

Neural Network Frequency Selector for Maximum Power Transfer

Karim Gamal El-Sayed, Ranim Al Ahdab, and Ahmed El-Shenawy

Abstract—This paper propose a method for reaching a maximum power transfer using wireless system. The power is transmitted using the method of impedance matching technique. It depends on choosing the parameters of the transmitter receiver circuit and proper distance and gap media , which allow the transfer of maximum power , we propose a neural network configuration to deliverer the required frequencies to achieve maximum power transfer from the given circuit parameters . The choice depends on thirteen parameters which are divided to fixed parameters like inductance, capacitance and variable parameters like distance and misalignment. The system is tested on the hardware set up and showed acceptable performance illustrated by presented experiments.

Index Terms—Energy transfer, maximum power transfer, neural network, wireless power transfer, Witricity.

I. INTRODUCTION

There are many applications like petroleum industries where transferring electricity using wired cable is very difficult. In addition to using batteries as supplies is not an option. Such problem increases the progress in the field of wireless energy transfer .The recent researches have worked a lot to achieve transferring a greater power across a larger air gap. The recent researches have worked a lot to achieve transferring a greater power across a large air gaps by using electromagnetic induction like transformer but it didn't give the required result for long transfer distance , by using electromagnetic induction with resonance which give a better result , and there are other method used for wireless power transfer like electromagnetic radiation with radio waves which more useful for low-power device such as wireless sensors and electromagnetic radiation with Light Amplification by Stimulated Emission of Radiation (laser), this method is called "power beaming" technology. It is being used in military weapons, aerospace applications, and consumer electronics. Wireless Power Transfer (WPT) is the transmission of electrical energy from a power source to an electrical load without a conductive physical connection or interconnecting wires. The transmission of wireless power process is much harder than wireless communication process. In this work we use the means of WPT methods, which depends on the electromagnetic (EM) induction with resonance technique. A variation of electric equipment has

been proposed, starting from low power consumption devices like cell phones and laptops until the large applications as electric cars and vehicles , as in biomedical to power the capsule endoscope [1] , to transfer the power from outdoor power source units like photovoltaic panels unit to indoor [2], also charging electric vehiclesetc . In order to maximum power transfer there are a lot of problems which is the difficulty of determine the perfect resonance frequency because the big number of nonlinear parameters which affect in this process , so Section II of this paper describe the theory of operation of wireless power transfer and why it's important the precise tuning of frequencies, Section III present the system configuration which is divided to two part , the data and the parameters used in the system and the topology of the neural network .

II. THEORY OF WIRELESS-POWER TRANSFER

Wireless power transfer is a technique which provides the ability to transfer high amounts of power between two coils that are tuned to resonate at the same frequency using (magnetic resonance coupling) method as shown in the Fig. 1, with magnetic resonance coupling electric current flowing through a primary coil creates a magnetic field that acts on a secondary coil producing a current within it. Coupling must be tight in order to achieve high efficiency. As the distance between the primary and secondary increases the more loss in transferred magnetic flux lines from the primary to secondary coils. Even over a relatively short distance range the inductive coupling is grossly in efficient, wasting much of the transmitted energy.

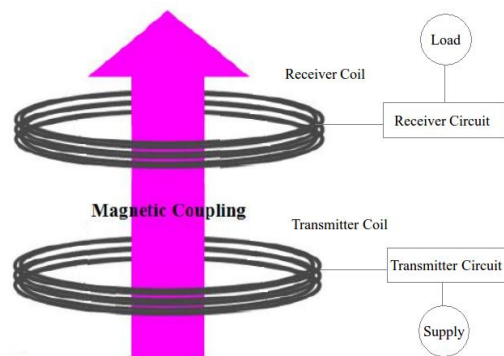


Fig. 1. Schematic drawing of mutual magnetic coupled coils for wireless power transfer systems.

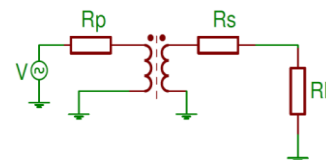


Fig. 2. The equivalent circuit of the system.

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As shown in Fig. 2 the primary and secondary resistance (R_p , R_s) represent the resistance of the transmitter and receiver circuit respectively, R_L represent the resistance of the load. The Q factor (quality factor) of any coil is

$$Q = \omega \times L / R \quad (1)$$

so

$$R_p = \omega \times L_p / Q_p \quad (2)$$

$$R_s = \omega \times L_s / Q_s \quad (3)$$

where L_p and L_s are the inductance of the primary and secondary coil and Q_p and Q_s are the Q -factor of the primary and secondary coil [3]. For effective system we need to maximize the power delivered to the load and this happen when $R_L \gg R_s$. As shown in Fig. 3 we referred the secondary resistive to the primary side using coupling factor K

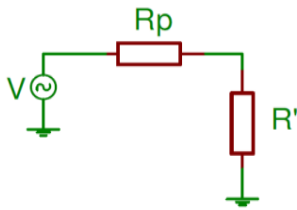


Fig. 3. Equivalent circuit after referring.

$$R' = K^2(L_p / L_s)(R_s / R_L) \quad (4)$$

And by the same logic for effective system we need to maximize the power delivered to the load and this happen when $R' \gg R_p$.

$$\text{So } R_L \gg \omega \times L_s / Q_s \quad (5)$$

By substitution equation 4 with 5 and 2 we get

$$K^2(L_p / L_s)(R_s / R_L) \gg \omega \times L_p / Q_p \quad (6)$$

To build an effective system we should constructed a very high Q value where the higher the Q is, the narrower the bandwidth of the resonant circuit.

$$W = 2 \times \pi \times f \quad (7)$$

$$Q = (\omega_o / \Delta\omega) = (f_o / \Delta f) \quad (7)$$

$$\omega_o = 1 / \sqrt{LC} \quad (8)$$

So one of challenges to improve the power transfer so can get very high Q by very precise tuning for the frequencies as shown in Fig. 4.

III. WIRELESS-POWER TRANSFER BASED ON NEURAL NETWORK SELECTOR

In this paper we build a wireless power transfer system controlled by a neural network selector where we can maintain transfer power with minimum losses and for a longer distance. Determining the best resonance frequencies is not an easy job. In this work we estimated the required frequency by using a neural network. The hardware configuration of the wireless power transfer system shown in Fig. 5 starting by the power source then the power electronics inverter to be transfer to an AC voltage to be able to control and tune the frequencies, then the current pass via the

transmitter coil which generate the electromagnetic field and in the receiver side we found the receiver coil followed by the rectifier then the load. We measure the current and the voltage in both side to permit to calculate the power and the frequencies.

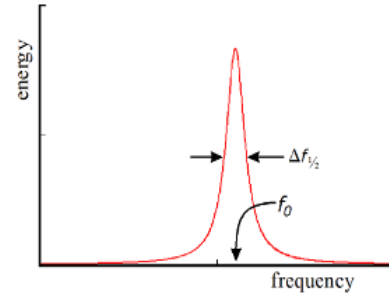


Fig. 4. Resonance curve.

Two kinds of data are introduced to the controller which are constant data (fixed values during the experiment) and variable data (which can change during the operation and they are measurable by regular sensors).

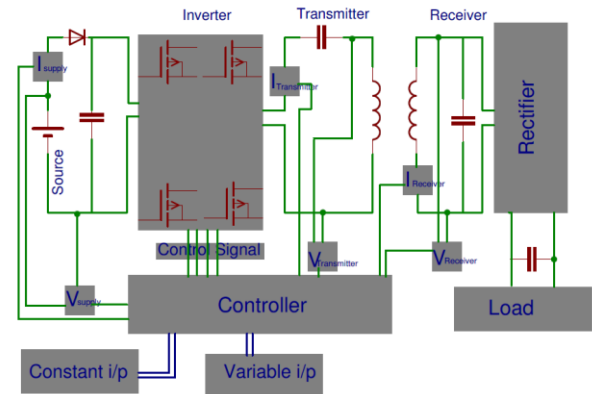


Fig. 5. System configuration.

A. Data Representation

TABLE I: SYSTEM PARAMETERS

| N# | Parameter | Description | Range |
|----|------------------|---|-----------------|
| 1 | Tx N-Turns | N-turns of transmitter coil | 1 → 50 |
| 2 | Rx N-Turns | N-turns of Receiver coil | 1 → 50 |
| 3 | Tx Radius | Tx coil Radius (in mm) | 1 → 350 |
| 4 | Rx Radius | Rx coil Radius (in mm) | 1 → 350 |
| 5 | C1 | Capacitance value in Tx circuit (in nF) | 0 → 200,000 |
| 6 | C2 | Capacitance value in Rx circuit (in nF) | 0 → 200,000 |
| 7 | L1 | Inductance value in the Tx circuit (in uH) | 0 → 90 |
| 8 | L2 | Inductance value in the Rx circuit (in uH) | 0 → 90 |
| 9 | Kind | Kind of resonance circuit Series or Parallel | Discrete values |
| 10 | Gap | Kind of Gap (air, brick, wood wall, Dry wall ..etc) | Discrete values |
| 11 | Distance | Between Tx and Rx (in mm) | 0 → 250 |
| 12 | Rotation (r) | angular misalignment where $r = \cos(\text{angle})$ | 0 → 1 |
| 13 | Displacement | lateral misalignments (in mm) | 0 → 50 |

Each experiment takes in consideration 13 main parameters divided into two groups firstly the constant parameters such as the numbers of turns of coil of transmitter and receiver and their radius , the capacitors and inductors value of transmitter and receiver circuit , the kind of their connection (series or parallel) , the kind of gap . The variable parameters which can change during our experiment such as the distance between transmitter coil and receiver coil and finally angular misalignment and lateral misalignments as shown in Fig. 6 , which represent in Table I .

B. Ann Topology and Performance

The ANN have been trained by 39 experiments data [4]-[9] So all this values have been normalized to the range of 0 to 1. Table II shows all the parameters that were used when training the network. The network ran for 1000 iterations with a learning rate of 0.007, a momentum rate of 0.44 and a minimum error of 0.005 since it's not a very critical application so it's an acceptable range of error. We ran the experiments for 10000 iterations. The Sigmoid activation function is defined as:

$$f(t) = \frac{1}{1 + e^{-T.P}} \tag{9}$$

It denormalizing and sending it to be convert to a PWM signal which can control the frequencies through a power electronic converter.

TABLE II: ANN PARAMETERS SETTING

| Parameters | Value |
|-----------------------------------|---------|
| Number of neurons in input layer | 13 |
| Number of neurons in output layer | 2 |
| Number of neurons in hidden layer | 3 |
| Iterations number | 1000 |
| Learning rate | 0.007 |
| Momentum rate | 0.44 |
| Error | 0.003 |
| Activation Function | Sigmoid |

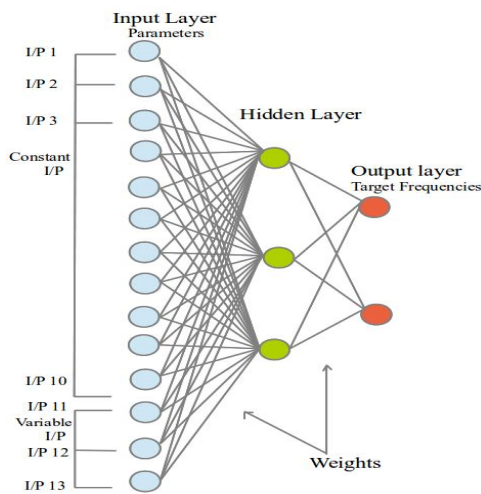


Fig. 6. ANN model.

Table III below represents the number of records that were recognized by the network in the training and the testing phase. The number of recognized records was divided by the total number of records with respect to each case set. The

result of this fraction is called the recognition rate [10].

TABLE III: RECOGNITION RATE

| | Training | Testing | Total |
|------------------|----------|---------|--------|
| Recognition Rate | 97.4% | 74% | 84.26% |

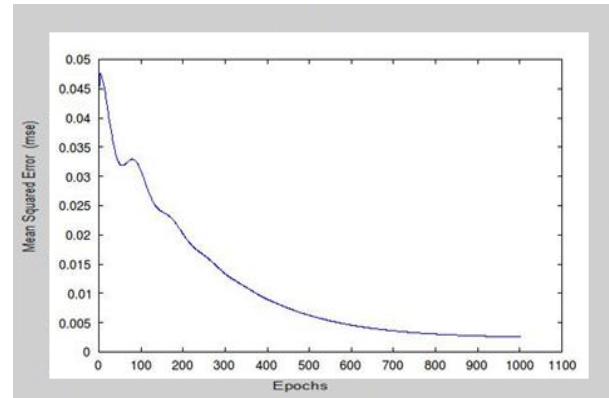


Fig. 7. Variation of the MSE with the iteration number.

In Fig. 7 we can see that the target error and the actual output curve are very close which means that the error is minimized and the network well trained. The system measure the power delivered at the receiver part and check if this is the maximum power by changing the frequency one step plus and one step minus and measure the power again until to confirm that this is the correct frequencies, if it was correct the system make a delay then check again, if not the system use a MPPT algorithm to reach to the target frequencies .If any, should be placed before the references section without numbering. MPPT is an algorithm usually used in the photovoltaic system to track the maximum power. In this method the controller adjust the voltage to maintain the maximum power point. In this paper we used the same algorithm but to adjusting the frequencies by controlling the duty cycle in the power electronics converter.

IV. EXPERIMENTAL RESULT

This section demonstrates the performance of the proposed controller by two experiments. The first experiment presents the change in the power delivered during the change in the distance and the selected frequency to achieve maximum power transfer as shown in Fig. 8, in the second experiment at 7 cm distance and 351 Khz frequency Table IV represents the result data of power delivered to the load when there is a change in the angular misalignment.

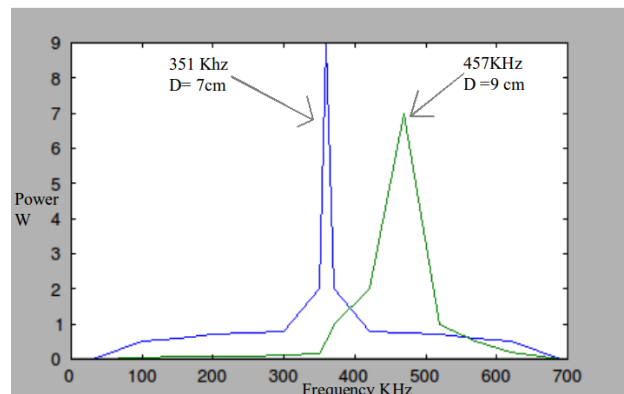


Fig. 8. Power-frequency response by changing distance.

The system tested at 7 cm distance and 351 KHz as show in Fig. 9, the led in the receiver circuit work without any trouble.

TABLE IV: RECOGNITION RATE

| Angle of misalignment | 0° | 30° | 60° |
|-----------------------|-----|-----|-------|
| Power delivered | 9 W | 4 W | 1.5 W |

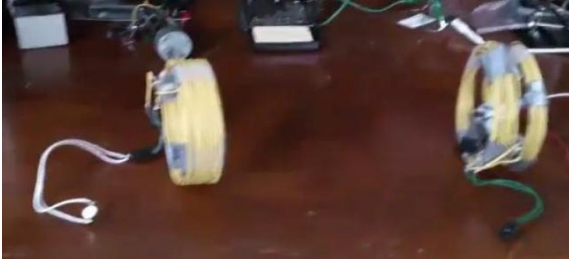


Fig. 9. Practical test.



Fig. 10. Practical test for rotational misalignment.

The system is work when there is a rotational misalignment as shown in Fig. 10 when the receiver coil rotate with an angle and the led still work.

V. CONCLUSION

In this study of wireless power transfer based on back-propagation neural network , after comparing the system in the same parameters and conditions with and without neural network we found that after building a neural network we can transfer a higher power for a longer distance for the same parameters and facilitate the controlling in changing some parameters .

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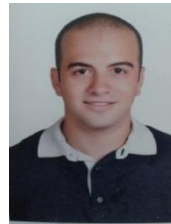
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