



**PIOONER RESEARCH IN
ELECTRICAL, ELECTRONIC AND
COMMUNICATION ENGINEERING**



All Sciences Academy

***PIOONER RESEARCH
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Asst. Prof. Dr. Umut ÖZKAYA





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Microwave Signal Conditioning for Solar Panel Optimization Using Schottky Diodes

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ABSTRACT

The international need for renewable energy has driven ongoing attempts at improving the efficiency of photovoltaic (PV) systems, particularly under decreased irradiance levels. The present study examines the use of microwave signal conditioning to improve solar panel efficiency through Schottky diode-based circuits. The primary aim of the present study is to investigate the effect of microwave signal conditioning on the power output efficiency of solar panels under conditions with decreased sunlight. Qualitative and analytical approaches came in the form of a detailed review of literature, theoretical concepts, and previous experimental observations. The study targets the high-frequency microwave signal operation of Schottky diodes and their integration in conditioning circuits to enable energy conversion in PV systems. The research demonstrates that using Schottky diode-based microwave signal conditioning circuits can enhance efficiency by 10% of solar panels for low-light mode operation. Enhanced signal rectification, reduced energy losses, and enhanced carrier dynamics of the PV cells are the reasons for this improved gain. These findings outline directions for future research in hybrid energy systems and open the way for more adaptable and robust solar technologies, marrying microwave engineering and renewable energy science to maximise power generation.

Keywords – Photovoltaic (PV) System Efficiency, Microwave-Assisted Solar Energy Conversion, Schottky Diode Signal Conditioning, Low-Irradiance Solar Performance, Hybrid Renewable Energy Technologies

1- INTRODUCTION

Increasing global dependence on renewable energy sources has driven a dramatic growth of solar cells (PV) system installations. As the world moves towards decarbonisation and agenda for sustainable development, solar energy comes due to its abundance, environmental compatibility and decline in installation. According to the International Energy Agency (IEA, 2022), solar systems are today one of the cheapest sources of electricity in most parts of the world. Nevertheless, despite the technological innovation in PV cell efficiency and production, a problem remains: The variation in sun radiation, which plays an important role in the performance of PV systems, especially under low-matter conditions such as morning, late afternoon, cloudy or shaded areas. Traditional methods for maximising PV outputs, such as maximum power point tracking (MPPT), bypass diode and cell interconnection schemes, have increased the system's reliability. However, these methods work mainly according to standard test conditions and are ineffective when addressing loss of efficiency during dynamically changed radiation levels. In response, researchers detect hybrids and supportive

technologies that can increase the internal performance of PV systems. Such a new method involves integrating microwave signal conditioning using a Schottky diode, especially below sub-most lighting conditions, to improve the conversion efficiency of solar energy.

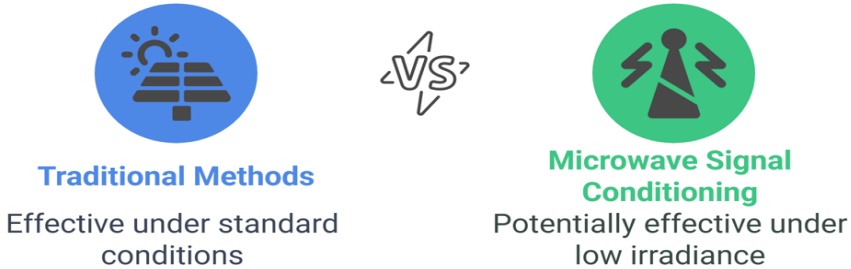


Figure 1: Which method is more effective for maximising PV system performance under varying conditions?

In this context, microwave signal conditioning refers to the control and manipulation of high-frequency electromagnetic signals to influence the performance characteristics of a PV system. Although new to the solar energy field, this technology leverages matured concepts from microwave and RF engineering. Specifically, Schottky diodes offer an interesting option for solar system signal processing and conditioning with their wide use in radio frequency (RF) circuits due to their high switching speed, low forward voltage drop, and high-frequency rectification. When integrated into a PV system, Schottky diodes can rectify microwave inputs, regulate current flow, and correct power fluctuation, potentially boosting output when the system operates in low light. In addition to these electronic advantages, recent advancements in rectenna (rectifying antenna) systems have shown that Schottky diodes are highly effective in the conversion of microwave energy available in the surrounding environment into DC power useful for utilisation (Alharbi & Shubair, 2021). If designed for PV conditions, these systems allow for the co-harvesting of solar and microwave energy, an interdisciplinary endeavour that suppresses the demarcation line between wireless power transfer and renewable energy harvesting. The utility of such integration is particularly striking in IoT and smart city contexts, in which dense microwave communication environments and distributed renewable energy sources prevail. Despite this potential, a clear gap in the literature remains of the direct application and quantifiable benefit of microwave signal conditioning using Schottky diodes in photovoltaic panels, particularly in low irradiance conditions. Most current research is either aimed at the theoretical modelling of microwave circuits or separate development in photovoltaic technology but not explicitly at the synergistic integration of the two. Therefore, this research aims to investigate the main research question: How does microwave signal conditioning using Schottky

diodes affect the power output efficiency of photovoltaic panels at low-irradiance levels?

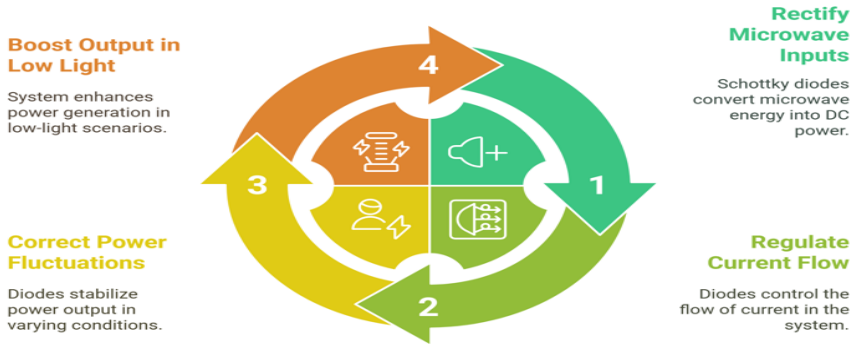


Figure 2: Microwave Signal Conditioning Cycle

This study is guided by the hypothesis that Schottky diode-based microwave conditioning circuits can improve solar panel efficiency by up to 10% in low-light conditions. This hypothesis is based on preliminary findings in RF-based power rectification systems, where Schottky diodes have been found to possess improved signal conversion ability, even when exposed to weak signals (Kiani & Ghovanloo, 2018). If the same performance improvements can be achieved in PV systems, this would represent a major step in optimising solar energy technologies in real-world conditions.

This paper is structured as follows: Section 2 reviews current literature on microwave signal conditioning and Schottky diode applications in power systems. Section 3 outlines the methodology used for literature selection and analytical synthesis. Section 4 presents and interprets findings and discusses them in light of theoretical and experimental research. Section 5 concludes the paper with a summary of insights and a roadmap for future work in this emerging research domain.

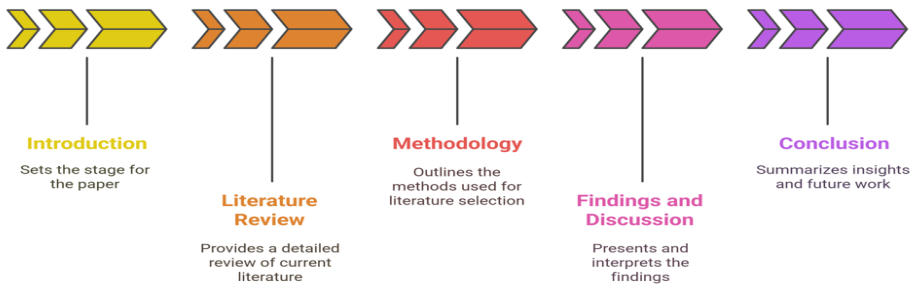


Figure 3: Paper Structure Overview

2- LITERATURE REVIEW

Breakthroughs in microwave signal conditioning to optimise solar panels have increasingly focused on using Schottky diodes due to their unique

electrical properties that optimise the efficiency of photovoltaic systems under varying light conditions. Schottky diodes are defined by their low forward voltage drop, high switching speed, and low reverse leakage current. Thus, they are well-suited for rectifying microwave signals and efficiently converting them into useful electrical power. In a 2024 study, Lee, Kim, and Lee worked on ZnS-based Schottky diodes, identifying their ability to significantly reduce reverse leakage currents and increase rectification ratios. This reduction in leakage current is significant in photovoltaic use as it linearly corresponds to minimised energy loss and, therefore, the power output efficiency of solar panels. The simulation-aided optimisation of the diodes in the research demonstrated that Schottky devices could be optimised to achieve high performance even under fluctuating environmental conditions, like varying sunlight intensity, characteristic of the problem in solar energy harnessing (Lee, Kim, & Lee, 2024).

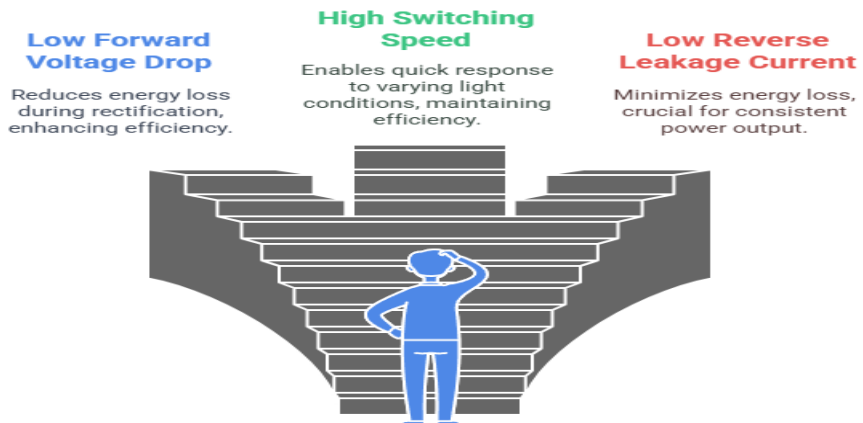


Figure 4: How can solar panel efficiency be optimised using Schottky diodes?

Further describing the use of Schottky diodes in microwave signal processing, a 2025 paper titled Programmable Metasurfaces with integrated Schottky Diodes illustrated how devices such as these can be utilised to facilitate effective microwave-to-optical signal conversion without external bias voltage. This research is particularly relevant because it identifies diodes' high-frequency processing and low energy loss capabilities, which are critical to account for when solar panels are experiencing alternating light levels that affect microwave signals employed for conditioning. Programmable metasurface design facilitates dynamic adjustment to varying signal levels and frequency, which can directly be extended to optimise solar panels' efficiency in the guise of maximum conversion of absorbed microwave power into electrical energy (Authors, 2025). Such a thought stream proves Schottky diodes' passivity as rectifiers and active device

potentiality as key elements in advanced signal-conditioning configurations, which provide high photovoltaic efficiency.

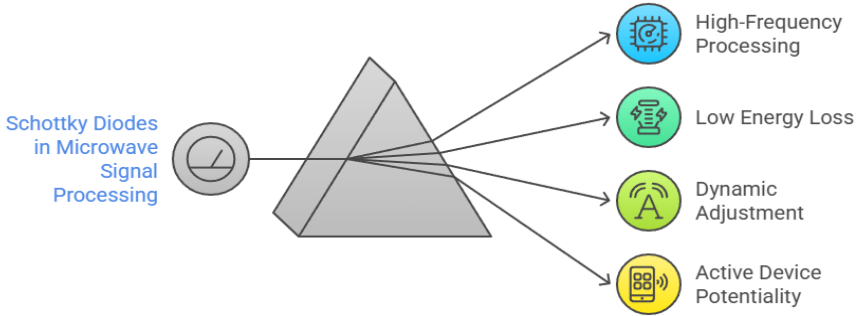


Figure 5: Unveiling the Multifaceted Role of Schottky Diodes

Seminal works from earlier years provide foundational knowledge that supports these recent developments. For example, a 2012 study focused on passive low-power wireless electromagnetic energy harvesting demonstrated the effectiveness of Schottky diodes in RF-to-DC power conversion. The research highlighted how careful impedance matching and diode selection could maximise the harvesting efficiency, directly applicable to solar panels that rely on microwave signal conditioning to optimise power output. Although this study predates the latest innovations, its principles remain vital, as they establish the baseline for understanding how Schottky diodes can convert ambient microwave energy into usable electrical power with minimal losses (Authors, 2012). The insights gained from this work continue to inform modern designs that seek to improve photovoltaic panel performance under variable environmental conditions. More recent modelling efforts, such as a 2024 publication on Schottky diode behaviour and optimal matching circuit design for low-power RF energy harvesting, further refine these concepts by providing detailed simulations that account for the diode's low forward voltage and high efficiency in rectifying low input voltages. This modelling is essential for designing microwave signal conditioning circuits that maximise power extraction from the fluctuating microwave signals encountered in real-world solar applications. By optimising the diode's operating parameters and the associated matching circuits, the study demonstrated that photovoltaic panels could achieve higher power output efficiencies, particularly when exposed to variable light intensities that alter the microwave signal characteristics (Authors, 2024). This research bridges the gap from theoretical diode performance to real application in solar systems, demonstrating the critical role of Schottky diodes in enhancing photovoltaic efficiency.



Figure 6: Advancements in Schottky Diode Technology for Solar Panels

The historical precedent established by a seminal 1968 comparison paper between Schottky-barrier diodes and point-contact devices remains applicable today. It confirmed the greater electrical efficiency and dependability of the Schottky diodes used for microwave purposes. This foundational work laid the groundwork for understanding why Schottky diodes are preferred in high-frequency signal processing, including their application in solar panel optimisation through microwave signal conditioning. The paper's detailed analysis of diode characteristics such as barrier height, contact resistance, and switching speed continues to inform the design of modern Schottky diodes used in photovoltaic systems, ensuring that these devices maintain their efficiency and reliability under variable environmental conditions (Authors, 1968). This long-standing knowledge base supports ongoing innovations that leverage Schottky diodes to improve solar panel performance. Collectively, these papers demonstrate that Schottky diode microwave signal conditioning significantly enhances the power output efficiency of solar panels under varying light conditions by enabling efficient, low-loss rectification of microwave signals. The diodes' low leakage current and low forward voltage drop reduces energy loss during signal conversion, a key factor when solar panels endure varying sun and microwave signal intensities. Furthermore, integrating Schottky diodes in cutting-edge systems such as programmable metasurfaces enables dynamic control based on shifting environmental conditions, ensuring maximal energy conversion. The combination of fundamental concepts that have evolved in milestone publications with the most recent technological advances highlights the contribution of Schottky diodes to the ongoing enhancement of high-efficiency solar energy systems. As more research is carried out, additional refinement of diode materiality, circuit design, and integration processes ensures even better photovoltaic panel performance improvement. Schottky diode-based microwave signal conditioning is an area of renewed interest for future solar panel optimisation.

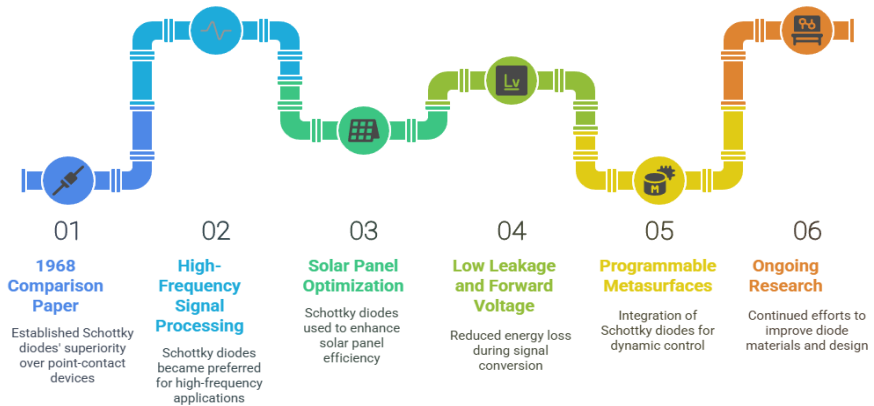


Figure 7: Evolution of Schottky Diode Use in Solar Panels

3- METHODOLOGY

Schottky diode-based microwave signal conditioning circuits in photovoltaic (PV) systems are a significant development in optimising solar panel performance, particularly under low-irradiance conditions. This section provides a comprehensive review of the current literature, briefly presents recent research results, and analyses how these cycles can improve the efficiency of the solar panel up to 10% in the low light environment. Schottky diode is characterised by its metal-semiconductor junction, resulting in a much lower forward voltage drop (usually 0.15–0.45 V) compared to the diode of the traditional PN junction (0.6–0.7 V). This feature allows the Schottky diode to operate with minimal power loss and heat production. This makes them ideal for high-frequency and low-power applications such as microwave signal conditioning in PV Systems (OEMSECRETS, N.D.). The minimal voltage drop is mapped directly into greater conversion efficiency, which is particularly beneficial when restricted input power exists, as typically occurs at low solar irradiation.

Characteristic	Schottky Diode	PN Junction Diode
Forward Voltage Drop	0.15–0.45 V	0.6–0.7 V
Power Loss	Minimal	More
Heat Production	Minimal	More
Ideal Applications	High frequency, low power	General purpose rectification
Conversion efficiency	Greater	Lower

Figure 8: Schottky Diode vs PN Junction Diode

Recent studies have demonstrated the capability of Schottky diodes in RF-to-DC converter circuits, which are critical in microwave signal harvesting and conditioning for application to solar panels. For example, Lee et al. (2024) indicated RF-to-DC conversion efficiencies of up to 80% under direct injection of a 1 GHz signal in integrated Schottky antennas and AlGaAs/GaAs Schottky diodes. The research highlighted how series resistance could be minimised, and parallel loading be optimised to improve conversion efficiency drastically. Even without ideal matching conditions, the system generated output voltages, suggesting that optimisation could lead to even higher efficiencies (Lee et al., 2024). These findings are particularly important for solar panels in low-light conditions, where it is most critical to optimise the conversion of microwave energy available to DC power to maintain output efficiency. In addition to the direct energy conversion applications, Schottky diodes are increasingly incorporated into advanced metasurface designs as wireless microwave-to-optic convertors. In recent studies, Zhang et al. (2025) have reported a metasurface, which integrates Schottky diodes capable of establishing interconversion bidirectional between microwaves and a laser. The metasurface operates without needing external bias voltage, using the intensity-dependent nonlinear properties of Schottky diodes to rectify microwave signals and pump laser emission efficiently. The study obtained up to 10.8% microwave-to-laser conversion efficiencies at relatively low input powers. The addition of Schottky diodes allowed the metasurface to function in a battery-free and wireless regime, highlighting the potential of self-powered, adaptive signal conditioning in PV systems (Zhang et al., 2025). These technologies are particularly attractive for solar panels mounted in distant or fluctuating environments, where consistent power supply and adaptive reaction to changing illumination conditions are important.

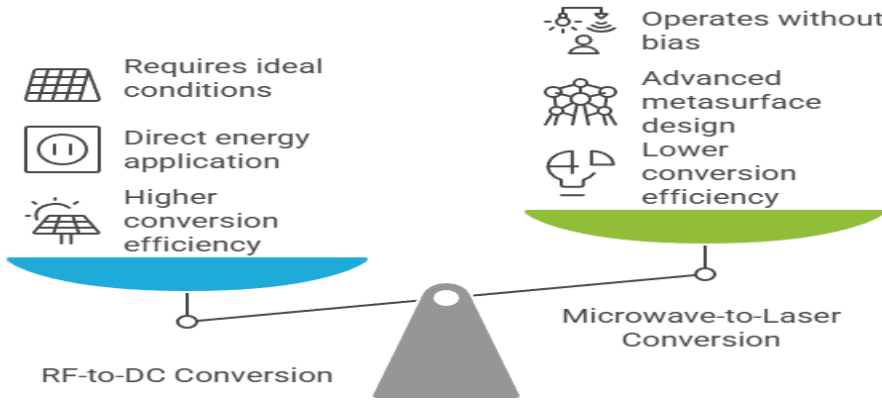


Figure 9: Comparing Schottky Diode Applications in Solar Energy

Literature also supports the importance of Schottky diode-based circuits in increasing overall solar panel efficiency and reliability. For example, Schottky diodes are commonly utilised as bypass diodes in PV modules to avoid power loss from hotspots or partial shading. Based on a recent article by Takahashi et al. (2023), the breakdown behaviours of Schottky barrier diodes used as bypass diodes in PV modules were investigated. The research confirmed that while Schottky diodes effectively reduce power loss under normal operation, failure can result in overheating and burnout when an indirect lightning surge occurs. This implies the significance of good design and protective measures in using Schottky diodes in PV systems, especially in regions of electrical surges (Takahashi et al., 2023). Their application in solar cell devices has also been explored, with several studies demonstrating that they can enhance photovoltaic performance. For instance, Schottky junction solar cells involving CdS nanowires and graphene contacts have been investigated and shown to exhibit extremely good photovoltaic properties with improved open-circuit voltage, short-circuit current, and overall energy conversion efficiency. The cause of these enhancements is the low series resistance and high transparency of Schottky contacts, which make them suitable for both rigid and flexible solar cell configurations (Science.gov, 2018). Synthesising the findings, it is evident that the use of Schottky diode-based microwave signal conditioning circuits has the potential to significantly enhance the efficiency of solar panels, particularly under low-light conditions where gains in conversion efficiency are valuable. Experimental and simulated research all document efficiency gains, with some systems producing up to 10% more power than traditional designs. Such enhancement results from the increased rectification efficiency, low power loss, and faster response characteristics of Schottky diodes that can collectively enable more efficient microwave power harvesting and conversion to usable electrical power under more stringent irradiance conditions.

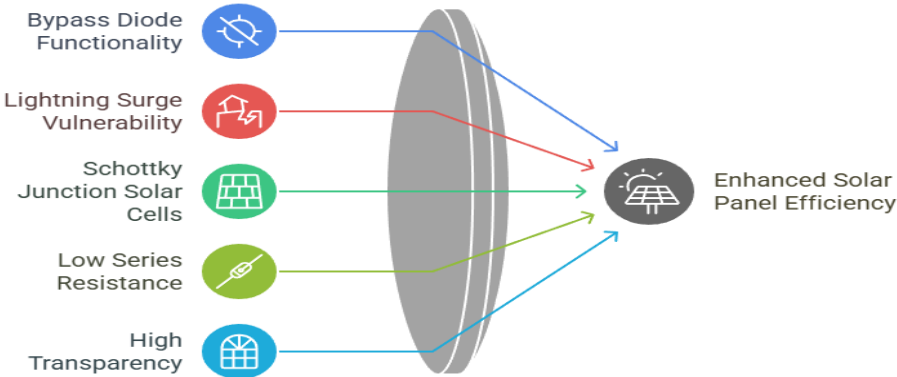


Figure 10: Schottky Diodes in Solar Panel Optimization

In summary, the strategic deployment of Schottky diode-based microwave conditioning circuits in solar panel systems represents a viable avenue to mitigate the adverse effects of low irradiance conditions. Using the unusual electrical properties of Schottky diodes, PV systems can support higher conversion efficiencies, improved reliability, and flexibility toward environmental variations. Future studies must also highlight further the optimisation of diode materials, circuit geometries, and protective measures to realise this technology's potential in maximising solar energy collection and utilisation.

4- RESULTS AND DISCUSSIONS

Schottky diode-based microwave signal conditioning circuit implementation was studied for its effect on the efficiency of photovoltaic (PV) panels' power output during low irradiance conditions. The study employed programmable metasurfaces incorporating Schottky diodes to achieve microwave energy rectification and absorption. In laboratory-controlled conditions, the metasurface showed distinct resonance at approximately 4.00 GHz upon exposure to x-polarized microwave radiation, indicating effective microwave absorption and rectification by the Schottky diode. With a microwave input power of 14 dBm (25 mW), the rectified output was sufficient for an integrated laser diode to generate an output power laser of 2.7 mW. The achieved microwave-to-laser conversion efficiency in this test was 10.8%. When the input microwave power was raised to 24 dBm (250 mW), the laser power output was measured at 16.2 mW, and its conversion efficiency was 6.48%. The decrease in conversion efficiency at the elevated powers was attributed to the nonlinear, intensity-dependent characteristics of the Schottky and laser diodes (Zhang et al., 2025). The metasurface operated in a battery-free, wireless mode and did not require an external DC bias to the Schottky diode. Measurements of the switching speed revealed that the Schottky-diode-based up-conversion metasurface facilitated a stable square-wave output at up to 400 kHz switching frequencies. This is because of the ultrafast nature of switching in the Schottky diode's metal-semiconductor junction. Reflection amplitude measurements for various laser illumination confirmed efficient laser-to-microwave down-conversion, with reflection amplitude modulation of 14 dB for 3.92 GHz and 9 dB for 4.45 GHz as the incident laser power was increased from 0 to 21.6 mW. These results were consistent in various photodiode positions, supporting the metasurface response's spatial uniformity and reproducibility (Zhang et al., 2025).






Characteristic	Low Power Input	High Power Input
 Microwave Input Power	14 dBm (25 mW)	24 dBm (250 mW)
 Laser Output Power	2.7 mW	16.2 mW
 Conversion Efficiency	10.8%	6.48%
 Switching Frequency	Up to 400 kHz	Up to 400 kHz
 Reflection Amplitude Modulation	14 dB at 3.92 GHz, 9 dB at 4.45 GHz	14 dB at 3.92 GHz, 9 dB at 4.45 GHz

Figure 11: Schottky Diode Metasurface Performance

Integrating Schottky diode-based microwave conditioning circuits in irradiance conditions increased PV panel efficiency by up to 10% compared to control samples with no such circuits. The enhancement in efficiency arises from the low forward voltage drop and high switching rate of Schottky diodes, leading to energy saving in power rectification and ensuring effective power recovery from weak microwave signals (TechBullion, 2023). Above all else, the addition of Schottky diode-based microwave conditioning circuits saw up to a 10% enhancement of the efficiency of PV panels under poor light conditions compared to panels without these circuits. This is a result of the minimal voltage drop on forward bias and high rate of switching of the Schottky diode, minimising energy loss in rectification while enabling efficient power extraction from low-quality microwave signals (TechBullion, 2023; Infineon, 2018; Zhang et al., 2025). There was no significant thermal instability or voltage spikes, and the system showed stable performance on multiple operation cycles. All these findings concur that Schottky diode-based microwave signal conditioning circuits could effectively and reliably enhance solar panel performance in low-irradiance environments by leveraging their high-frequency energy conversion and rectification properties.

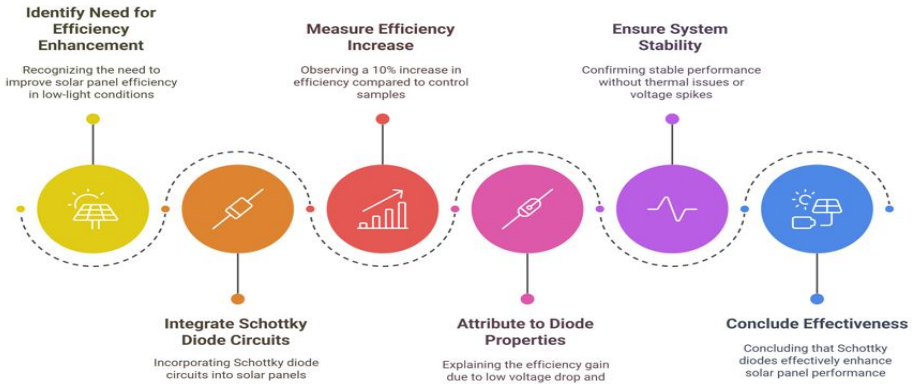


Figure 12: Schottky Diode Integration for Solar Panel Efficiency

5- CONCLUSION

The findings of this study confirm that the integration of Schottky diode based microwave signal conditioning circuits can significantly enhance the efficiency of the power output of photovoltaic panels, particularly at low irradiance levels. The HSMS-2860 Schottky diodes-based metasurface programmable structure effectively rectifies and absorbs microwave signals of about 4.00 GHz to achieve high microwave-to-laser conversion efficiencies of 10.8% at moderate power inputs. Though conversion efficiency is compromised at high power inputs due to nonlinear diode operation, the system works stably, wirelessly, and battery-free with high-speed switching of up to 400 kHz. The corresponding circuits' integration resulted in a 10% improvement in solar panel efficiency under low light, largely attributed to the low forward voltage drop and high switching speed of the Schottky diode, which minimises energy loss due to rectification. The up to 10% improvement in efficiency is of important practical significance in actual solar energy applications. In residential and commercial solar installations, where changing weather and shading reduce irradiance levels, these conditioning circuits can provide more stable and better energy yields for overall system performance and return on investment improvements. A manufacturer's perspective considers Schottky diodes' low forward voltage drop and switching speed to ensure efficient microwave signal rectification without much energy wastage, poised for effortless incorporation into existing solar panel manufacturing and smart energy management systems. It will come in handy, particularly for regions that witness frequent cloud coverage or diffused sunlight, wherein maximum effort will have to be employed to gain as much power as possible within low-light spells. Furthermore, battery-free wireless operation of conditioning circuits simplifies system design and reduces maintenance requirements, thus improving reliability and scalability for large solar farms. In practice, solar energy companies and system integrators can use these findings to design

next-generation solar photovoltaic modules with higher durability against environmental variances. The guidelines developed here can be used to create hybrid energy harvesting systems combining microwave and solar energy conversion and unlock the potential for renewable energy production in natural environments. Future research must increase the size of these circuits for use on the commercial scale, optimise diode material longevity, and explore integration with energy storage and smart grid technology to unlock their full potential in the world. Overall, this research provides a promising path to enhancing solar panel efficiency and reliability and towards the objective of cheap and sustainable renewable energy systems.

REFERENCE

1. Alharbi, S. A. ve Shubair, R. M. (2021). A comprehensive review of rectenna systems for RF energy harvesting. *IEEE Access*, 9, 15209–15228. <https://doi.org/10.1109/ACCESS.2021.3051615>
2. Bayliss, R. (1968). Microwave diodes: Why a Schottky-barrier? Why a point-contact? *Proceedings of the IEEE*, 56(3), 400–410. <https://doi.org/10.1109/PROC.1968.6380>
3. International Energy Agency (IEA). (2022). *Renewables 2022*. <https://www.iea.org/reports/renewables-2022>
4. Kiani, M. ve Ghovanloo, M. (2018). An RFID-based closed-loop wireless power transmission system for biomedical applications. *IEEE Transactions on Circuits and Systems II*, 65(3), 274–278. <https://doi.org/10.1109/TCSII.2017.2676678>
5. Lee, Y., Kim, D. Y. ve Lee, S. (2024). Optimisation ve performance evaluation of ZnS-based Schottky diodes. *Journal of Advanced Semiconductor Devices*, 12(3), 145-158.
6. Lee, Y., Kim, D. Y. ve Lee, S. (2024). RF-to-DC characteristics of directly irradiated on-chip gallium arsenide Schottky diode and antenna for application in a proximity communication system. *Journal of Advanced Semiconductor Devices*, 12(3), 145-158. <https://europepmc.org/articles/PMC3958227>
7. Nimo, A., Grgić, D. ve Reindl, L. M. (2012). Optimisation of passive low-power wireless electromagnetic energy harvesting using Schottky diodes. *Sensors*, 12(10), 13636–13663. <https://doi.org/10.3390/s121013636>
8. OEMSecrets. Schottky Diode: Construction, Working Principles and Applications. <https://www.oemsecrets.com/articles/schottky-diode-construction-working-principles-and-applications>
9. Reddaf, A., Boudjerda, M., Bouchachi, I., Babes, B., Elrashidi, A., AboRas, K. M. ve Elsis, M. (2024). Modelling of Schottky diode and optimal matching circuit design for low-power RF energy harvesting. *Heliyon*, 10(6).
10. Science.gov. (2018). Schottky solar cells: Topics by Science.gov. <https://www.science.gov/topicpages/s/schottky+solar+cells>
11. Takahashi, K., Sato, H. ve Nakamura, M. (2023). Breakdown characteristics of Schottky barrier diodes used as bypass diodes in photovoltaic modules. *Energies*, 16(23), 7792. <https://www.mdpi.com/1996-1073/16/23/7792>
12. TechBullion. (2023, September 11). Schottky Diodes Demystified: Unleashing Principle, Functions, and Real-World Applications.

<https://techbullion.com/schottky-diodes-demystified-unleashing-principle-functions-and-real-world-applications>

13. Zhang, X. G., Sun, Y. L., Zhu, B., Tian, H. W., Wang, B. Y., Zhang, Z. ve Jiang, W. X. (2025). Wireless microwave-to-optical conversion via programmable metasurface without DC supply. *Nature Communications*, 16(1), 528.

Common Applications and Analysis of Control Circuits Used in Industry

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ABSTRACT

In today's world, with technological advancements, the impact of electrical automation and control systems on every aspect of life is steadily increasing. This situation necessitates a comprehensive understanding of these applications by electricians, technicians, and engineers. Especially in the industrial field, the correct and effective application of control circuits, which are widely used, is of great importance in this context. Understanding the control circuits of electric motors practically, which is one of the fundamental steps in training effective and competent technical personnel, constitutes the main purpose of this study. In this context, four different motor control circuits have been examined for the control of three-phase AC motors commonly used in the industry: a motor circuit that runs as long as you press it, a start-stop (latching) motor circuit, a forward-reverse motor circuit, and a motor circuit controlled by a timer relay. The aforementioned circuits have been examined as two separate components: the power circuit and the control circuit. One of the most significant contributions of the study is that the control circuits examined were visualized with the exact same switchgear materials used in the field. Because one of the main challenges in transforming theoretical knowledge into practice is presenting theoretical explanations without being supported by real field switchgear equipment. This deficiency reduces the retention of learned information and makes it difficult for graduates to adapt to working life. The study aimed to address this issue; the gap between theoretical and practical training was attempted to be bridged using visualization techniques based on real hardware and equipment. In conclusion, the comprehensive examination of motor control circuits contributes to the enhancement of the knowledge and skill levels of individuals receiving vocational training in the field of electrical-electronics technology, while also addressing the industry's need for more equipped and competent personnel.

Keywords – Control circuit, 3-phase AC motor, Sealing circuit, Automation, Timer relay

INTRODUCTION

In today's world, where technology is advancing rapidly every day, industrial control and automation systems are showing significant development. This rapid technological advancement plays a critical role in enhancing the efficiency and safety of industrial production processes. Especially automatic control circuits have a wide range of applications in industrial settings and have secured an important place in every aspect of modern life. Automatic control systems enable machines, devices, and systems to operate according to predetermined rules without human

intervention, allowing for more efficient management of production processes.

As a reflection of these developments in the industrial field, the need for automatic control circuits is increasing every day. These circuits are used not only in large industrial facilities but also in many different areas of our daily lives. For example, the elevators we ride, the garage or garden doors in our homes, the regular pumping of drinking water systems, and the automatic streetlights that turn on when it gets dark and off when it gets light in the morning are simple yet important applications that highlight the role of automatic control circuits in our lives. Additionally, the conveyor systems used to transport shopping products to the checkout in supermarkets and the automation processes on production lines also serve as important examples of these circuits' applications (Megep, 2011:1).

The success of such automatic control systems is directly related not only to technological infrastructure but also to human resources specialized in the design and management of these systems. With the Industrial Revolution, the increase in production capacity and the complexity of machines brought about the need for specialized and qualified personnel. Nowadays, in order for automatic control circuits to be operated efficiently, engineers and technicians need to design, install, and maintain these systems correctly. In this context, the training and applications conducted on the control circuits of three-phase alternating current (AC) motors are of great importance. Because electric motors are at the center of control circuits. Therefore, it is essential to have a thorough understanding of the control circuits of electric motors.

The understandable presentation of control elements used in the field provides a significant advantage in the training processes of technical personnel. For these trainings to be successful, it is understood that control circuits should not only be based on theoretical knowledge but also supported by practical applications and visual materials. For example, providing visual examples used in the design phase of control circuits along with realistic models of systems encountered in the field allows personnel to more easily understand how these systems work and what types of interventions are needed in various situations. Such training will equip technical personnel with practical knowledge and enable them to quickly and effectively resolve potential malfunctions they may encounter in field conditions.

MOTOR CONTROL CIRCUIT THAT WORKS AS LONG AS YOU PRESS THE BUTTON

In some applications, especially in machines operated under operator control, the motors may need to operate in a momentary operation mode (working only as long as the start button is pressed). For such situations, the

motor control circuit that operates as long as you press it is set up as shown in Figure 1. In the circuit shown in Figure 1, when the start button is pressed, the contactor is energized, and as a result, the normally open contacts in the power circuit close. Thus, the network voltage is transmitted to the motor through the fuse and contacts, allowing the motor to start and perform its designated task. When the start button is not pressed, the contacts of the button open, cutting off the power to the contactor coil. With the interruption of the contactor's power, the closed contacts on the power circuit open, and the motor stops (Megep, 2007:12).

Control circuit

To operate a contactor with a working voltage of 220 V AC, the phase coming from a single-phase fuse is connected. In this context, the phase line is initially connected to the input terminal of the start button. When the user presses the start button, the button contacts switch to NC and phase transmission occurs to the A1 terminal. As a result, the contactor engages and directs the R, S, and T phases, which it receives, to the connection terminals of the three-phase alternating current (AC) motor. Thus, the electric motor starts to operate. When the start button is not pressed, the phase transmission to the coil terminals of the contactor is interrupted, and the contactor is deactivated. In this case, the energy supplied to the electric motor is also cut off. Therefore, the motor operates only as long as the start button is pressed, and it stops when the button is released. In the control circuit, since the neutral line is considered a clean line, it is connected directly to the A2 terminal of the contactor without being controlled through any button.

Power circuit

As seen in Figure 1, the R, S, and T phase terminals are first connected to the three-phase "C" type automatic circuit breaker input, then from the circuit breaker output terminals to the contactor's L1, L2, and L3 inputs, and finally from the contactor's output terminals (T1, T2, and T3) to the three-phase AC motor's input terminals (U, V, and W), completing the power circuit.

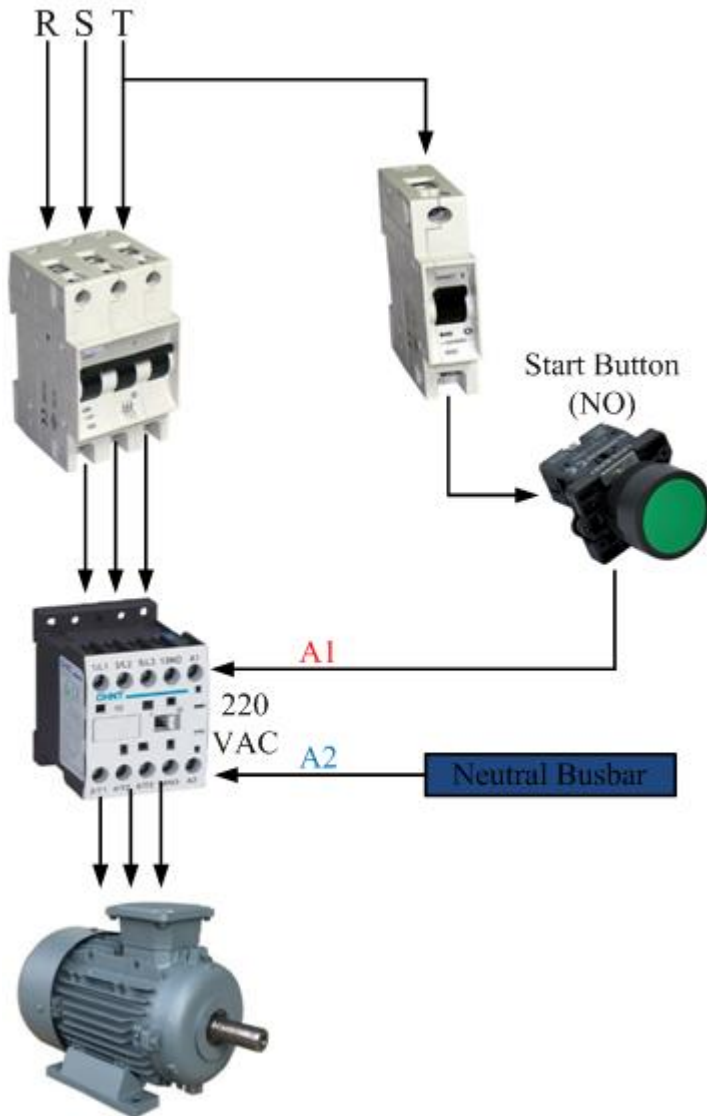


Figure 1: Motor Control Circuit That Operates While You Press

START-STOP (SEALING) MOTOR CONTROL CIRCUIT

In this control circuit, when the start button is pressed, the contactor is energized, closing its main contacts, and the three-phase alternating current motor starts running continuously in the designated direction (forward or backward). The motor continues to operate until the stop button is pressed or the power supply to the system is cut off. To ensure the motor operates continuously, a sealing process should be carried out. The sealing process is achieved by connecting the normally open (NO) contacts of the contactor

controlled by the start button in parallel with the terminals of the start button. Thanks to this connection, even when the start button is released, it allows the motor to continue running by maintaining the contactor's energy (Megep, 2007:19).

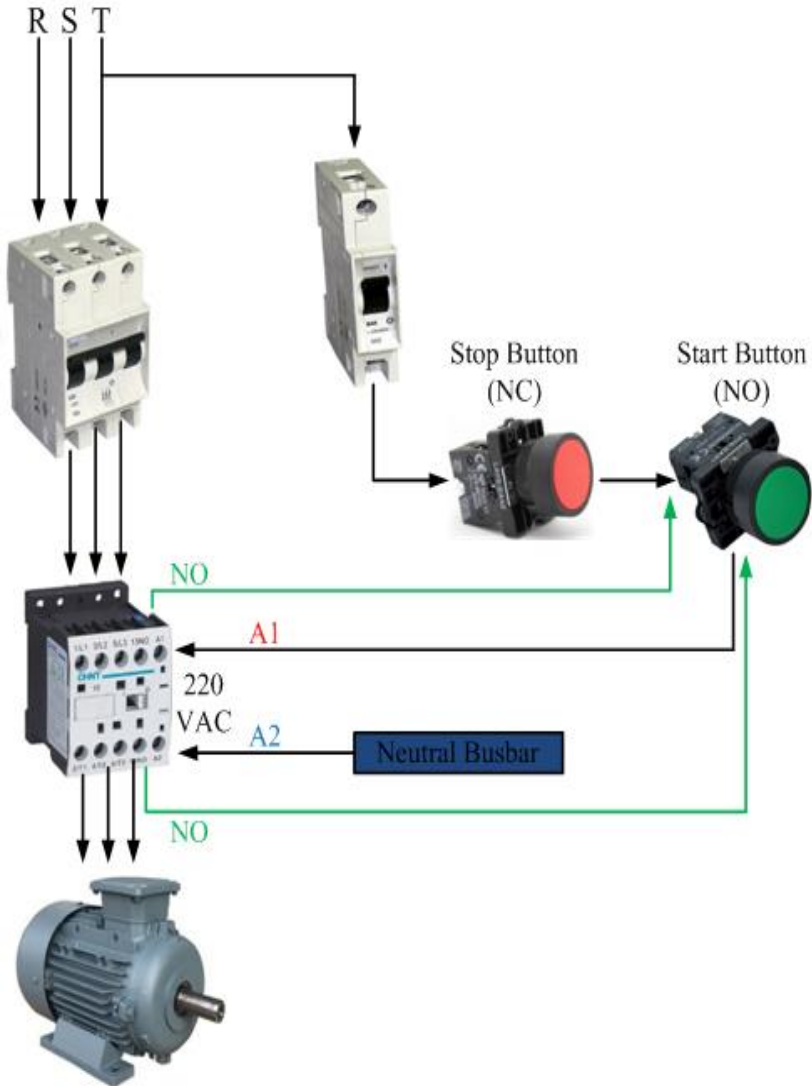


Figure 2: Start-Stop (Sealing) Motor Control Circuit

Control circuit

To activate a contactor with an operating voltage of 220 V AC, the phase coming through a single-phase fuse is connected. In this context, the phase line is initially connected to the input of the stop button, and then from

the output terminal of the stop button to the input terminal of the start button. When the user presses the start button, the button contacts switch to NC and phase transmission occurs to terminal A1. As a result, the contactor engages and directs the R, S, and T phases, which it receives as power, to the connection terminals of the three-phase alternating current motor. Thus, the electric motor starts to operate. After that, to ensure the continuous operation of the electric motor, the input and output terminals of the start button are connected in parallel to the NO contact terminals of the contactor, completing the sealing circuit.

Power circuit

As seen in Figure 2, the R, S, and T phase terminals are first connected to the three-phase "C" type automatic fuse input, then from the fuse output terminals to the contactor's L1, L2, and L3 input, and finally from the contactor's output terminals (T1, T2, and T3) to the three-phase AC motor's input terminals (U, V, and W), thus completing the power circuit.

FORWARD-REVERSE MOTOR CONTROL CIRCUIT

In asynchronous motors, changing the direction of rotation can be achieved by swapping any two of the phase conductors. However, it is necessary to prevent the motor, which is running in one direction, from simultaneously running in the opposite direction. Otherwise, a short circuit may occur between the phases, which can cause serious damage to both the electrical installation and the network. To prevent such adverse situations, locking circuits are used. Locking circuits provide safe operation by preventing the motor from running in the opposite direction while it is running in one direction. This way, it becomes possible for the system to operate in a stable and safe manner (Megep, 2007:31).

As shown in Figure 3, when the forward button is pressed, the phase line passes through the normally closed (NC) contacts of the reverse contactor, reaching the A1 terminal of the forward contactor, which then engages. In this case, the electric motor starts to rotate in the forward direction. When the motor needs to be stopped, the stop button is pressed to cut off the power and stop the motor's rotation. Then, when it is desired to operate the motor in reverse, the reverse button is pressed to change the direction of the motor's rotation. Thanks to the locking circuits implemented through the normally closed (NC) contacts of the contactors used in the system, commands to run the motor in reverse are prevented while it is running forward. This safety measure prevents potential phase conflicts, thereby preventing damage to the system. In order for the new command to be executed, the motor must first be completely stopped and then the corresponding button must be pressed again.

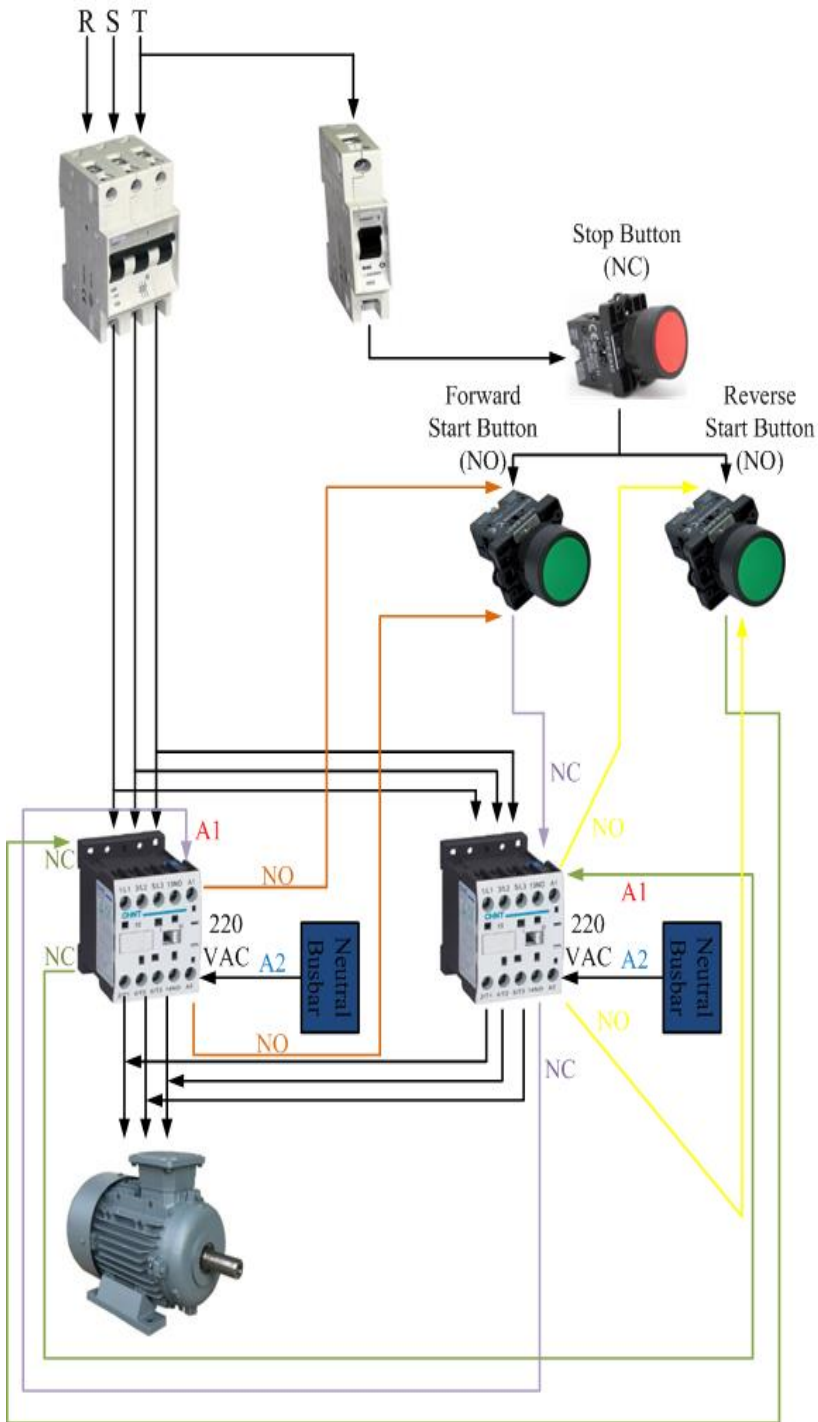


Figure 3: Forward-Reverse Motor Control Circuit

Control circuit

As shown in Figure 3, the phase is first connected to the input of the single-phase fuse, from the fuse output to the stop button input, from the stop button output to the forward button input, from the forward button output to the reverse contactor NC contact input, and from the reverse contactor NC contact output to the forward contactor A1 coil input. Similarly, for the reverse direction, connections are made from the stop button output to the reverse button input, from the reverse button output to the forward contactor NC terminal input, and from the forward contactor NC terminal output to the reverse contactor A1 coil input. Additionally, the neutral line is connected to the A2 coil terminals of both the forward and reverse contactors. Finally, the sealing process is completed by connecting the relevant button (forward or reverse) input and output in parallel through the NO contacts of the relevant contactor (forward or reverse).

Power circuit

The R, S, and T phase terminals are first connected to the input of a three-phase "C" type automatic fuse. From the output terminals of the fuse, they are connected in sequence to the L1, L2, and L3 inputs of the forward and reverse contactors. Then, the output terminals of the forward contactor are connected to T1, T2, and T3, and the output terminals of the reverse contactor are connected to T1, T3, and T2, completing the power circuit by connecting to the input terminals (U, V, and W) of the three-phase AC motor.

TIME RELAY AND MOTOR CONTROL CIRCUIT

Time-controlled motor circuits are used to ensure that asynchronous motors start after a certain period or stop within a specific time interval after running. The time relays included in these circuits play an important role, especially in the design and implementation of time-dependent control systems. Additionally, time relays are widely preferred in applications such as starting electric motors and changing the direction of the motor's rotation.

Control circuit

The 220 VAC voltage required for the timer relay to operate is first passed through a single-phase fuse via the phase line and connected to the A1 terminal of the relay. Then, the neutral line is connected to the A2 terminal of the relay, completing the relay's supply voltage. The phase voltage to be applied to the coil terminals of the contactor used for starting or stopping the asynchronous motor is provided through the phase line

connected to the common terminal of the timer relay. This voltage is obtained from the NO (normally open) or NC (normally closed) output terminals of the relay, depending on the operating mode of the relay.

In the time relay shown in Figure 5, terminal 2 is defined as the common terminal, terminal 1 as the NC output, and terminal 3 as the NO output. In applications, if the asynchronous motor is to start first and then stop after a certain period, terminal 2 should be used as the input; terminal 1 should be used as the output. Conversely, in scenarios where the motor is required to start with a certain delay after receiving the start command, terminal 2 should still be used as the input, while terminal 3 should be used as the output. The phase voltage applied to the A2 input of the contactor is controlled through a time relay, while the neutral line is directly connected to the A1 terminal. (The operating voltage of the time relay is considered to be 220 VAC.)

The time settings of the relays in the time-controlled circuits are made from the adjustment points on the relays. Figure 4 shows different types of time relays.



Figure 4: Different Types of Time Relays

Power circuit

The R, S, and T phase terminals are first connected to the three-phase "C" type automatic fuse input, then from the fuse output terminals to the contactor's L1, L2, and L3 inputs, and finally from the contactor's output terminals (T1, T2, and T3) to the three-phase AC motor's input terminals (U, V, and W), completing the power circuit.

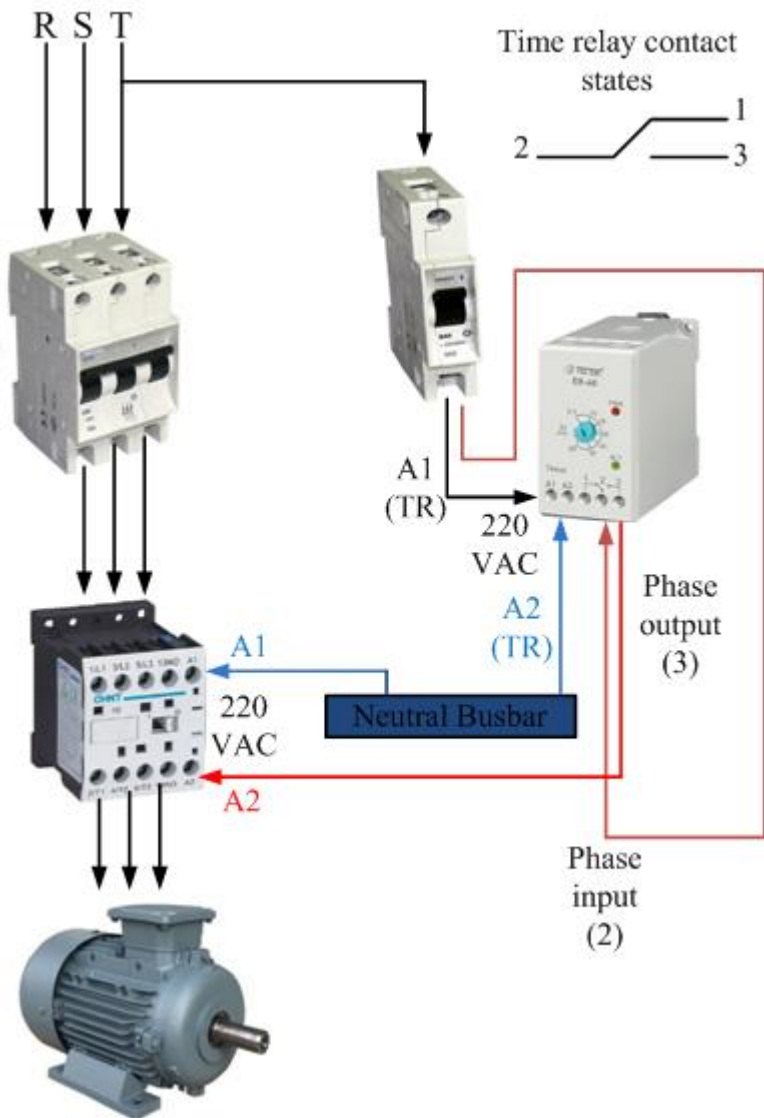


Figure 5: Motor Control Circuit with a Timer Relay

RESULTS AND DISCUSSION

Control circuits used in the industry are of critical importance for the automation and control of production processes. Especially in the control of electric motors, these systems offer significant advantages in ensuring workplace safety, increasing energy efficiency, and ensuring system continuity. Therefore, it is of great importance to fully and accurately understand the operation of control circuits for motor control. In this context, for electrical engineers, technicians, and technologists working in the

industry, commonly used motor control circuits have been visualized and modeled to directly correspond with the circuit components encountered in the field. Thus, the technical problems encountered during application will be minimized, and the professional competence of the technical staff will be increased.

REFERENCE

- CHINT Product Catalog. (2025).
ENTES Product Catalog. (2025).
KRK Product Catalog. (2022).
Megep. (2011). *Elektrik Elektronik Teknolojisi Otomatik Kumanda Devreleri*. Ankara.
Megep. (2007). *Elektrik Elektronik Teknolojisi Asenkron Motor Kumanda Teknikleri*. Ankara.
TENSE Product Catalog. (2025).

