A Safety Mechanism Design for Inductive Power Transfer Systems

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Abstract—Many applications have appeared since the invention of Wireless Power Transfer. One of the constraints for WPT to be applied to wider applications is the safety concerns. This paper introduced an object-detecting safety mechanism for wireless power transfer by only using on-board signals of the inverter. With a simple machine learning technique, the trained classification model could achieve a detection accuracy of 95% via simulation data.

1. introduction
Wireless Power Transfer (WPT) is a technology invented by Nikola Tesla more than a century ago [1]. Since the invention of this technology, many applications have appeared [2]. One of the popular use of WPT is the wireless charging of consumer electronic devices e.g. mobile phones, thanks to the inductive power transfer (IPT) based Qi standard [3]. There are also far-field WPT technology, usually based on radio frequency for example Mobile charging of sensor node [7]. One of the constraints for WPT to be applied to wider applications is the safety concerns [4]. In order to increase the range power of a WPT system, a more reliable safety mechanism is necessary. For example, Inductive heating of foreign objects is one of the safety concerns that limits the power and range of wireless power. Without a reliable foreign object detection (FOD) system, overheating This paper proposes a WPT safety mechanism to detect foreign objects by applying pattern recognition techniques.

2. background
The fundamental theory of IPT is to convert electrical energy to magnetic fields and convert back to electricity, as shown in Fig 1. The technique proposed in this paper was designed based on a resonant IPT system. Resonant IPT system optimises the efficiency of an IPT system by adding resonant capacitors to both the transmitter and receiver circuit, which has become a common IPT design in many applications [5]. Foreign objects, on the other hand, are usually not perfectly tuned to an IPT system, which could behave differently from a designed wireless power receiver. Therefore, this paper explores the possibility to detect such different behaviour by applying pattern recognition techniques.

3. the ipt circuit design
The overall frame picture of wireless charging is shown in the Fig. 1, which is composed of two parts: the wireless power transmitter and the receiver. A typical wireless power transmitter has an inverter, a coil and a resonant capacitor.
Figure. 1. A basic diagram of IPT

TABLE 1 SIMULATION COMPONENT VALUES

| Parameter | Value   |
|-----------|---------|
| \( V_{dc} \) | 12 V    |
| \( C_p \)  | 2.5355 \( \mu \text{F} \) |
| \( C_s \)  | 190 \( \mu \text{F} \) |
| \( L_p \)  | 1 \( \mu \text{H} \) |
| \( L_s \)  | 1 \( \mu \text{H} \) |
| \( C_r \)  | 50 \( \mu \text{F} \) |
| **Switching Frequency** | 100 kHz |

A wireless power receiver typically has a coil, a resonant capacitor, and a rectifier. The inverter on the Tx side converts DC supply to an AC current, which passes through the Tx coil to generate a changing magnetic field, and therefore induces a voltage in the Rx coil, thus complete the link [Ampere’s law and Faraday’s law reference]. In this manuscript, the proposed idea is tested on a popular half-bridge IPT system design [Qi reference].

3.1. the transmitter
The transmitter design used for this work is a simple half-bridge inverter, which consist of two switching devices, as shown in Fig. 2. The principle of this inverter is simple, by turning on and off each device accordingly, current can flow in both directions in the coil, therefore generating the changing magnetic flux for wireless charging. Comparing to full-bridge inverter, the half bridge reduces the number of switching devices by half, which could potentially achieve a lower cost for the final application.

Figure. 2. Half-bridge inverter circuit topology

3.2. the receiver
The wireless power receiver is simply the resonant tank plus a Class D rectifier, as shown in Fig. 3. In real-world applications a DC-DC converter is usually connected after the rectifier to provide a constant voltage output. However, a simple resistive load will be used in for this work to simplify the
simulation. The class D rectifier has the advantage of using only 2 diodes instead of 4 comparing to a typical full-wave rectifier.

\[ \begin{align*}
C_f & \quad \text{(input capacitor)} \\
L_f & \quad \text{(filter inductance)} \\
R_{\text{load}} & \quad \text{(load resistance)}
\end{align*} \]

**Figure 3.** Class D rectifier circuit topology

### 4. Foreign Object Detection Safety Mechanism

The wireless power transfer system setup in this paper based on the popular resonant inductive power transfer, which means both the transmit and the receive side coil have resonant capacitors that are tuned at the same operating frequency. By this the reactance in the circuit can be reduced therefore improve the efficiency of the system. Foreign objects, however, are not perfectly tuned at the exactly frequency as the WPT system, which could change the behaviour of the system when strongly coupled to the Tx or Rx coils. The proposed method is to use the available signals on the WPT circuit to see if such behaviour can be detected and therefore detect the foreign objects. To verify this, a basic machine learning technique - support vector machine (SVM) is used to train a classification model. Two signals from the inverter circuit are used as the input data to the model, one is the voltage between the two switching devices (Fig. 5), and another is the current in the coil (Fig. 4). The foreign objects are modelled as a 10% change of inductance of the receive coil. The coupling between the Tx and Rx varies between 0.5 to 0.6 to see if the classification could still detect the change with different coupling. The two sets of training data were then exported to MATLAB for the machine learning training process. A linear SVM algorithm was then used to train the model. A 10-fold cross-validation was used and the validation error is 0.039. There were also 10 sets of data taken out from the training data to be used as a test data. The test error is 0.05, which matches the validation error.

\[ \begin{align*}
\text{Current} [\text{A}] \\
0 & \quad \text{(current at 0 time)} \\
-50 & \quad \text{(current at 0.5 time)} \\
50 & \quad \text{(current at 1 time)} \\
\end{align*} \]

**Figure 4.** Current in Tx Coil
5. conclusion
This paper presented a safety mechanism for wireless power transfer by detecting the presence of foreign objects by only using on-board signals of the wireless power transmitter. With a simple machine learning technique, it is possible to train a classification model that could achieve a detection accuracy of 95%. Further work is needed to test the proposed method in real-world applications and to analyse its real-world performance.

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