 1 can be utilized.

$$P_{req} = \frac{\text{Total Energy (Wh)}}{\text{Full Sun Hours (H per day)}} \tag{1}$$

Once the required power is determined, the number of photovoltaic modules needed ($N_{modules}$) can be calculated using Equation 2 [5].

$$N_{modules} = \frac{P_{req}}{\text{Module Capacity}} \tag{2}$$

To meet daily energy demands, the battery capacity required can be calculated using Equations 3 and 4, where t is the charging time in hours, C is the battery capacity in ampere-hours (Ah), I is the average current in amperes (A), and P and V are the total load in watts (W) and the required voltage in volts (V), respectively [1, 18–22].

$$I = \frac{P}{V} \tag{3}$$

$$C = I \times t \tag{4}$$

The inverter capacity (P_{Inv}) must account for peak load power and a safety factor of 1.25 [23–25]. The inverter power capacity (P_{ACload}) is calculated by multiplying the load power by the safety factor, as shown in Equation 5.

$$P_{Inv} = P_{ACload} \times 1.25 \tag{5}$$

For traffic flow analysis, the traffic volume for each type of movement (left turn, straight, and right turn) is converted into passenger car units per hour (pcu/hr) using the passenger car equivalent (PCE) factor. The formula for calculating traffic flow (Q) is shown in Equation 6, where Q_{LV}, Q_{HV}, and Q_{MC} represent light vehicles, heavy vehicles, and motorcycles, respectively.

$$Q = Q_{LV} + Q_{HV} \times emp_{HV} + Q_{MC} \times emp_{MC} \tag{6}$$

The basic saturation flow rate (S_O) for each approach can be calculated using Equation 7.

$$S_O = 600 \times We \quad \text{sfrac\{pcu\}\{hr green\}} \tag{7}$$

The adjusted saturation flow rate (S) is determined using Equation 8, obtained by multiplying the basic saturation flow rate by adjustment factors:

$$S = S_O \times F_{CS} \times F_{SF} \times F_G \times F_P \times F_{RT} \times F_{LT} \tag{8}$$

To determine the saturation flow ratio:

$$FR = \frac{Q}{S} \tag{9}$$

Then, calculate the intersection flow ratio (IFR) using Equation 10:

$$IFR = \sum(FR_{crit}) \tag{10}$$

The preliminary cycle time before adjustment (C_{ua}) is calculated based on lost time interval (LTI) and intersection flow ratio, as shown in Equation 11:

$$C_{ua} = \frac{(1.5 \times LTI + 5)}{1 - IFR} \tag{11}$$

The green time for each phase (g_i) is calculated by:

$$g_i = (C_{ua} - LTI) \times Pri \tag{12}$$

The adjusted cycle time (C) is then:

$$C = \sum g + LTI \tag{13}$$

By following these steps, the calculations for PLTS power capacity, traffic flow, and signal cycle time can be simplified, enhancing efficiency in energy system planning and traffic management.

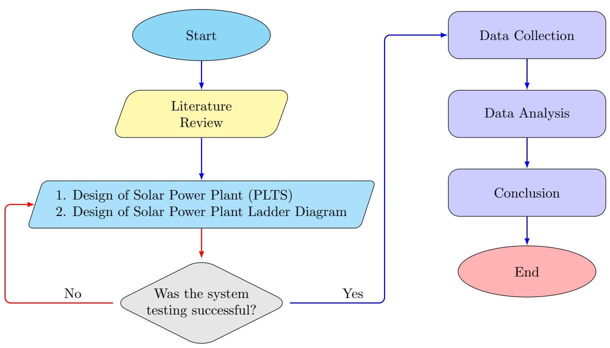

Figure 1: Research flowchart

Based on the research flowchart in Figure 1, the study begins with a literature review to explore various sources, including journals and books. Subsequently, the Solar Power System (PLTS) and ladder diagram for the PLC are designed to harness solar energy, reduce conventional electricity consumption, and lower operational costs. The ladder diagram is intended to control traffic lights based on time scheduling tailored to the specific requirements of the location. System testing aims to ensure that all components function properly. The data collection process is crucial to addressing the research questions, followed by simulation result analysis to evaluate the achievement of objectives. If the objectives are met, conclusions will be drawn to confirm that the proposed concept is effective in solving the identified problems and achieving the research goals. The results and discussion will elaborate on the findings and demonstrate the feasibility and effectiveness of the proposed system.

III. Results and Discussion

This section discusses the results of the PLTS design for four-way traffic lights based on time scheduling using a PLC. The objective of this testing is to evaluate the system's performance and effectiveness in traffic management and ensure that the system operates as intended.

i. PLTS System Design

Before proceeding to the design results, it is crucial to calculate the total energy required to support the optimal performance of the PLTS system. Table 1 summarizes the total energy requirements.

Table 1: Total Energy Requirements

Load	Power (W)	Duration (h)	Energy (Wh)
PLC	45	2	90
Lamp 2 W (12 Unit)	24	2	48
Total			**138**

Using the data in Table 1, the total energy consumption (Wh) is calculated and divided by the full sunlight duration (hours), using Equation 1:

$$P_{req} = \frac{138\ \text{Wh}}{5\ \text{h}} = 27.6\ \text{W} \tag{14}$$

After determining the required power, the number of modules needed is computed using Equation 2:

$$N_{modules} = \frac{27.6\ \text{W}}{50\ \text{Wp}} = 0.552\ \text{modules} \tag{15}$$

Next, the battery capacity is calculated to meet the energy needs. First, the average current is determined using Equation 3:

$$I = \frac{69\ \text{W}}{12\ \text{V}} = 5.75\ \text{A} \tag{16}$$

Then the battery capacity is calculated using Equation 4:

$$C = 5.75\ \text{A} \times 5\ \text{h} = 28.75\ \text{Ah} \tag{17}$$

After determining the battery capacity, the inverter capacity is calculated as shown in Equation 5:

$$P_{Inv} = 69\ \text{W} \times 1.25 = 86.25\ \text{W} \tag{18}$$

Although the calculation yields a requirement of 86.25 W, an inverter with a capacity of 220 W or higher is selected to ensure the traffic light system operates reliably and accommodates possible energy fluctuations. A larger inverter capacity increases system resilience and reduces performance risk.

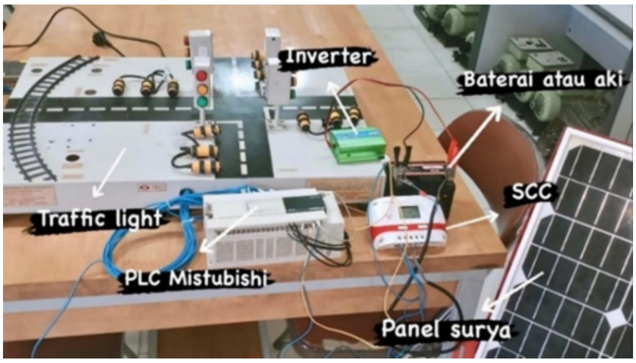

Figure 2: Design of PLTS for four-way traffic lights based on time scheduling using PLC

Figure 2 illustrates the design of a solar power plant (PLTS) for a four-way traffic light system based on time scheduling controlled by a programmable logic controller (PLC). The solar panel converts sunlight into electrical energy, while the inverter transforms the direct current (DC) generated by the solar panel into alternating current (AC) required by the traffic light module. The battery stores the electrical energy produced for use during periods without sunlight (e.g., nighttime or cloudy weather). A charge controller manages the battery's charging process to prevent overcharging or over-discharging. The PLC controls the traffic light system according to a preprogrammed time scheduling framework.

ii. Adjustment of Traffic Light Timing

The adjustment of traffic light timings requires an analysis based on traffic volume data collected over seven days (from 07:00 to 18:00) at 15-minute intervals. Data from Monday, representing the highest traffic volumes during peak hours, is used for capacity, delay, and queue analysis to optimize traffic light timing at the four-way intersection.

iii. Geometric, Traffic, and Environmental Data

Geometric data include approach codes, environmental types, side friction levels, medians, slopes, direct left turns, parking vehicle distances, and approach widths (MKJI, 1997). This data is collected manually via direct field measurements [26–28]. Table 2 presents the geometric conditions at the Kol. Yos Sudarso and Jalan H. Adam Malik intersection.

Table 2: Geometric Conditions at the Kol. Yos Sudarso and Jalan H. Adam Malik Intersection

Code	Road Type	Side Friction	Median	LT Direct	WA	Wentry	WLTOR	Wexit
S	Commercial	Low	Yes	Yes	19	14	5	7
B	Commercial	Low	Yes	Yes	9	4	5	9
T	Commercial	Low	Yes	Yes	8	5	3	6
U	Commercial	Low	Yes	Yes	13	8.5	4.5	8

iv. Traffic Flow Data

Traffic flow data is gathered from field surveys in units of vehicles per hour and converted into passenger car units per hour (pcu/h) based on approach plans. Table 3 contains the converted traffic flow data.

Table 3: Vehicle Traffic Flow Data (Excerpted)

Time	LT	ST	RT	LT	ST	RT	LT	ST	RT	LT	ST	RT
		South			North			East			West	
07:00–08:00	136	443	177	90	89	109	40	34	30	38	56	90
12:00–13:00	73	432	165	73	121	121	48	64	46	45	24	129
16:00–17:00	215	470	183	117	109	127	37	43	84	56	223	180

v. Determining Signal Timing and Capacity

The protected approach traffic flow (Q) is calculated using Equation 6:

$$Q_{\text{South}} = 215 + (0 \times 1.3) + (539 \times 0.4) = 1524.5 \text{ pcu/h}$$
$$Q_{\text{North}} = 579 \text{ pcu/h}$$
$$Q_{\text{East}} = 328.7 \text{ pcu/h}$$
$$Q_{\text{West}} = 679.6 \text{ pcu/h}$$

Using Equation 7, the basic saturation flow rates (S_O) are:

$$S_{O,\text{North}} = 600 \times 14 = 8400 \text{ pcu/h}$$
$$S_{O,\text{East}} = 600 \times 4 = 2400 \text{ pcu/h}$$
$$S_{O,\text{South}} = 600 \times 5 = 3000 \text{ pcu/h}$$
$$S_{O,\text{West}} = 600 \times 8.5 = 5100 \text{ pcu/h}$$

With $F_{CS} = 0.83$, $F_{SF} = 0.97$, and the rest of the factors = 1, the adjusted saturation flows S using Equation 8 are:

$$S_{\text{South}} = 8400 \times 0.83 \times 0.97 = 6762.8 \text{ pcu/h}$$
$$S_{\text{North}} = 2400 \times 0.83 \times 0.97 = 4106 \text{ pcu/h}$$
$$S_{\text{East}} = 3000 \times 0.83 \times 0.97 = 2415.3 \text{ pcu/h}$$
$$S_{\text{West}} = 5100 \times 0.83 \times 0.97 = 1932.2 \text{ pcu/h}$$

The saturation flow ratios using Equation 9:

$$FR_{\text{South}} = \frac{1524.5}{6762.8} = 0.2254$$
$$FR_{\text{North}} = \frac{579}{4106} = 0.1410$$
$$FR_{\text{East}} = \frac{328.7}{2415.3} = 0.1361$$
$$FR_{\text{West}} = \frac{679.6}{1932.2} = 0.3517$$
$$\sum FR_{crit} = 0.8543$$

Using Equation 11, the preliminary cycle time is:

$$C_{ua} = \frac{1.5 \times 16 + 5}{1 - 0.8543} = 199 \text{ seconds}$$

Green times per phase using Equation 12:

$$g_{\text{South}} = (199 - 16) \times \frac{0.2254}{0.8543} = 48.28 \text{ sec}$$
$$g_{\text{North}} = (199 - 16) \times \frac{0.1410}{0.8543} = 30.20 \text{ sec}$$
$$g_{\text{East}} = (199 - 16) \times \frac{0.1361}{0.8543} = 29.15 \text{ sec}$$
$$g_{\text{West}} = (199 - 16) \times \frac{0.3517}{0.8543} = 75.33 \text{ sec}$$
$$\sum g_i = 182.96 \text{ sec}$$

Final adjusted cycle time using Equation 13:

$$C = 182.96 + 16 = 198.96 \text{ seconds} \approx 199 \text{ seconds}$$

Table 4: Cycle Time of Each Phase

Approach	Red (R)	Yellow (Y)	Green (G)	All-Red (AR)	Cycle Time (CT)
South	147	3	48	1	199
North	165	3	30	1	199
East	166	3	29	1	199
West	120	3	75	1	199

Based on the calculations, the total intersection cycle time is 199 seconds. Green times are dynamically allocated to each direction based on traffic volume, while a consistent 3-second yellow and 1-second all-red time ensures safety during transitions. These settings form the basis for constructing the traffic signal timing diagram and optimizing traffic flow at the intersection.

vi. Vehicle Density for Specific Periods

Table 3 illustrates traffic flow data collected on Monday, showing adjustments to green light durations based on vehicle density levels at different times of the day:

1. **Traffic Condition Type A (07:00–08:00):** During this period, with a flow rate of 4,271 vehicles/hour (moderate traffic), the green light duration was slightly extended to reduce queuing.
2. **Traffic Condition Type B (12:00–13:00):** With a flow rate of 3,821 vehicles/hour (normal traffic), the green light duration remained at the standard setting with minimal adjustments.
3. **Traffic Condition Type C (16:00–17:00):** During peak hours with a volume of 4,911 vehicles/hour (heavy traffic), green light durations were significantly extended to prevent congestion.

The vehicle volume-based traffic control system dynamically adjusts green light durations for lanes experiencing peak vehicle volumes. Using consistent calculation methods and the equations referenced previously, the following adjustments were derived:

1. **07:00–08:00:** Southbound receives 20 seconds, Northbound 11 seconds, Eastbound 11 seconds, and Westbound 19 seconds of green light.
2. **12:00–13:00:** Southbound receives 16 seconds, Northbound 11 seconds, Eastbound 12 seconds, and Westbound 18 seconds.
3. **16:00–17:00:** Southbound receives 48 seconds, Northbound 30 seconds, Eastbound 29 seconds, and Westbound 75 seconds.

These variations demonstrate the necessity of implementing time scheduling to optimize traffic signal settings based on vehicle volume at different times. Table 5 presents the proposed time scheduling design aimed at enhancing traffic flow efficiency and minimizing congestion. Notation: R = Red, Y = Yellow, G = Green, AR = All Red, CT = Cycle Time.

Table 5: Design of Time Scheduling on Traffic Lights

Time Period	Approach	R (s)	Y (s)	G (s)	AR (s)	CT (s)
16:00–17:00	South	147	3	48	1	199
	North	165	3	30	1	199
	East	166	3	29	1	199
	West	120	3	75	1	199
12:00–13:00	South	55	3	16	1	75
	North	60	3	11	1	75
	East	59	3	12	1	75
	West	53	3	18	1	75
07:00–08:00	South	54	3	20	1	78
	North	63	3	11	1	78
	East	63	3	11	1	78
	West	55	3	19	1	78

Table 5 outlines the traffic light scheduling configuration tailored to varying traffic conditions. The logic is as follows:

1. **Red Light:** Baseline red duration is 1 second (all-red) per MKJI standards, with additional waiting time based on calculated green times. For example, in peak hours, Southbound = 147 s, Northbound = 165 s, Eastbound = 166 s, and Westbound = 120 s.
2. **Yellow Light:** A constant 3-second duration across all directions and time periods, ensuring a safe tran-

sition interval.

3. **Green Light:** Dynamically adjusted according to traffic conditions:
   (a) *16:00–17:00 (Heavy Traffic):* South = 48 s, North = 30 s, East = 29 s, West = 75 s.
   (b) *12:00–13:00 (Moderate):* South = 16 s, North = 11 s, East = 12 s, West = 18 s.
   (c) *07:00–08:00 (Morning Rush):* South = 20 s, North = 11 s, East = 11 s, West = 19 s.

By employing flexible scheduling, this system is designed to optimize traffic flow and reduce congestion at intersections effectively, ensuring better responsiveness to varying demand throughout the day.

vii. Testing the Ladder Diagram for the Traffic Light

Figure 3 illustrates the system state when the green light is active. Upon program execution, a coil in the normally open (NO) position allows current flow to the timer. This timer controls the duration of the green light as per the defined schedule. While current flows, output Y001 is activated, illuminating the green light at Intersection 1 and signaling vehicles to proceed. Once the timer T0 reaches its preset duration, or the time elapses, the normally closed (NC) coil of T0 opens the circuit, cutting off the current flow and deactivating the green light.

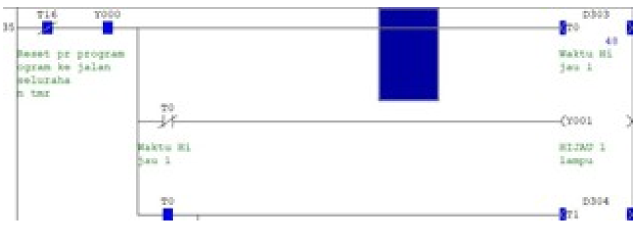

Figure 3: Condition when the green light is active

viii. Traffic Volume Type C Condition

At 16:00, contact D102 is activated to extend the green light duration, addressing increased vehicle volume and alleviating congestion. By 17:00, contact RTC is deactivated, and the system reverts to its default configuration, as illustrated in Figures 4 and 5.

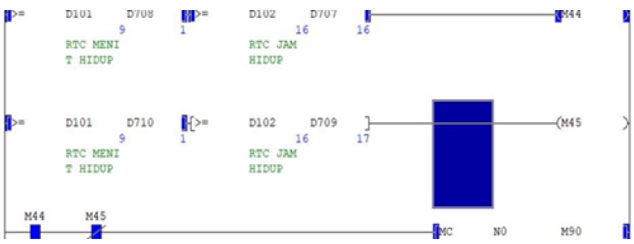

Figure 4: Ladder diagram of traffic light timer at 16:00–17:00

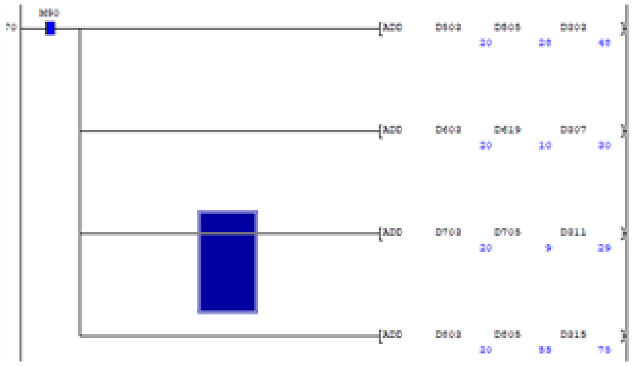

Figure 5: Ladder diagram of traffic light timer and green light at 16:00–17:00

The previously displayed ladder diagram demonstrates four distinct ADD instructions, each performing a summation between two registers and storing the result in a designated register. These operations are triggered when signal M90 is active. This program constitutes a critical component of the traffic light control system, specifically for green light timing. The summation process calculates or adjusts the light duration based on predefined input parameters.

Testing of traffic light timing at each intersection yielded results aligned with expectations. The system successfully managed light durations based on vehicle volumes and time schedules, ensuring smooth and safe traffic flow. Figure 6 illustrates the implementation of the system on the traffic light module, showing how the signal settings function to automatically regulate traffic conditions at the intersection. When connected to the traffic light module, the durations of green, yellow, and red lights are controlled by the PLC program using time scheduling. Timing at each intersection is optimized in real-time, allowing the system to adapt dynamically to changing traffic conditions.

IV. Conclusion

The design of a solar-powered traffic light system (PLTS) for a four-way intersection based on time scheduling and utilizing a Mitsubishi FX3U PLC with GX-Developer software comprises two main components: the PLTS subsystem (solar panels, SCC, battery, inverter) and the control system implemented using PLC technology.

During testing, challenges arose when connecting the PLTS to the PLC and traffic light module due to insufficient battery capacity (12V, 5Ah) to support the 220W inverter. Nevertheless, the use of PLC enhanced the accuracy and flexibility of traffic light scheduling, enabling real-time responses to traffic changes.

For example, during peak hours (16:00–17:00), the total cycle time was 199 seconds. Waiting and

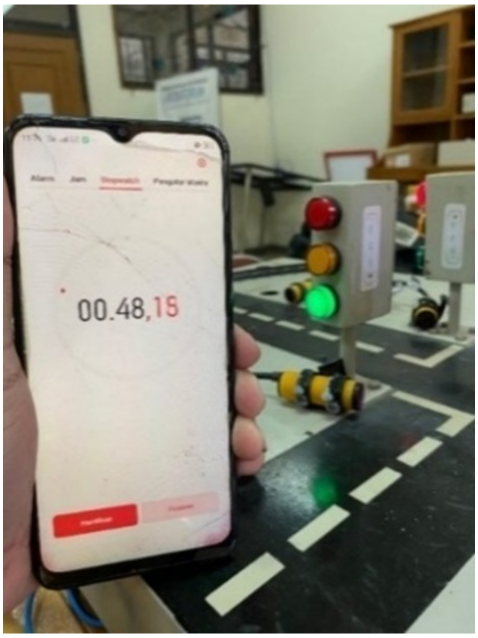

Figure 6: Traffic light system on the module

green light durations were as follows: southbound for 147 seconds with 48 seconds green, northbound for 165 seconds with 30 seconds green, eastbound for 166 seconds with 29 seconds green, and westbound for 120 seconds with 75 seconds green. Yellow lights were consistently set to 3 seconds across all directions, with a 1-second red light overlap before transitions.

During normal hours (12:00–13:00), the total cycle time was reduced to 75 seconds. Waiting and green light durations were: southbound for 55 seconds with 16 seconds green, northbound for 60 seconds with 11 seconds green, eastbound for 59 seconds with 12 seconds green, and westbound for 53 seconds with 18 seconds green. The yellow light duration remained at 3 seconds across all directions, with a 1-second red overlap.

System testing using ladder diagrams in GX-Developer confirmed that the input and output functions of the lights corresponded accurately with the programmed design.

Acknowledgment

I want to express my deepest gratitude to my Supervising Lecturer for their invaluable guidance and unwavering support throughout the completion of this thesis. Their insightful feedback and encouragement have been instrumental in shaping the quality of this work. Without their expertise and mentorship, this research would not have been possible.

References

[1] A. W. Hasanah, T. Koerniawan, and Y. Yuliansyah, “Kajian kualitas daya listrik plts sistem off-grid di stt-pln,” *Energi & Kelistrikan*, vol. 10, pp. 93–101, 2018.

[2] D. F. Silalahi, A. Blakers, M. Stocks, B. Lu, C. Cheng, and L. Hayes, “Indonesia’s vast solar energy potential,” *Energies*, vol. 14, p. 5424, 2021. [Online]. Available: https://doi.org/10.3390/en14175424

[3] V. Dwisari, S. Sudarti, and Y. Yushardi, “Pemanfaatan energi matahari: masa depan energi terbarukan,” *OPTIKA: Jurnal Pendidikan Fisika*, vol. 7, no. 2, pp. 376–384, 2023.

[4] E. Nurhidayat, A. I. Septiana, A. N. Putra, A. Syaripudin, and D. I. Saputra, “Desain sistem kontrol traffic light adaptif pada empat persimpangan berbasis plc omron cp1e,” *Jurnal Otomasi Kontrol dan Instrumentasi*, vol. 10, p. 485835, 2018.

[5] S. Sudarmaji, “Sistem kerja pengendali otomatis lampu traffic light pada persimpangan 4 (empat) jalan raya menggunakan programmable logic controller (plc),” *Turbo: Jurnal Program Studi Teknik Mesin*, vol. 2, 2013.

[6] S. Nepali, S. S. Bohara, N. Lama, and R. Rabin Thapa, “Assessment of Traffic Characteristic at Major Urban Road Intersection of Kathmandu Valley: A Case Study of Khanivivag, Kesarmahal, and Narayanhiti Intersections,” *Journal of Civil and Construction Engineering*, vol. 10, no. 1, pp. 22–31, feb 14 2024. [Online]. Available: http://dx.doi.org/10.46610/jocce.2024.v010i01.003

[7] R. A. Ramanathan, B. R, R. S. Bama Krishna, and M. P. Selvan, “A Review of Intelligent Traffic Management Systems,” in *2023 7th International Conference on Trends in Electronics and Informatics (ICOEI)*. IEEE, apr 11 2023, pp. 1652–1657. [Online]. Available: http://dx.doi.org/10.1109/ICOEI56765.2023.10126024

[8] W. Viriyasitavat, “Self-organized intersection control management for motorized and non-motorized traffic,” in *2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC)*. IEEE, 1 2015, pp. 437–442. [Online]. Available: http://dx.doi.org/10.1109/CCNC.2015.7158015

[9] R. Naumann, R. Rasche, and J. Tacken, “Managing autonomous vehicles at intersections,” *IEEE Intelligent Systems*, vol. 13, no. 3, pp. 82–86, 5 1998. [Online]. Available: http://dx.doi.org/10.1109/5254.683216

[10] V. Slavych and M. Savchenko, “Criterion MODEL OF MOTOR VEHICLE TRAFFIC MANAGEMENT,” *Bulletin of the National Technical University «KhPI». Series: Automobile and Tractor Construction*, no. 2, pp. 65–70, nov 28 2024. [Online]. Available: http://dx.doi.org/10.20998/2078-6840.2024.2.08

[11] O. Avatefipour and F. Sadry, “Traffic Management System Using IoT Technology - A Comparative Review,” in *2018 IEEE International Conference on Electro/Information Technology (EIT)*. IEEE, 5 2018, pp. 1041–1047. [Online]. Available: http://dx.doi.org/10.1109/EIT.2018.8500246

[12] Z. Wu and B. Waterson, “Urban Intersection Management Strategies for Autonomous/Connected/Conventional Vehicle Fleet Mixtures,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 8, pp. 12 084–12 093, 8 2022. [Online]. Available: http://dx.doi.org/10.1109/tits.2021.3109783

[13] A. Ait Ouallane, A. Bakali, A. Bahnasse, S. Broumi, and M. Talea, "Fusion of engineering insights and emerging trends: Intelligent urban traffic management system," *Information Fusion*, vol. 88, pp. 218–248, 12 2022. [Online]. Available: http://dx.doi.org/10.1016/j.inffus.2022.07.020

[14] J. M. R. N. M. T. Bawalo, "Perencanaan pembangkit listrik tenaga surya di rumah kebun desa ammat kabupaten kepulauan talaud," 2021, unpublished.

[15] T. Kaewnukultorn, S. B. Sepúlveda-Mora, and S. Hegedus, "The impacts of dc/ac ratio, battery dispatch, and degradation on financial evaluation of bifacial pv+bess systems," *Renewable Energy*, vol. 236, no. 2, p. 121402, 2024. [Online]. Available: https://doi.org/10.1016/j.ijhydene.2022.06.098

[16] M. F. Beyoğlu and M. Demirtaş, "Determination of optimal dc/ac ratio for grid-connected photovoltaic systems," *CBUJOS*, vol. 19, no. 1, pp. 19–29, 2023.

[17] I. Buratynskyi, T. Nechaieva, S. Shulzhenko, and N. Ivanenko, "The optimization of pv-plant's dc/ac equipment ratio using the non-linear least-cost model," in *2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*, 2021, pp. 358–362. [Online]. Available: https://doi.org/10.1109/UKRCON53503.2021.9575720

[18] S. Q. K. Suhaflam and N. I. Mayasari, "Rancang bangun sistem kontrol suplai beban plts menggunakan pulse width modulation (pwm) dan real time clock (rtc)," Ph.D. dissertation, Politeknik Negeri Ujung Pandang, 2021.

[19] Y. Marniati, A. Suyadi, H. Yani, and S. Marsus, "Analyses of battery usage characteristic in electrical car," *Journal of Physics: Conference Series*, vol. 1500, no. 1, p. 012008, Apr. 2020. [Online]. Available: https://doi.org/10.1088/1742-6596/1500/1/012008

[20] C. Prapanukool and S. Chaitusaney, "An appropriate battery capacity and operation schedule of battery energy storage system for pv rooftop with net-metering scheme," in *Proc. 2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Phuket, Thailand, 2017, pp. 222–225. [Online]. Available: https://doi.org/10.1109/ECTICon.2017.8096213

[21] K. Hidayat, M. C. Hasani, N. A. Mardiyah, and M. Effendy, "Strategi pengisian baterai pada sistem panel surya standalone berbasis kontrol pi multi-loop," *Jurnal Teknik Elektro*, vol. 13, no. 1, pp. 25–33, 2021.

[22] D. Irmanto and J. Kurniawan, "Analysis of battery charging using 100 wp solar cells as power supply for water desalination equipment: Technology," *Jurnal Elkasista*, vol. 5, no. 2, pp. 21–31, 2024.

[23] B. L. Sitorus, R. Samosir, and M. D. Sebayang, "Design of hybrid power plants (solar module-generator set)," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 878, no. 1, p. 012070, 2021.

[24] J. Good and J. X. Johnson, "Impact of inverter loading ratio on solar photovoltaic system performance," *Applied Energy*, vol. 177, pp. 475–486, 2016.

[25] A. Jahid and S. Hossain, "Dimensioning of zero grid electricity cellular networking with solar powered off-grid bs," in *2017 2nd International Conference on Electrical & Electronic Engineering (ICEEE)*, Rajshahi, Bangladesh, 2017, pp. 1–4. [Online]. Available: https://doi.org/10.1109/CEEE.2017.8412862

[26] M. Vanidi, "Analisis kinerja simpang empat bersinyal glugur darat medan timur sampai tahun 2031," Undergraduate thesis, Program Studi Teknik Sipil Fakultas Teknik, Universitas Muhammadiyah Sumatera Utara Medan, 2021.

[27] M. G. Kashani, M. Mobarrez, and S. Bhattacharya, "Smart inverter volt-watt control design in high pv-penetrated distribution systems," *IEEE Transactions on Industry Applications*, vol. 55, no. 2, pp. 1147–1156, 2018.

[28] A. M. Prasetia, L. Sartika, S. Nurholifah, and I. A. Syarif, "Analisis waktu sinyal traffic light pada simpang empat menggunakan pkji," *Borneo Engineering: Jurnal Teknik Sipil*, vol. 8, no. 2, pp. 227–237, 2024.