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ANALYSIS OF THE EFFECT OF DISTANCE BETWEEN TRANSMITTER AND RECEIVER COILS IN WIRELESS PHOTOVOLTAIC POWER TRANSFER SYSTEMS

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ABSTRACT

Wireless power transmission technology can eliminate the use of cables, thereby increasing the mobility, convenience and security of electronic devices for all users. The wireless photovoltaic power transfer system will be modeled using Mathlab Simulink software built by a PV module, half-bridge inverter, transmitter and receiver coils. The distance between the transmitter and receiver coils is changed from 1 m to 10 m. PVWPT (Photovoltaic Wireless Power Transfer) is a system that combines photovoltaic (PV) technology and wireless power transfer to transfer electrical energy from a PV module to a receiving device or system without using physical cables. By using PVWPT, electrical energy can be generated from sunlight by PV modules and wirelessly transferred to receiving devices that require power. The farther the distance, the less voltage will be sent. And the error percentage is 5%.

Keywords : PVWPT, Distance, Receiver, Transmitter

INTRODUCTION

Wireless photovoltaic power transfer system is the transmission of electrical energy without cables as a physical link. In wireless power transmission, a transmitting device, driven by electrical power from a power source, generates a time-varying electromagnetic field that transmits power across space to a receiving device, which extracts power from the field and supplies it to the power grid. An application of the electromagnetic principle that transfers energy from a transmitter to a receiver coil (TC and RC) is called a wireless power transfer (WPT) system (Butar-Butar *et al* 2020). This describes how the generation of an electromagnetic field and the resulting induced AC voltage on the transmitter coil lead to the achievement of an appropriate frequency (Surajit and Ahmed, 2020)

The wireless photovoltaic power transfer system will be modeled using Mathlab Simulink software built by a PV module, half-bridge inverter, transmitter and receiver coils. The distance between the transmitter and receiver coils is changed from 1 m to 10 m. Any change in distance will be observed in the form of AC voltage and current in the transmitter and receiver coils of the PVWPT system. The results of the AC voltage and current on the sending and receiving coils of the wireless photovoltaic power transfer (PVWPT) system are depicted in the form of a two- dimensional (2d) graph. Each two-dimensional (2d) graph is analyzed to determine the effect of the distance between the transmitter and receiver coils on the PVWPT system.

METHODS

Wireless Electric Power Delivery is a system that has a process where electrical energy can be transmitted from an electrical source to an electrical load without going through cables (Dai *et al*, 2023). Wireless electrical power transmission is useful if we need electrical energy, but there are no cables near us. The method of sending electrical energy wirelessly has the same working principle as a transformer, namely mutual inductance between two circuits connected by

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magnetic flux.

If an Electromotive Force (EMF) is induced in the same circuit where the current changes, this condition is called Self-induction, (L). However, if an EMF is induced into an adjacent coil that is within the same magnetic field lines of force, the EMF is said to be induced magnetically, inductively or by mutual induction. Then when two coils are connected together by a common magnetic flux, this is said to have Mutual Inductance properties or commonly called Mutual Inductance.

Mutual Inductance refers to the basic principle of operation of transformers, motors, generators and other electrical components that interact with other magnetic fields. Then it can be defined that mutual induction is a current flowing in one coil that induces a voltage in the adjacent coil. But mutual inductance can also be a bad thing because "stray" or "leakage" inductance from the coil can interfere with the operation of other components nearby by electromagnetic induction, so some form of electrical screening to ground potential may be necessary. The amount of mutual inductance connecting one coil to another depends greatly on the relative position of the two coils. If one coil is positioned next to another coil so that the physical distance between them is small.

Solar Electric Energy Generation System

Solar panels / solar cells are an important component of solar power plants (Harianto and Karjadi, 2022). Get electric power from morning to evening as long as there is sunlight. Generally, we calculate that the maximum amount of sunlight converted into electrical power throughout the day is 5 hours. Electric power from morning to evening is stored in batteries, so that electricity can be used at night, where there is no sunlight (Mujaahid *et al*, 2021). Because solar power plants are very dependent on sunlight, good planning is very necessary. Planning consists of: The amount of power needed for daily use (Watts).

Photovoltaic type solar power plants are power plants that use voltage differences due to the photoelectric effect to produce electricity. Solar panels consist of 3 layers (Qazi *et al*, 2019), the boundary layer in the centre, the N panel layer at the bottom, and the P panel layer at the top. Protons flow to the bottom of the N panel layer due to the photoelectric effect, which releases electrons from the P panel layer. This proton current transfer is an electric current. Solar Charge Controller usually consists of: 1 input connected to the solar cell output (Irwanto *et al*, 2020), 1 output connected to the battery and an output connected to a DC load (Irwanto *et al*, 2022). It is impossible for the battery's DC electric current to enter the solar cell because usually a "diode protection" is installed which functions to pass the solar cell current to the battery, not vice versa (Wang *et al*, 2023) .

Inductance

The circuit's inductance is a feature that links the rate of change in current with the voltage generated by the flux change. The induced voltage and the rate of flux change, which includes a circuit, are connected in the first equation that explains inductance. Equation 1 represents the induced voltage.

$$e = \qquad dt$$

Where:
e = induced voltage (Volt)
φ = number of series axle fluxes (Weber-turns)

The magnetic field produced by the circuit will fluctuate in response to changes in current. The induced voltage is proportionate to the rate of change in current if it is assumed that the medium in which the magnetic field is generated has constant permeability. This is because the amount of coupling flux is directly proportional to the current.

Magnetic Energy Delivery Principle

The electromagnetic resonance induction principle is used by the wireless energy delivery system, which consists of a transmitter circuit and a receiver circuit (Rezeki *et al*, 2022). An alternating current source is first rectified in the transmitter circuit using a DC module, and then the inductor (L) and capacitor (C) are added to the LC circuit to generate a nonradiative, Additionally, there is an LC circuit on the receiver side of the circuit, where L and C work to create resonance from the magnetic field the transmitter circuit creates in order to receive electrical power. A copper cable will be used in the design of this kind of winding in a wireless power transfer system. Equation 2 can be used to determine how many windings are needed for the sender and the side circuit.

$$L = \frac{r^2N^2}{9r+10l}$$

Where:
L = Inductance (H)
N = Number of turns
r = The coil radius (m)
l = Length of coil (m)

The design of the winding at the receiving end shall be equal to or close to the existing coil on the sender side.

Inductive Link Design

In order to validate the idea of inductive powering with backwards data transmission, the inductive link was developed using commercial off-the-shelf components. The inductive link is made up of two circular coils that are coaxially aligned and function as a weakly coupled air core transformer. One coil is located inside the human body, and the other is situated in an external unit above the skin. The two fundamental components of the powering system are the internal secondary power system unit (power receiver) and the external primary power system unit (power transmitter). In addition to providing the internal unit with power, the external unit also receives data from the internal unit, allowing for backward data transfer. The sensor signal conditioning circuit provides the processed sensor data to the internal unit, which then transforms it into an FSK modulated signal and transmits it back to the external unit. The next sections provide an overview of these two units together with the design considerations of a class E power amplifier for driving the primary coil.

Design Considerations

1. *The Coil System.*

The circular coil system, which consists of two hand-wound coils with appropriate geometrical, magnetic, and electric properties, functions as a weakly coupled air-core transformer between the system's internal (secondary) and external (primary) components. Physical limitations, system compatibility, and performance are taken into consideration when choosing various parameters.

2. *Choice for Secondary Resonance.*

According to reports, the best coupling efficiency can be obtained by using either parallel or series resonance. It has been demonstrated that the series resonance architecture requires a very large secondary coil inductance to attain optimum link efficiency for a given combination of coil quality factors (Q) and low-coupling factor (therefore low-efficiency connections). Due to size restrictions for the internal secondary coil in the majority of applications, including implantable biomedical sensor applications, these enormous inductance values may not be practically achievable in terms of implementation. As a result, secondary parallel resonance is typically used with low-power links, turning the LC tank into a voltage source. Similar findings have been made by Vandevoorde and Puers for high power, high coupling applications, showing that both resonance schemes are practically realizable and can be quite efficient as well.

Work Procedures

1. Preparatory stage. Because research activities focus on simulation, the first thing to do is determine the components that will be used. The components to be used are a 60 uf capacitor, frequency 5 khz, wire diameter 1.25 mm, solenoid diameter 49 cm, and number of windings 98.
2. After knowing the known components, the next step is to calculate the inductance and mutual inductance.
3. Then, after completing the calculation of inductance and joint inductance, the next step is to create a model of the wireless photovoltaic power sending system.
4. After completing the model, we run the model that we have created while observing the performance of the wireless photovoltaic power sending system and then analyzing the wireless photovoltaic power sending system.

The first step in making PVWPT is to make several component models that will be used, such as PV modules, transmitter and receiver windings, pulse driver modules and half- wave inverters. The PV module functions as a source of DC voltage which is converted into AC voltage. Pulse driver circuit to produce 5 KHz waves to drive the switching of the H-bridge circuit. Meanwhile the sending and receiving coils send and receive AC power. Solar radiation and temperature are needed to operate the PV module with specific parameters to produce voltage. The PV module, pulse driver, half-bridge circuit, transmitter coil, magnetic relay, and receiver were modeled using MATLAB-SIMULINK. system performance simulation results PVWPT was observed and analyzed.

Modeling the PV module

PV modeling is needed as a voltage source from PVWPT. Solar radiation affects the performance of PV modules and PVWPT systems. PV and PVWPT performance will increase when solar radiation is high. And if solar radiation is low, there will be a decrease in output power, power transfer efficiency, reduction in power transfer distance, and affect the reliability of the fractional PVWPT system.

RESULTS AND DISCUSSION

The performance of the photovoltaic module was analyzed using solar radiation of 1000 W/m2 and a temperature of 25°C. The results of the system performance were presented in the form of current, voltage and power curves. Based on the PV module, it has an open circuit voltage of 21.5 volts, then the voltage will enter the inverter to be converted from DC to AC voltage to supply AC voltage to the sending coil and receiving coil of the photovoltaic wireless power transfer (PVWPT) system. simulated at a temperature of 25°C and radiation of 1000 W/m^2 at a distance of 1 meter.

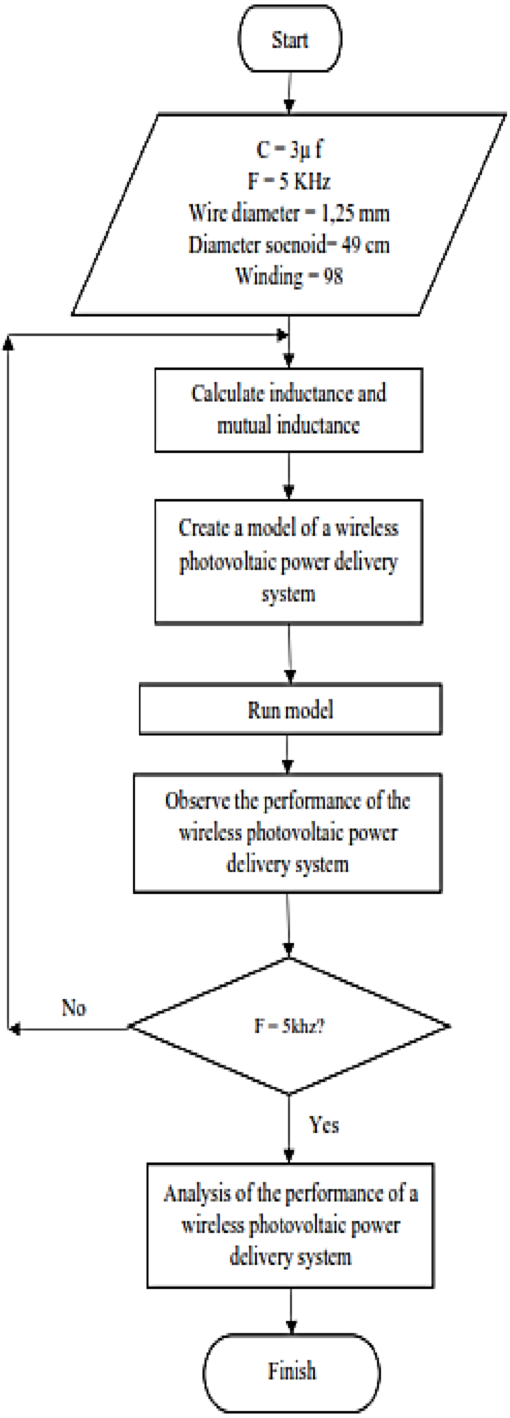

Figure 1. Research Flowchart

PV Module Performance

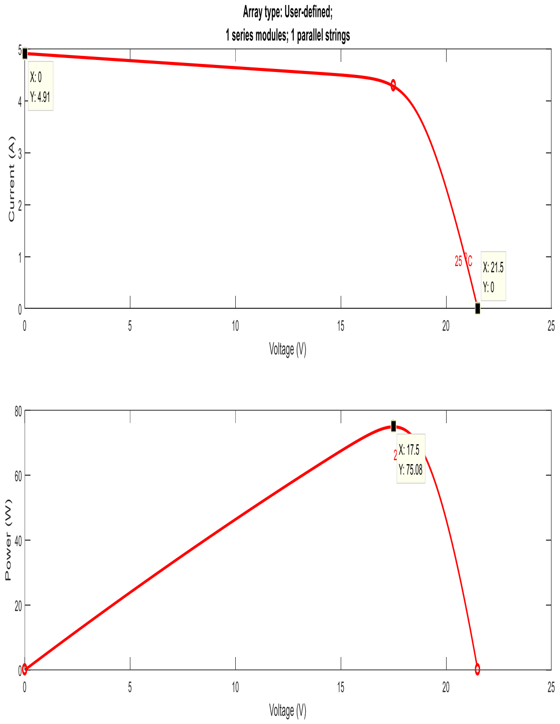

Figure 2. PV Module Current, Voltage and Power Curves

Figure 2 above is a picture of the PV module performance curve where at a solar radiation level of 1000 W/m2 and a temperature of 25°C, the PV module produces a current of 4.91 A when the voltage supplied is 21.5 V. If the PV module is in the condition solar radiation higher or lower than 1000 W/m2, or operating at a temperature different from 25°C, the resulting current and voltage values will be different. For example, when the intensity of sunlight is higher, the current and power produced by the PV module may increase, and vice versa. starting from zero current value when the voltage is zero (because current only flows when there is voltage), increasing exponentially with increasing voltage until it reaches the maximum current peak value (Imax) at the MPP point (Maximum Power Point) of 75.08 w and a voltage of 17 .5 V. After reaching the MPP point, the current will decrease with increasing voltage. (Irwanto *et al*, 2023).

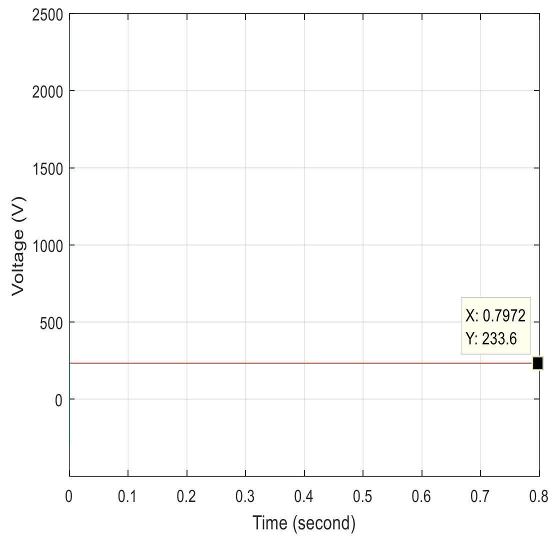

Figure 3. PV Module Voltage Output

Based on an open voltage of 21.5 V, the DC source in the PV module is converted into AC voltage in the TC using an H- Bridge. The graph above is the result of the converter voltage from 1 series and 1 parallel. For solar radiation and a temperature of 1000 W/m2 and 25°C, the output voltage of this converter is 233.6 V under PVWPT system conditions.

Performance of Sending And Receiving Coils

Based on the picture, the PVWPT circuit produces a DC output voltage of 233.6 V which is converted into an AC wave. The sinusoidal shape of the AC voltage wave is due to the 60 µF capacitor and 100 µH inductor which are connected in series in the middle of the receiving coil and connected to the sending coil. The sending and receiving coils use copper cables with a wire diameter of 1.25 mm, a resistivity of 1.68 x 10-8 Ωm, and a wire diameter of 49 cm. Based on equations 3 to 5, the coil resistance is 2.08 Ω.

At a temperature of 1000 W/m2 and 25°C and a distance of 1 meter it will produce an AC voltage on the sending coil of 278.3 V and a current of 6.191 A. On the receiving coil side it will receive an AC voltage of 268.1 V and a current of 4.584 A. AC voltage is obtained from the conversion of a half-bridge inverter. This AC voltage will create a fluctuating magnetic field around it. This magnetic field then passes through the receiving coil,

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producing an induced voltage in the coil. This relationship describes the phenomenon of mutual inductance between the sending coil and the receiving coil in PVWPT.

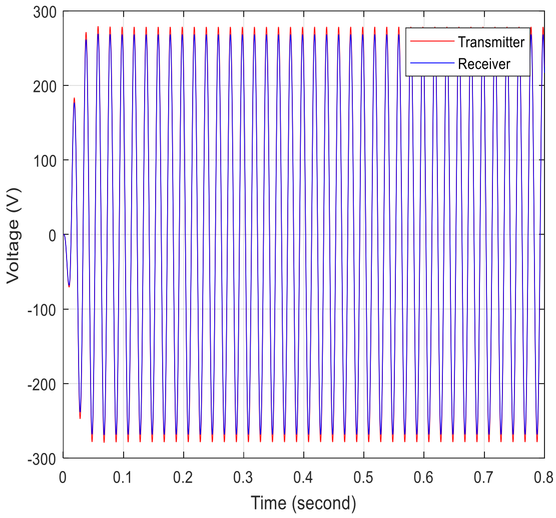

Figure 4. Graph of AC Voltage on the Sending and Receiving Coils at a Distance of 1 Meter

Mutual Inductance

Mutual inductance, also known as mutual inductance is when two or more inductive coils influence each other and produce a mutually related magnetic flux. Mutual inductance occurs when a change in current in one coil produces a magnetic flux across the other coil, and this flux then induces a voltage in that coil. Mutual inductance is measured in henry units (H) and is an important parameter in coils connected in an inductive circuit. If two coils are interconnected and have significant mutual inductance, a change in current in one coil will induce a voltage in the other coil, and vice versa. In PVWPT (Photovoltaic Wireless Power Transfer), mutual inductance also plays an important role. Mutual inductance in the context of PVWPT refers to the magnetic interaction between the transmitter coil and the receiver coil.

When alternating current (AC) flows through the sending coil, it creates a fluctuating magnetic field around it. This magnetic field then passes through the receiving coil, producing an induced voltage in the coil. This relationship describes the phenomenon of mutual inductance between the sending coil and the receiving coil in PVWPT. Good mutual inductance between the sending coil and the receiving coil is essential for efficient power transfer in a PVWPT. In the presence of strong mutual inductance, most of the magnetic field generated by the sending coil can be induced and used by the receiving coil to transfer electrical energy wirelessly. In addition, mutual inductance can also influence the efficiency and characteristics of wireless power transfer in PVWPT. The geometric design of the sending coil and receiving coil, the distance between them, and the resulting magnetic linkage directly influence the level of mutual inductance and the overall performance of the PVWPT system.

Table 1. Results of Testing the Effect of Distance on PVWP

Distance	Mutual Inductance	Sending Voltage	Sending Current	Receiver Voltage	Receiver Current
1	0.0790	278.3	6.191	268.1	4.584
2	0.0788	278.3	6.189	268.1	4.581
3	0.0784	278.1	6.184	267.9	4.577
4	0.0779	277.9	6.18	267.6	4.574
5	0.0772	277.6	6.17	267.4	4.558
6	0.0764	277.3	6.156	267.1	4.557
7	0.0755	276.8	6.143	266.6	4.546
8	0.0744	276.3	6.125	266.1	4.533
9	0.0733	275.6	6.104	265.4	4.518
10	0.0720	274.7	6.077	263.8	4.497

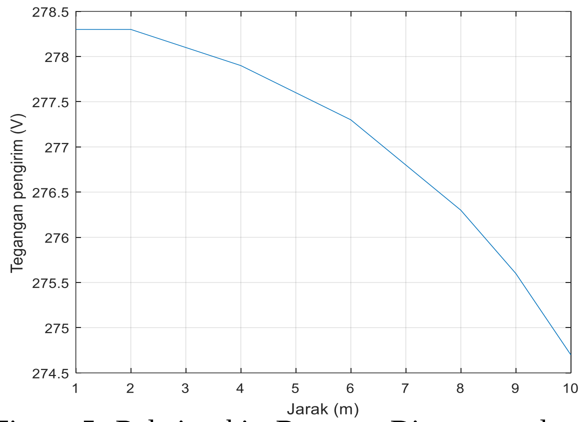

Figure 5. Relationship Between Distance and Sender Voltage

In Figure 5, the greater the distance, the smaller the mutual inductance.

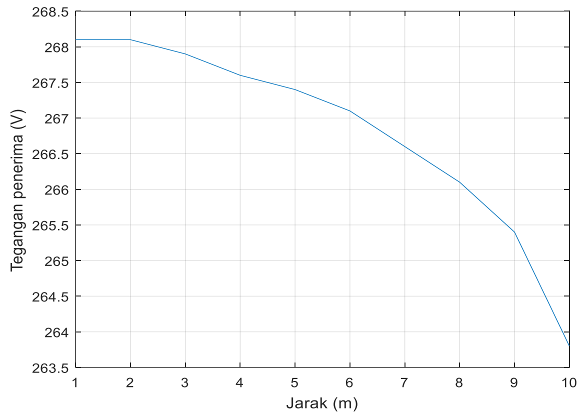

Figure 6. Relationship Between Distance and Receiver Voltage

In Figure 6, the farther the distance, the less voltage will be received on the receiving coil.

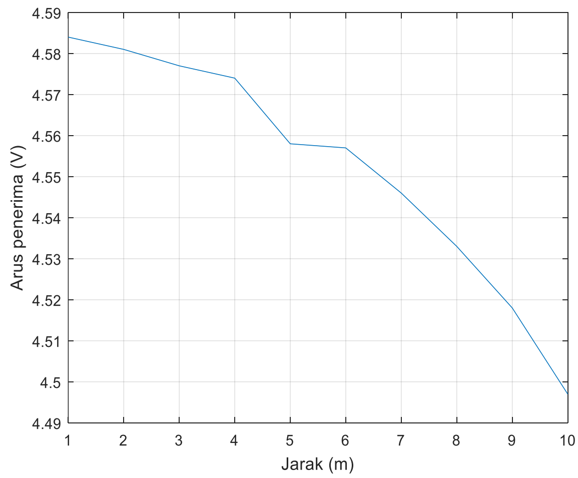

Figure 7. Relationship Between Distance and Receiver Current.

In Figure 7, the farther the distance, the less current is received in the receiving coil.

CONCLUSIONS

PVWPT (Photovoltaic Wireless Power Transfer) is a system that combines photovoltaic (PV) technology and wireless power transfer to transfer electrical energy from a PV module to a receiving device or system without using physical cables. By using PVWPT, electrical energy can be generated from sunlight by PV modules and wirelessly transferred to receiving devices that require power. The farther the distance, the less voltage will be sent. And the error percentage is 5%.

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