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Experimental Analysis on Wireless Power Transfer for Continuous Charging of a Mobile Robot

Abstract— Wireless Power Transfer (WPT) is not a new finding in Electrical Engineering technology; however, currently, it is back to fame due to the increment of device mobility, avoiding the hazardous wiring application, cleaner connection, and improves vehicle mobility. The WPT can be an alternative to power an automatic transport system that results in an aesthetic and safe system. The continuous charging ensures system reliability. The main problem with WPT is that it is still limited by the distance, which can be overcome by setting the transmitter and receiver in a sufficient distance. This paper discussed [1] the prototype of automated transport and simulated using a line follower mobile robot, which is charged continuously by a WPT system. The proposed method is tested by two experimental test-bed settings; the under the track and overhead transmitter setting. The produced voltage and currents move the robot at a different speed that is achieved by varying the distance between transmitter and receiver. The ideal distance between transmitter and receiver attached to the line follower robot is 2 cm indicated by DC motor speed. For [1] under the track transmitter setting, at the distance of 2 cm, the robot's DC motor moves in 104.5 RPM, and for the overhead transmitter setting, DC motor speed is 93.4 RPM. This difference is not very significant; therefore, both applications are applicable. However, for the application in a real automated transport system, the under the track transmitter setting is aesthetically more pleasant for city planning.

Keywords— Line follower robot, mobile robot, receiver, transmitter, wireless energy transfer.

I. INTRODUCTION

[1] Wireless Power Transfer (WPT) is not a new finding in Electrical Engineering technology, which was developed for the first time in 1890 by Nikola Tesla. His invention,

named Tesla Coils, was the first demonstration of WPT to power all lamps located within a radius of twenty-five miles from the source without any wires required. Despite the success of Tesla's demonstration, at that time is was wired technology cheaper to build that building a power generation required by the Tesla Coil [1][2]. Despite the success of Tesla's demonstration, the wired electrical energy development is rising due to its easiness and not limited by distance. However, as the Electrical and Electronics technology development is raising faster and resulting in excessive usage of cable and aesthetically unpleasant and hazardous, WPT is back to fame recently due to the increment of device mobility, avoiding the hazardous wiring application, cleaner connection, and improve vehicle mobility [3][4]. There are up to seventh methods in generating WPT, and the most famous ones are inductive coupling, microwave power transmission, and laser technology application [5]-[16].

The WPT application can be extended to the power of an automatic transport system. WPT transmitter can be installed overhead or under the track of the vehicle. WPT implementation creates an aesthetic and safe system. The continuous charging ensures system reliability. The main problem with WPT is that it is still limited by distance or radius of energy transfer, however, if the charging point is not too far from the load or repeater or node are installed at the specified distance, WPT can be an alternative for powering a transport system [4]-[16].

The automated transport system [3] is defined as a system where an automated system partially or fully replaces the driver consists of a controller, sensors, and communication devices. The automation of this area is a very high potential for a redundant or fixed track, for example, from one station to another in a factory. The driver replacement, in the long term, is contributing to decreasing the company cost. The fully automated system might be not available in a very near future in Indonesia, moreover involving wireless energy transfer without requiring any cables [15][16]. The objective of this study is to show the possibility of creating a wireless transport system. This paper discussed [1] the prototype of automated transport and simulated using a line follower mobile robot, which is charged continuously by a WPT system. Two possible experimental settings are presented to prove the effectiveness of the proposed method.

II. METHOD

WPT works by utilizing the principle of electromagnetic resonance emitted by two copper coils that resonate with the same frequency between them. The two coils are called Transmitter and Receiver. The transmitter coil is connected to the output of an Oscillator, which is connected to the electric source. The copper winding coils on the receiver attached to the line follower robot system is the main load in this study.

Electrical energy originating from an electrical source creates resonance at a certain frequency (Mhz) at the copper coil. Furthermore, the space around the copper coil will be filled with non-magnetic radiation, and this will create a magnetic field that will transfer energy to the copper coil. The magnetic field connects the transmitter to the receiver side, which resonates in the same frequency as the first copper coil.

Fig. 1. The setting of an automated transport system.

Fig. 2. Block [3] diagram of the proposed method.

In this study, the WPT [2] is used to power a line follower robot as the prototype of an automated transport system. The design is kept simple to the basic line follower robot in which the transmitter part is positioned in two alternatives, at the upper line or below the vehicle track, as shown in Fig. 1.

The design of WPT for continuous charging a line follower robot simulated in Fig. 1 [7] is shown in Fig. 2, while Fig. 3 gives the electrical one line diagram of the whole system. The one-line diagram shows the detail of electric components to create a WPT. The components that build the proposed WPT system shown in Fig. 2 and 3 considered in this study are elaborated as follow

A. The Transformer step down

used to step down the voltage from the utility source to be the input of the system. It converts the higher voltage and lower current power into a low voltage and high current power. The primary winding of the transformer or primary coil is connected to the source. The magnetization occurs due to the running current in the ring of primary coils. The magnetic induction reaches the secondary coils without a physical connection between them. The transformer steps down considered in this study is shown in Fig. 4.

B. The Rectifier

converts Alternating Current (AC) from utility sources to Direct Current (DC) to be the input to the system. In this study, the full-wave rectifier circuit applied CT transformer equipped with two rectifier diodes and capacitors. The rectifier in Fig. 4 shows the connection of a 3A step-down transformer primary coil to supply of 220 V/ 50 Hz. The AC produces by transformer secondary coils is 24 V and 3 A, and the current is rectified by converting both electrical polarities (positive and negative) of the AC input waveform to pulsating DC and resulted in a higher average output voltage.

C. The Oscillator Royer

was first applied [6] by George H. Royer in 1954. The Oscillator Royer used in this study is shown in Fig. 5. A capacitor is connected to the primary circuit to make a resonant circuit. Each half of the primary circuit is driven by a transistor in a push-pull configuration. Winding coupling feedback from some of the remaining transformer flux returns to the transistor base to provide positive feedback, resulting in oscillations. [4] The oscillation frequency is determined by the maximum magnetic flux density, electrical voltage, and inductance of the primary winding. The Oscillator circuit consists of two 80NF70 MOSFET transistors that work on the concept of a flip-flop, to produce a working frequency determined by a combination of inductor and capacitor values in the circuit.

Fig. 3. One line diagram of the proposed WPT system to power [2] a line follower robot.

D. The Receiver circuit

shown in Fig. 4 consists of a series of receiver coils that are parallel to the balancing capacitor. [5] The value of the LC combination design is arranged in such a way to respond to

frequency resonance generated by the transmitter circuit. The capacitor in the circuit is used to store electric charge and a 7805 LC regulator to regulate 5V. The results of this rectifier produce 5V stable DC source to move [2] a line follower robot.

Fig. 4. Transformer step down, rectifier, and regulator considered in this study.

Fig. 5. Oscillator Royer applied in this study.

Fig. 6. Receiver applied in this study.

E. Line follower robot

considered in this study is moved by a DC motor shown in Fig. 7. Fig. 7a is the front view of the robot, and Fig. 7b is the receiver winding coils that receive the supply to move DC motor as the main actuator of the robot. The robot reads the track using an LDR sensor that differentiates between the black (track) and white (environment).

The complete specification of WPT considered in this study is given by table I, where n is the amount of winding, d is the thickness of the windings, r is the radius of coil, L is the inductor in Hendry (H), C is a capacitor in Farad (F), and F is frequency in Hz. The inductance, Frequency (F) and Induction Voltage (VL) are given by

Fig. 7. Line follower robot which is the load in this study.

The magnetic induction relative to 3 the distance between the transmitter and line follower robot (receiver) is given by

B = $\mu 0$,

$2\pi a$

(2)

where B is the magnetic induction, $\mu 0$ is 4π × 10−7 (WbA), i is the electric current (A), and a is the distance from the centre of winding (m).

The amount of magnetic flux (Φ) generated based on the area of coil (A) is given by

Φ = B × A,

(3)

and the electromagnetic force (Ei) produced can be calculated as

E = N ΔΦ,

i Δt

(4)

where N 3 is the amount of windings, ΔΦis the changing of magnetic flux, and Δt is the time changing.

TABLE I. SPECIFICATION OF TRANSMITTER (TX) AND RECEIVER (RX)

IN THIS STUDY.

Terms

N

d

(cm)

r (cm)

L

(mH)

C

(F)

F

(Hz)

VL

(Volt)

Tx

36

3

4.5

15.08

1.14 x 10-7

1213.85

22,62

Rx

10

2.8

3.4

0.78

2.76 x 10-7

340.92

5,52

III. RESULT AND DISCUSSION

In order to show the effectiveness of the proposed method, experiments were conducted by following the experimental settings shown in Fig. 1. The experiments were conducted by letting [2] the line follower robot to move on the track with two conditions; the track with overhead transmitter and below the track transmitter. Both experimental tracks are round tracks since this track is harder to follow that straight-line one.

A. Experimental test-bed with below the track transmitter

The experimental setting with the transmitter located below the track is to show the possibility of an underground transmitter line along the vehicle track. This [1] setting is aesthetically more pleasant, and the vehicle is more comfortable to move, as shown in Fig. 7 since all the necessary components are hidden under the track. Fig. 8a shows the detail of the mechanical design of transmitter and receiver, and Fig. 8b is the experimental test-bed [2] of the line follower robot. For real application of automated transport system, this arrangement is more environmentally friendly.

(a) Mechanical design.

(b) Experimental test-bed

Fig. 8. Experimental setting for below the track transmitter.

the robot is getting slower as 3 the distance between the robot and WPT increase.

Table V shows the relation between distance and the produced magnetic induction, magnetic flux, and electromagnetic force. The value of magnetic induction, flux, and electromagnetic force are decreasing as the distances are increasing between the transmitter and receiver (attached to the robot).

Fig. 9 shows the relation between distance and the produced voltage and current. As the distance gets further, the produced power output is decreasing. The maximum produced voltage and current is 5.19 V and 0.19 A within 1 cm distance between transmitter and receiver. Based on table IV, the ideal distance is 2 cm. However, the robot is still moving up to 5 cm with a prolonged speed. The maximum distance between the transmitter and the line follower robot's receiver coils is 5 cm.

TABLE IV. RELATION BETWEEN DISTANCE AND WPT POWER OUTPUT WITH MOTOR SPEED.

Table II presents the transmitter data according to Fig. 4 and 5, and table III presents receiver data. The data is taken by measuring the input and output. The calculation of frequency oscillations for transmitter (FTX) and receiver (FRX) are given by eq. 1, where FTX is 58.946 KHz and FRX is

58.217 KHz.

TABLE II. TRANSMITTER DATA.

TABLE V.

RELATION BETWEEN DISTANCE AND WPT POWER OUTPUT WITH MOTOR SPEED.

No

Input

MOSFET

Output

Fm

Fc

V

I

V

I

V

I

54.5

Khz

58.946

Khz

1

22.78

0.54

22.1

0.58

22.5

0.16

2

22.77

0.53

22.5

0.57

22.7

0.15

3

22.75

0.54

22.55

0.57

22.6

0.13

4

22.76

0.52

22.4

0.56

22.4

0.16

Av

22.65

0.53

22.4

0.57

22.55

0.15

TABLE III. RECEIVER DATA.

No

Input

MOSFET

Output

Fm

Fc

V

I

V

I

V

I

54.6

Khz

58.217

Khz

1

18.98

0.24

18.53

0.29

5.37

0.9

2

18.63

0.23

18.44

0.31

5.2

0.9

3

18.44

0.23

18.3

0.3

4.98

0.1

4

18.51

0.24

18.97

0.31

5.1

0.9

AV

18.64

0.23

18.31

0.3

5.16

0.7

Transmitter averagely sends 22.55 V and 0.15 A, and the received voltage in the receiver is averagely 18.59 V and

0.24 A, [2] and the output of the receiver to power line power robot is averagely 5.29 V and 0.70 A. These amounts of [4] voltage and current are enough to move the robot. Table IV shows the relation between distance and WPT power output with motor speed. The measurement data shows that distance dramatically affects the value of voltage, current, power, and speed of the robot (RPM). From table III, [3] it can be seen that the ideal distance is at 2 cm. At 2 cm distance, the generated power is enough to move the robot, while at the distance of 3-5 cm the value of the energy transferred is not sufficient to power the robot indicated that

Fig. 9. The relation between distance and the produced voltage, current, and power for [1] under the track transmitter.

B. Experimental test-bed with overhead transmitter

The second experimental setting for wireless powered is overhead transmitter as designed in Fig. 1. This receiver in this setting is placed on top [2] of the line follower robot. Fig. 10 shows the complete set up and the experimental test-bed. Line follower robot is set to drive in the black track by utilizing LDR functioning as a light sensor.

Fig. 10. Experimental setting for overhead transmitter.

Figure 11 shows the screenshot of the line follower robot moving on the track powered by WPT proposed in this study. The distance is set into the ideal 2 cm between the transmitter and receiver.

[5] (a)

(b)

(c)

(d)

Fig. 11. Screenshot of WPT system and line follower robot.

The power received in the receiver circuit is lower than the power in the transmitter circuit due to the voltage at the transmitter [3] is greater than the voltage at the receiver, as shown Table VI. The measure voltage range at the transmitter (VTX) is 21.4V - 21.6V, the measured current (ITX) is 0.297 – 0.303A, and the measured power (PTX) is 6.356 – 6,545 watts. The measured range of receiver voltage on [2] the Line Follower robot (VLF) is 5.18 – 5.21V, the measured current (ILF) is 0.17 – 0.184A, and the measurement power (PLF) robot is 0.884 – 0.953 W.

Fig. 12 shows the measurement result of voltage to power the line follower robot relative to the distance between the transmitter and receiver. The furthest distance to power the robot is 4 cm with [5] the output voltage of 2.25 V, and this limit is indicated by whether the power generated is not enough to move the robot. At a distance of 2-3 cm, the most effective distance to move the robot. The shortest distance is 1 cm and the robot moves to fast when the voltage source (the produced voltage is 5.20 V) is more than the required voltage (5 V). The voltage generated is very distance dependence. The produced voltage is decreasing as the distance increases. Figure 16 3 shows the effect of distance on robot speed ,and it is getting slower as the distance gets further.

TABLE VI. THE RELATION BETWEEN ROBOT SPEED AND TRANSMITTED POWER.

Jarak

Transmitter

Receiver

RPM

VTX

ITX

PTX

VRX

IRX

PRX

(V)

(A)

(W)

(V)

(A)

(W)

1 cm

21.45

0.30

6.4

5.20

0.19

0.98

103.5

2 cm

21.60

0.31

6.6

4.30

0.18

0.77

93.4

3 cm

21.40

0.29

6.2

3.15

0.17

0.53

88.4

4 cm

21.48

0.30

6.4

2.25

0.09

0,20

67.7

Fig. 12. The relation between distance and the produced electricity.

Fig. 13. The relation between distance and the produced current.

Fig. 13 shows that the changing distance between the transmitter and receiver attached to 2 the line follower robot affects DC motor speed indicated by the decreasing of its RPM. The ideal distance is 2 cm with a motor speed of 93.4 RPM. The generated WPT is sufficient to power line follower robot. At 1 cm distance, the generated power is more than required to power the robot that causes the robot to get over speed indicated by 103.5 RPM. The robot is getting slower by the distance of 3 cm (88.4 RPM), and 3 at the distance of 4 cm, it is almost not moving at all (67.7 RPM).

TABLE VII. THE RELATION BETWEEN ROBOT SPEED AND TRANSMITTED POWER.

Dist (cm)

1 Under the track

transmitter setting

Overhead Transmitter

setting

Difference

VRX

IRX

RPM
VRX
IRX

RPM
V
I

RPM
(V)
(A)
(V)
(A)
(V)
(A)
1
5.19
0.19
118.5
5.2
0.19
103.5
0.01
0
-15
2
3.6
0.18

104.5

4.3

0.18

93.4

0.7

0

-11.1

3

2.8

0.17

87.8

3.15

0.17

88.4

0.35

0

0.6

4

2.1

0.13

75.8

2.25

0.09

67.7

0.15

-0.04

-8.1

Table VII shows the comparison between under the track and overhead transmitter setting. The produced voltage, current, and power are similar; therefore, both setting are applicable. The application in the real automated transport system, [1] the under the track transmitter setting is aesthetically more beautiful for city planning.

IV. CONCLUSION

This paper presents the experimental analysis on WPT for continuous charging of a mobile robot. The proposed method is tested by two experimental test-bed settings; the under the track and overhead transmitter setting. Both experimental setting results give good result to prove the proposed method. The produced [4] voltage and current are enough to move the robot in different speed by varying the distance between transmitter and receiver. The ideal distance between transmitter and receiver attached to [2] the line follower robot is 2 cm indicated by DC motor speed. For [1] under the track transmitter setting, at the distance of 2 cm, robot's DC motor moves in 104.5 RPM, and for the overhead transmitter setting, DC motor speed is 93.4 RPM. This difference is not very significant; therefore, both applications are applicable. However, for the application in a real automated transport system, the under the track transmitter setting is aesthetically more pleasant for city planning.

Sources

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