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A Quick Method for Determining the Best Frequency for Wireless Power Transfer

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Research Article

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Abstract—How much power can be sent across coils powered by an AC power source is one of the most frequent queries in the Wireless Power Transfer (WPT) technology. The topic of this study is how to find the AC power supply frequency that maximizes WPT. It is practically crucial to identify the ideal frequency in a few frequency trials, even if it is theoretically feasible to do so by using a broad range frequency sweep. A frequency spotting method using a square wave input power signal is proposed in this research. With knowledge of response by square wave input, the technique eliminates a lengthy and time-consuming sweeping operation. On each data sample increment iteration, the Automatic Multiscale-based Peak Detection (AMPD) method is used to choose the first peak discovery. This is followed by further analysis to determine the set of peak patterns by computing error parameters.

***Index Terms*—Wireless power transfer, optimal frequency, square wave input, AMPD**

INTRODUCTION

WPT has the potential to eliminate the need for batteries and wires in electrical goods, making it a viable technology for a sustainable future [1]. The WPT techniques, which date back to the Tesla experiment [2], are divided into two categories: radiative (such using a microwave) and non-radiative (using inductive and capacitive power transfer) [3]. The study [4] conducted in 2007, which demonstrated that non-radiative inductive power transfer could effectively transmit 60 watts within a 2-meter range and achieve 40% efficiency, has increased the popularity of the inductive power transfer technique. The WPT is now being used in a variety of applications, including consumer appliances [6], electric cars [5], the Internet of Things [7], and biological applications [8].

One of the challenges in WPT is increasing power transfer efficiency to send a lot of power across coils. A number of efficiency-boosting techniques, including as impedance matching [10], parameter optimization [11], and frequency selection [12], have been reviewed in [9]. Additionally, a number of efficiency-tracking techniques, including adaptive frequency [15], phase shift [14], and dynamic coupling coefficient estimate [13], have been suggested to achieve the necessary efficiency. Consequently, a number of critical factors, including frequency, the form of the input power source signal, the type and section of coils, the radius of coils, and transfer distance, affect the overall performance of the WPT system [16].

By determining and providing a fixed parameter value, the desired power transfer efficiency may be determined. However, as the ideal parameters were only appropriate for the prior state, the power transfer efficiency would drop whenever the parameter is changed. The only way to achieve optimal power transmission in the given scenario was to recalculate and re-find the parameters. In this sense, an important issue in the area of WPT research is the inverse problem of determining optimal settings for a scenario that is always changing. Situational examples that may lower a WPT system's efficiency include impedance and resonant frequency parameters (in the case of frequency) toward the coil distance fluctuation [15]. By employing frequency monitoring and tuning to ensure that the WPT system always receives the right frequency input, this issue may be prevented. Several studies have shown frequency monitoring and adjustment [12], [15], [17], and [18]. However, it takes a lot of time to monitor the ideal frequency without taking the amount of frequency sweeps into account. Therefore, a technique enhancement for monitoring and confirming optimum frequency must be carried out by taking into account the number of frequency sweeps.

The topic of this study is how to find the AC power supply frequency that maximizes WPT. By using frequency sweep, an ideal frequency may be precisely determined. Nevertheless, frequency sweeping is time-consuming, and there is a good chance that conditions and parameters may change while the operation is underway. In this research, a method for determining and verifying the ideal power transfer frequency in WPT using a square wave input signal is proposed. Even if the input frequency is limited to a lower frequency than the resonance frequency, square wave input signals may offer more power than sine wave input signals [19], [20]. Additionally, as the best frequency contains a set of peak patterns between the frequency ranges, the optimal power transfer may be verified by Fourier analysis of the response provoked by the square wave input signals.

I. METHODS

In the preliminary research and experiment, the WPT system received a 5 kHz to 100 kHz (with a 100 Hz interval) square wave input signal. We obtained 950 power data from the receiver with a 20 Ω load resistance and 35 mm distance between coils. Thus, based on the experiment result observation, a set of essential peaks (l) was found, including the optimum frequency that delivers the highest power to the receiver. Fig. 1 shows that obtained data include the optimal power transfer frequency 56.9 kHz (l_0), followed by other local peaks $\{l_1, l_2, l_3, l_4\}$, located at 18.2 kHz, 11 kHz, 7.8 kHz, and 5.9 kHz, respectively.

Furthermore, let $l=\{l_0, l_1, l_2, \ldots, l_n\}$, with respect to frequency, the pattern formula from a set of peaks was obtained and expressed as

$$\quad 1 \quad 1 \qquad 1 \quad$$

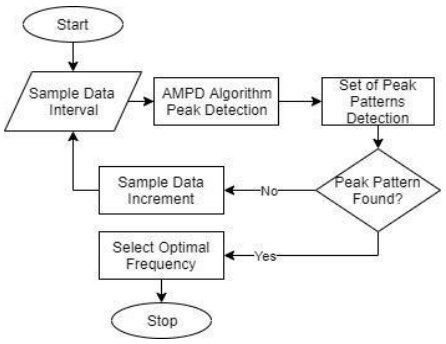


Fig. 2. Flowchart of the proposed method.

2. Increase the number of sample data until the number of p is higher or equal to the number of peak patterns to be found (n).
3. Afterward, the optimal frequency (l_0) assumption (g) is decided by finding the highest power in p. Next l_1,

$$l \quad l_0 ,$$

$$-l_0 ,$$

$$-l_0 , \quad ,$$

$$l_0$$

$$1)$$

l_2, $\ldots$, l_n pattern approximation are found by

$$\quad 3 \quad 5 \qquad 2n \quad 1 \quad$$

Moreover, since the square wave signal has 3rd, 5th, 7th, n^{th}-times frequencies in addition to the fundamental frequency, deciding an optimal frequency will be possible, by referring this knowledge to discover the set of peak patterns.

Our spotting method uses the AMPD algorithm [21] to find the initial peak since it is suitable for our WPT system that has a set of peak patterns with a multiscale periodic type of peaks [22], [23]. The AMPD algorithm will collect the initial peaks to further analyze by our spotting method. Afterward, our spotting method will determine the optimal frequency by validating its existence on each set of sample data. If the spotting method recognizes the set of peaks, the optimum power transfer value could be obtained. The generic process from the proposed method illustrates using the flowchart shown in Fig. 2.

By using (1) as a rule to validate the optimal frequency, the proposed spotting method is described as follows:

1. Retrieve a sample of data in 5-100 kHz starting from 10 kHz sampling interval (i). Collect a set of peaks by using the AMPD algorithm (p) in sample data by using several intervals.

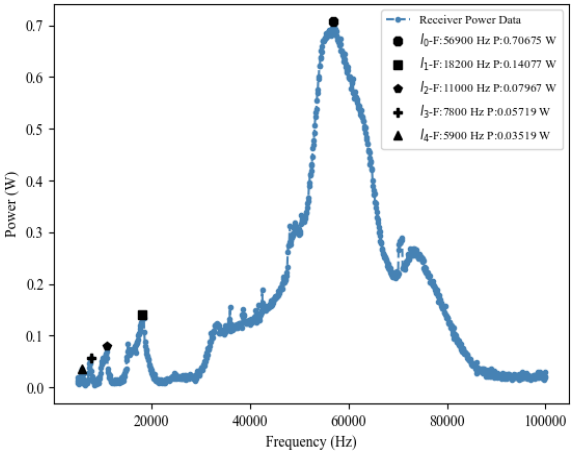


Fig. 1. Transferred power to 20 Ohm load depending on the driving frequency (experiment).computing a set of peak approximation frequency (a) by multiplying g with $1/(2n+1)$.

4. For each a, find the nearest frequency as a candidate peak (c) for each in p and measure the distance error (e_d) by averaging $|c_n - a_n|/9500$, where 95000 is the observed frequency width 5 kHz to100 kHz.
5. Measure the amplitude error by identifying whether the amplitude for each $c_n > c_{n+1}$ is satisfied using Boolean value, or not. If the result is false, then $e_a=1$ otherwise $e_a=0$.
6. Decide the optimal frequency validity by computing total error $e_{total}=(0.2e_d+0.8e_a)$, where 0.8 weight is given to e_a since the error is unacceptable. Therefore, if the result of e_{total} is higher than 0.8, the status of the optimal frequency will be considered invalid, and more data samplings are required.
7. Check whether all l_n have been found and e_{total} is less than 0.8. Increase the sample data if some l_n is missing or less then the desired n.

Increment of the sample data will include the previously gathered data appended with new sample data. The newly sampled data by reducing the initial interval of frequency (i) by a decrement variable (d) that decided by the experiment are shown in Fig. 3. The iteration process will continue until $i=0$.

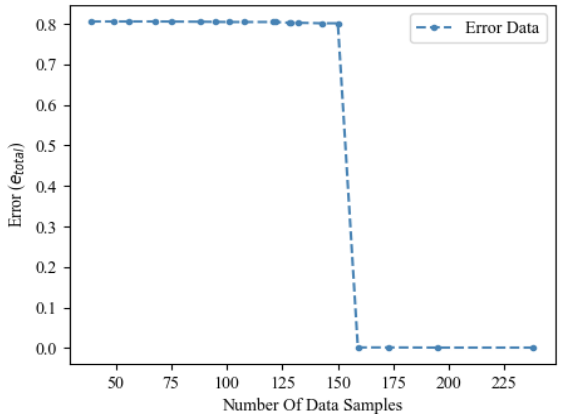


Fig. 3. The experiment conducted to collect $e$total on each iteration with d=400. The data sample increment (i) starts with 10 kHz interval and find the $e$total value from 5 kHz to 100 kHz.

TABLE I: SET OF PEAK CANDIDATE, ERROR COMPUTATION, OPTIMAL FREQUENCY DECISION, AND VALIDATION. OBTAINED DURING 159 DATA WITH TEN PEAKS FOUND BY THE AMPD ALGORITHM

Highest power frequency found by AMPD algorithm (p)		Set of peak candidate (c) (Hz)				Error		
Frequency $c0$ (Hz)	Power (Watt)	$c1$	$c2$	$c3$	$c4$	ed	ea	$e$total
57000 ($l0$)	0.69452	18200 ($l1$)	11000 ($l2$)	7800 ($l3$)	5000 ($l4$)	0.005464	0	0.001093

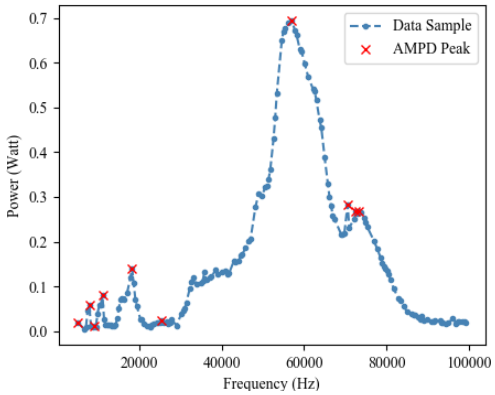


Fig. 4. The Experiment during the 159 data samples with 10 peaks found by the AMPD Algorithm.

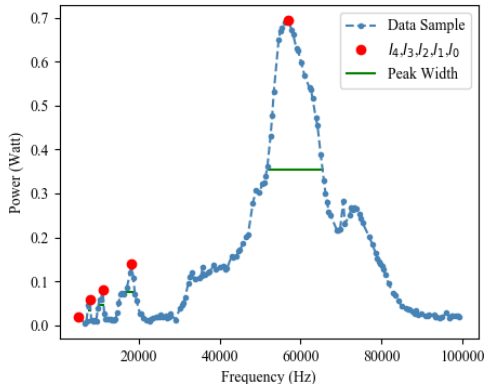


Fig. 5. The 159 data samples with set of peak (l=l4, l3, l2, l1, l0) respectively from smallest to highest frequency alongside with the peak width, after being selected by the spotting strategies.

II. Result and Discussion

The experiment begins with determining the decrement interval variable and uses the Python computer language to implement the spotting tactics. As shown in Fig. 3, the experiment is carried out by gathering the etotal on each iteration. Ten samples are collected at intervals of 10 kHz in the first iteration. The ideal frequency is deemed incorrect since etotal is more than 0.2, and it will proceed to the subsequent iteration. Subtracting i by 400 will propagate the sample data, including the previously obtained data. As a result, sample data will be added at intervals of 9.6 kHz on the subsequent cycle.

238 data were collected for the experiment, and the iteration will go on until i=0. Since there are 159 data samples in Fig. 3, the ideal frequency may be established. The ideal frequency may thus be determined whenever the etotal value is less than 0.8 in certain repetitions by recording it on each iteration. The scenario where the AMPD algorithm locates the peaks using 159 data samples is seen in Fig. 4. In order to identify the proper collection of peaks, the AMPD algorithm gathers 10 peaks for further examination using the spotting technique.

When the iteration reaches a total of 159 data samples, Table I displays the outcome. Since ed is tiny, the AMPD algorithm's peak collection contains the approximation value (a) for each local peak. Since the power amplitude criterion for c0>c1>c2>c3>c4 is valid, ea is 0. A collection of peaks l=l4, l3, l2, l1, and l0 will then be chosen using etotal, as seen in Fig. 5.

We compare the set of peak l findings from Table I with the actual peak acquired from direct observation, as shown in Table II, in order to verify the results produced by the AMPD and the spotting technique. This result demonstrates that the suggested algorithm's ideal power transfer frequency has an error distance of 0.1757% from the actual optimum. Additionally, if a more precise outcome is needed, this method may keep retrieving the data within the peak width.

The purpose of the second experiment is to assess how well the spotting approach performs using various experimental data. Additional data with comparable features are included in Fig. 6. Despite the near proximity of the peaks, the ideal frequency of these three data sets varies.

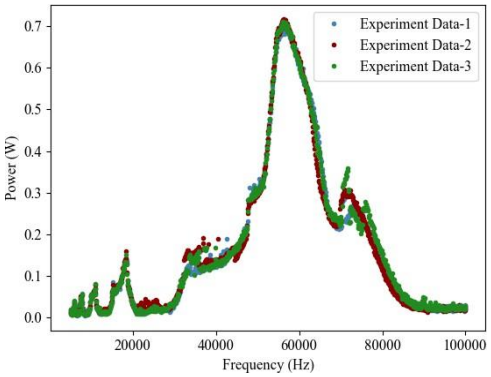


Fig. 6. Three experimental data consists of 950 power data, received from WPT system by 20 Ohm resistor using square wave input signal.

TABLE II: THE SET OF PEAK (L) COMPARISON BETWEEN THE SPOTTING METHOD RESULT AND CORRECT (L) SET OF PEAKS OBTAINED FROM DIRECT OBSERVATION

Set of peak pattern (l)	Peak detection with 205 data (Hz)	Power (Watt)	Peak width range (Hz)	Real peak frequency (Hz)	Power (Watt)	Error Distance (%)
$l0$	57000	0.69452	51800-65800	56900	0.70675	0.1757
$l1$	18200	0.008421	16200-19000	18200	0.14707	0
$l2$	11000	0.07967	9800-11400	11000	0.07967	0
$l3$	7800	0.05719	7400-8200	7800	0.05719	0
$l4$	5000	0.01956	5000-5000	5900	0.03519	15.2542

TABLE III: ERROR DISTANCE COMPARISON BETWEEN THE SPOTTING STRATEGIES SET OF PEAKS WITH 159 SAMPLES WITH THE DIRECT OBSERVATION WITH 950 DATA

Data	AMPD Peak Find	Total Data	The spotting strategies error distance (%) compared to the real distance by direct observation					Optimal Power Difference (Watt)
			l0	*l1*	*l2*	*l3*	*l4*	
1	10	159	0.1757	0	0	0	15.2542	0.01223
2	18	173	0	1.0869565	0	0	16.666667	0
3	5	150	0.1782531	1.0869565	0	0	16.666667	0.00636

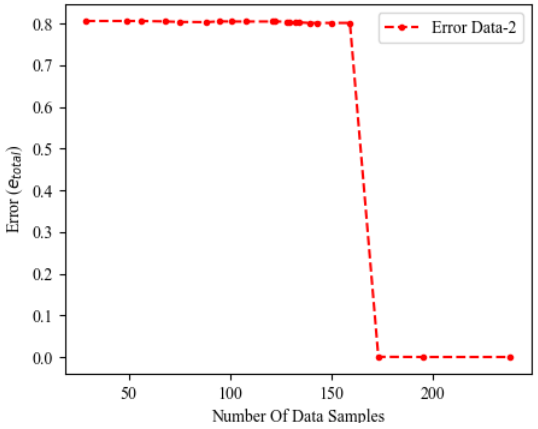


Fig. 7. The experiment conducted to collect e_{total} on each iteration with d=400 from a total 238 of data samples in Data-2 with $e_{total} < 0.8$ start at the 173 data samples.

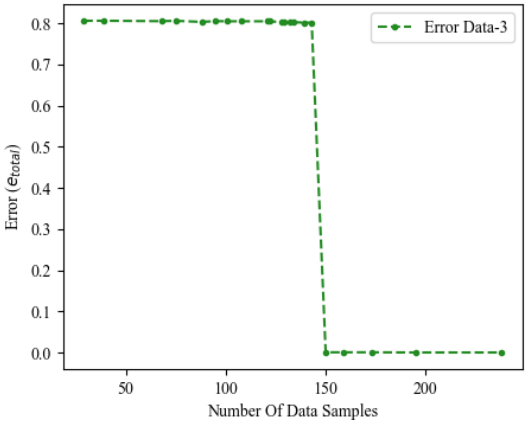


Fig. 8. The experiment conducted to collect e_{total} on each iteration with d=400 from a total 238 of data samples in. Data-3 with $e_{total} < 0.8$ start at the 150 data samples.

Using the original 10 kHz frequency (i) and the 400 Hz decrement variable (d), the identical scenario is carried out, which is to examine the etotal plot on each iteration. Next, examine the plot output and identify the initial condition on both data where etotal<0.8. In the last stage, we contrast the outcome with the peak found from direct observation.

The etotal plot for data-1 is shown in Fig. 3. However, the whole plot for data-2 and data-3 is shown in Figures 7 and 8, respectively. The best frequency is found when the spotting technique identifies the etotal<0.8 criterion, as both figures demonstrate. Once the iteration reaches 173 data samples on data-2 and 150 data samples on data-3, the ideal frequency is confirmed. As a result, the suggested spotting technique finds the ideal frequency without requiring a laborious sweeping procedure.

The error distance between the collection of peaks discovered by the spotting technique and the direct observation is shown in Table III. The result demonstrates that the precision of the

III. Conclusions

Any WPT system must quickly and precisely determine the ideal driving frequency in order to transmit a significant amount of power between coils powered by an AC power source. By understanding how the WPT system reacts when triggered by a square wave input signal, this research has developed a spotting technique to determine the ideal frequency. By using initial peak picks from the AMPD algorithm, the spotting approach circumvents a laborious sweeping procedure. Our approach uses fewer than 180 sample data with 950 recorded data sweeps from 5-100 kHz to determine and confirm the ideal frequency based on the experiment. When comparing the detected ideal frequency to the true optimal frequency, the method's inaccuracy is less than 1%. By using a reliable pre-processing technique and contrasting it with other peak finding algorithms during the first peak choices, we hope to improve the spotting method's performance as future research. Additionally, a variety of situations, including load, coil, and distance change in WPT, may be used to apply and assess the spotting method's best frequency tracking and tuning.

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