# Answer to the Reviewers’ Comments:

The authors would like to appreciate the associate editor and reviewer team for giving us this reasonable period of time to improve the prototype and addressing the comments. We found the comments very realistic and of a of a high level of importance in improving the quality of this article.

In this reply letter, reviewers’ comments are responded one-by-one, and, where applicable, the article is modified. The modifications are highlighted in the revised article, and they are referenced here.

The page numbering of these references is consistent with the revised article, which is started after this letter from page XX and ends up at page XX.

# Associate Editor

Comments to the Author:

The authors are invited to review the high-quality comments provided by reviews carefully. The AE opinion is that the current manuscript lack some critical components. The results presented by the authors do not give the reviewers chance to evaluate the system. For example, the tests are conducted at 5 VDC while transferring 1.5W at aligned conditions. At the same time, the coils are designed for kWs of power, and LCC compensation is applied that is commonly considered for high-power charging applications.

Moreover, the authors provide the estimated efficiency and power, but they do not measure power and efficiency for comparison. Testing under the dynamic conditions is missing, too. Further, the switching instant yo take the signal samples is probably the worst moment for that, and the experiments should demonstrate the robustness of the algorithm. The authors should evaluate the algorithm's ability to work with different compensation structures and with various control methods, e.g., phase-shift modulation.

Dear associate editor, we thank you for reviewing our manuscript and appreciate your valuable comments. We kindly listed the associate editor’s comments as below:

1. The results presented by the authors do not give the reviewers chance to evaluate the system. For example, the tests are conducted at 5 VDC while transferring 1.5W at aligned conditions. At the same time, the coils are designed for kWs of power, and LCC compensation is applied that is commonly considered for high-power charging applications.

Thank you for pointing this important concern. Although, we spend a lot of time on desiginig the best possible coil formers and selection the Litz wire to be compatible with the Queensland University of Technology’s ratings (in terms of power and voltage). To address this insightful comment and to show that this technique can be implemented for higher powers, the setup is developed and redesigned to transfer higher level of power. For this purpose, (MOSFETs and/or GanFETs) with higher ratings are used in the H-Bridge(Fig. 1), three DC power supplies are connected in seires (200 VDC, 6 A) to deliver higher power to the receiver (Fig. 2). To consume this power, high-rated resistors are used at the receiver-side (Fig. 3).

Moreover, to make the prototype more industrially acceptable, the operating frequency is changed to 80 kHz, which is within the standard range of WPT transmission (standard number). Therefore, the LCC network at the transmitter-side is redesigned to compensate the transmitter at 80 kHz (Fig. 4), similarly, for the receiver side, the series compensator is tuned for 80 kHz (Fig. 5).

As already mentioned above, due to the limitations that we have in the Queensland University of Technology’s laboratory, we could not increase the transfer power to more than 300 W.

1. The authors provide the estimated efficiency and power, but they do not measure power and efficiency for comparison.

Thank you for raising this concern. The main concern of this work is to show that the demand factor has a meaningful relationship with the transferred power. For this purpose, in the previous revision, the input and output powers shown in Fig. 13 are measured, and having their actual values, the actual results for the efficiencies are obtained and shown in Fig. 14. These actual values of input and output powers are used to obtain the actual value of the demand factor, shown in Fig. 12 to validate the concept. To show the effect of the detuned parameters and stray series resistances, the estimated error is compared with the efficiency. Efficiency here is a factor that can make a reasonable sense on the consumption of power in the stray resistors in the transmitter, and it shows how the presence of these components can influence the estimated error.

To address the reviewers’ reasonable comments, in the current revision we increased the level of power (which may increase the efficiency and the accuracy of the proposed method). We also completely agree with the reviewer comment with providing the estimated power along with the measured input and output power for clarity. Similar approach has been taken for the estimated efficiency and it is plotted next to the actual efficiency for the comparison. We also extended our studies for the reactive power; therefore, a new diagram is added to show how this method can estimate the reactive power.

1. Testing under the dynamic conditions is missing, too. Further, the switching instant yo take the signal samples is probably the worst moment for that, and the experiments should demonstrate the robustness of the algorithm.

Thank you for raising this insightful comment. To study the way that proposed load estimation technique works under dynamic conditions, transferred power is estimated for the four following cases, and the results are compared with the conventional techniques of estimation.

1. When the coupling between transmitter and receiver is maximum, and the input voltage changes stepwise (a step change of the phase angle between the voltages of the H-bridge legs from to ).
2. When transmitter and receiver are not coupled, and the input voltage changes stepwise (a step change of the phase angle between the voltages of the H-bridge legs from to ).
3. When the coupling between transmitter and receiver is maximum, and the input voltage changes gradually (a ramp change of the phase angle between the voltages of the H-bridge legs from to ).
4. When transmitter and receiver are not coupled, and the input voltage changes stepwise (a ramp change of the phase angle between the voltages of the H-bridge legs from to ).

As it can be seen in the provided results, the proposed technique can effectively estimate the dynamic changes of the active and reactive powers. For clarity, only the worst case of step change in the input voltage when the transmitter and receiver coupling is maximum is added in the paper.

In the proposed technique of sampling, the rate of sampling is significantly minimized that makes the sampling technique to be more vulnerable against the negative effects of noises and harmonics in the sampled signal and jittering in the sampling moments. However, compared to the conventional d-q and envelope estimation techniques, the proposed technique, can estimate the power more rapidly. This fact implies that by forgoing (sacrificing) the speed of estimation and using digital or analogue low-path filters, the undesirable effect of noises and harmonics (in the sampled signal) and jittering in the sampling can be significantly decreased. For the comparison amongst the proposed technique and other techniques of sampling (d-q and envelope detection), the proposed technique of sampling is equipped with a digital low-path filter and the samplers are set to have similar dynamic responses, then the sampled signals obtained from the same WPT system are compared. To have a fair comparison, the influence of harmonics in the sampled signal (change in the quality of the LCC network), the effect of noise, and different levels of jittering in the sampling instances are considered as the main criteria of comparison. This investigation is added as Section XX in the paper.

Different compensation structures and with various control methods, e.g., phase-shift modulation.

We appreciate the reviewer futuristic comment. We completely agree that this works should be further investigated for different compensating networks and with different control strategies. However, as it is clear from the current structure of the paper, analyzing and investigating each topology and each control strategy take extra pages. Therefore, it is decided to investigate these interesting topics in our future works.

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments to Author (Required or else review is ignored). Please give a thorough and technical detailed review to the author. What is done well? What needs improvement?

The paper proposes an interesting technique that allows to estimate the transferred power, and then the efficiency, of an LCC compensated.

The paper is generally well written and arranged and only minor spelling check is required.

The proposed technique seems effective, but it has a strong limitation due to the necessity to have a high quality factor at the transmitter side.

We appreciate the reviewer for his/her careful consideration. The comment is completely reasonable and the proposed technique is completely vulnerable against the quality factor of the network. The synchronized sampling technique can only be used when the sampled signal is properly filtered before being fed to the sampler. As the reviewer wisely mentioned, this technique is limited to the applications in which the compensation network effectively mitigates the harmonics and has the least possible amount of stray resistances. However, owing to its low sampling rate and its need for measuring only one signal (voltage across the parallel capacitor in the LCC network) to estimate the transferred power, the proposed technique is considerably simple and cost-effective.

LCC networks used as compensators in resonant converters seem an ideal case to implement this technique as their order is high and the quality of their components is recommended to be as high as possible. The features such as behaving as a current source at their operating frequency and their high noise and harmonic cancellation make LCC networks an attractive option for different power electronic applications, especially in wireless power transfer systems. The selection of high-quality components and tuning the resonance frequency can make LCC networks costly. Therefore, minimizing the resultant costs, especially when the system is mass production, seems to us an attractive industrial (and academic) topic. Hence, in the proposed technique it is tried to reduce the overall cost of a WPT system by offering a cost-effective and straightforward technique of transferred power estimation.

Therefore, to appreciate this critical point mentioned by the reviewer, we included more experimental results to investigate the quality of the network on the estimation of the transferred power with the use of the proposed technique. Towards this aim, the equivalent series resistance (ESR) of the series inductor in the front-end of the LCC network is arbitrarily changed for two other cases (“case1” and “case2”), and its effect on the power estimation is investigated through experiments and numerical analysis. The reason for choosing the ESR of the front-end series inductor (to experiment and investigate the effect of the LCC network quality factor on the transferred power estimation) is its dominant and nonlinear effect compared to the other stray resistances. To be more elaborated, the ESR of the capacitors (MKP Polyprilyn capacitors) is significantly smaller than that of the inductors (N97 ferrites wired with Litz wires) used in this system, and ESR of the back-end inductors (self-inductance of the transmitter pad and the inductance of the fine-tuning inductor) is simply added to the reflected load and has a linear effect on the deviation of the estimated power.

Places that are changed in the paper should be mentioned.

The authors should investigate and add, at least in the experimental part, the effect of a low power factor (by providing a limit value) on the effectiveness of the proposed technique. This can be also done by accompanying the information about the load resistance with the one of the primary side quality factor.

In the following some additional comments:

Introduction:

- I propose to substitute the term consumer with “user” as it is more general and strictly referred to who is using the system (that is not necessarily the consumer)

This comment is minor and should be addressed after the exeprimentations have been carried out.

- What “coupled side parameters” are? Please, provide a definition

This comment is minor and should be addressed after the exeprimentations have been carried out.

- Fig. 1 does not provide a clear idea on the distinction between the different identification techniques. The authors should try to improve it or, at least, improve their description in the text

This comment is minor and should be addressed after the exeprimentations have been carried out.

- What did the authors mean with the sentence “the sensing needs to be done in the realm of WPT”. The work is dealing with WPT systems so, please, clarify this statement.

This comment is minor and should be addressed after the exeprimentations have been carried out.

- Sensing pads are not introduced neither described. This decreases the readability of the paper

This comment is minor and should be addressed after the exeprimentations have been carried out.

- What does this sentence mean “… sniffing its reflection at the same side”? Please improve and clarify

This comment is minor and should be addressed after the exeprimentations have been carried out.

- A reference should be added to support the statement “without knowing the load information of the far-end coil, the estimation of mutual inductance is not possible.”

This comment is minor and should be addressed after the exeprimentations have been carried out.

Sec. II

- Please, note that omega is an angular frequency and not a frequency

This comment is minor and should be addressed after the exeprimentations have been carried out.

Table I

- Why is this table put in a dedicated appendix? It can be left as a part of the related section as it has not the role of an appendix analysis

This comment is minor and should be addressed after the exeprimentations have been carried out.

Reviewer: 2

Comments to Author (Required or else review is ignored). Please give a thorough and technical detailed review to the author. What is done well? What needs improvement?

This paper proposed a new technique of synchronized sampling to estimate the transferred power in wireless power transfer (WPT) systems. The calculated results match well with experimental results. There are some questions need to be revised.

1. In Section II.B, ”However, as vin is a rectangular waveform, some capacitive Zin is needed to maintain the zero current switching.” It should be inductive Zin for LCC to realize ZVS, please revise it.

2. In Section II.B, ” Therefore, receiver current IR is equal to (LTR/ LS)Vin”, the expression of IR is wrong, please revise it.

3. In Section V, please give the detailed experiment specification, like input voltage, output voltage, output power, output current, geometric parameters of coil, type of litz wire and so on.

4. In Section V,” while the system was driven by a resonant converter with the DC link voltage of VDC = 5 V and the frequency of 100 kHz”, please explain why the DC link voltage is 5V, and its application in industrial or domestic area.

5.Compared with other power estimation methods, please explain the advantage of the proposed method and prove it.

6.What’s the performance of the proposed method in load jump?

Reviewer: 3

Comments to Author (Required or else review is ignored). Please give a thorough and technical detailed review to the author. What is done well? What needs improvement?

The reviewer wants to thank the authors for the effort of putting this work together. This paper presents an impedance-based technique to estimate transferred power in transmitters in IPT systems. Here are my comments /suggestions:

1) The analytical formulation is done in both tuned and detuned conditions to show that the quadrature voltage of the primary compensation capacitor, and the active power of the transmitting pad have always a direct relationship to the reflected impedance defined as demand factor as the paper(ξ= (Mꞷ)^2/Rl). However, the online estimation of this factor does not give any specific information about the secondary side. This factor is related to mutual inductance(M) and secondary loading condition (Rl), any change in the factor can be interpreted as misalignment, clearance change, or loading change. The proposed estimation method couldn’t estimate the secondary side parameters namely: traction battery current and voltage and coupling factor) based on measurement from the primary side.

2) Parameter estimation methods based on impedance analysis are investigated in the literature, which is not a novel idea.

3) The efficiency of the primary pad is formulated in (26), and the experimental result shown in Fig. 14 to verify it. As earlier mentioned, estimating the efficiency of the primary-side converter is not a useful method. It is recommended to estimate the efficiency of IPT system (from primary power supply to receiver DC side), and compare it with the actual value.

4) Receiver current expression on page 8 should be revised, the correct relation is Vin \*M/ (Ls\*Rl) .

5) According to (13), to measure the quadrature part of the capacitor, measurement should be done on ꞷt= (2k+1)π.

6) (14) given in SectionII. C presents another formulation of the output power different from what is derived in (6)? The DC-Link(Vdc) parameter given in (6) is not shown in Fig.6.

7) The paper language is in some parts very unclear and poorly written which makes it difficult to understand for readers, especially in the introduction section. For instance, the problem with online parameter identification via data communication between receiver and transmitters is not clearly explained in the introduction?

8) There are some figures which are left unexplained in the paper for example Figs.13, 14

Reviewer: 4

Comments to Author (Required or else review is ignored). Please give a thorough and technical detailed review to the author. What is done well? What needs improvement?

1. This method is dependent on measuring the parameter across the Cp, it seems this method is only effective in the LCC-S topology, while it can not be directly utilized in other compensations such as SS, double LCC etc.?

2. Based on your analysis, the inner resistance of Rs and Rt can be ignored, then the Pout is approximately equal to Pin. So that the Pout can be calculated just by directly measuring Pin, why do you need to measure the voltage of Vcp?

3. Equation (5) and (6) are deduced without considering the ESRs loss, please provide the corresponding equations in Section IV with the consideration of the ESRs loss. And compare them.

4. For the Section II part C and Section III, there are no following experimental results to validate your analysis. What's the use of the theoretical analysis of these two parts, and how to verify them?

5. Please explain in detail how to perform PWM-Synchronized sampling from the quadrature term of Vcp,q. Provide relevant programming, sampling waveforms or flow-charts.

Reviewer: 5

Comments to Author (Required or else review is ignored). Please give a thorough and technical detailed review to the author. What is done well? What needs improvement?

Energy metering in wireless power transfer is important for both billing and technology evaluation. The authors offer a method to estimate transferred power through the terminal voltage measurement at the the transmitter LCC compensator input. The estimation method proposed in this paper may be useful for closed-loop real power control in a WPT system and also for tuning a WPT system in a laboratory.

It is a credit to the authors to identify and analyze the errors and the shortcomings in there propsed method. However, there are a number of reasons from the authors' analysis and explanation that make the proposed method in the manuscript lacking for real-world applications. The paper could be improved by offering some research trajectories that may overcome these shortcomings.

1) The accuracy that is offered appears to be much worse than the minimum accepted energy metering targets of 0.2%.

2) The SAE J2954 wireless charging standard allows charging over a 10 cm misalignment in the SAE J2954 wireless charging standard. Hence, metering accuracy must be maintained over this misalignment.

3) The base assumptions of lossless WPT and well-tuned compensation networks is not borne out in real-world commissioned systems where corrosion, vibration, temperature cycling, etc. degrades power electronic systems and components. The robustness of an energy metering system should not rely on the robustness (e.g. consistency) of the power electronics. For example, component tolerances over the required environmental temperature of the power tuning components cannot be relied upon.

4) Fig. 15 is particularly concerning because both a positive and negative error estimate are possible. This is borne out in the experimental data as well with the RL=1 ohm data. This means one cannot be sure whether the estimate is positive or negative. It is important to be able to properly attribute losses either to the utility (transmitter) vs. loss by the receiver so that billing can be performed appropriately.

5) Why not measure terminal voltage and/or current at the WPT coils instead of the input of the compensator. This would have fewer variances and would be more reliable because fewer component parameters are involved in the estimation, resulting in better robustness.

6) Sampling once per cycle makes the measurement vulnerable to noise/interference. This is especially true at realistic power levels for wireless power transfer where dv/dt, di/dt, and switching transient amplitudes are high. This is missed in the ~10 W hardware implementation demonstrated in this paper. 100 kHz is relatively low in switching frequency with ADC easily able to make many measurements. Sampling can still be synchronized to your PWM controller in this case to maintain the phase reference.

7) Please include a plot of error vs. misalignment.

8) Please include a plot of error vs. power level,

9) There are a few spelling errors that ought to be corrected as well.

Research Contribution Assessment:

Reviewer: 1

Research Contribution Assessment: The work proposes some interesting improvement starting from previous literature

Reviewer: 2

Research Contribution Assessment: In this paper, a new technique of synchronized sampling to estimate the transferred power in wireless power transfer (WPT) systems is proposed. Defining demand factor as a criterion linking unknown

receiver parameters to the transferred power, it can be estimated by measuring the front-end variables of the transmitter LCC compensating network. Moreover, with the use of this technique, one does not need to know how the mutual inductance or load varies.

Reviewer: 3

Research Contribution Assessment: This paper does not have enough contribution

similar work can be found which use impedance analysis to estimate parameters

The proposed method of parameters estimation does not solve any problem from IPT systems since it can only estimate the parameters which are accessible for measurement in the primary side

Reviewer: 4

Research Contribution Assessment: This paper proposes a method to estimate the output power of the LCC-S compensated wireless power transfer.

Reviewer: 5

Research Contribution Assessment: What is new in this paper is the proposition of a way to estimate transferred power from a particular terminal power measurement. They offer this method as a way to perform energy metering.

The accuracy offered does not approach what is required for the accuracy targets of energy metering : 0.2%. The authors do not offer a research trajectory toward this goal.

There are too many assumptions in the base measurement that are unrealistic and make this not very useful in practice. These include: 1) lossless WPT; 2) compensation networks have to be well tuned. In the real world,

It would be remarkably simpler to measure the terminal voltage and terminal current at the wireless power transfer coils and perform calculations from there. The authors do not explain why they do not do this.

Also, introducing a "demand factor" parameter is not particularly useful. It is an idealized term for systems with no loss and exact tuning. It assumes an invariant Ls inductor (which is outside the "demand factor") to the LLC compensation, which in the real-world and what is likely in their experimental setup has a magnetic which makes the inductance vary with current level. Although the authors analyze this "demand factor"

Single-point measurement as proposed in this paper are particularly vulnerable to noise/coupling from switching transients etc. for di/dt and dv/dt. This was not borne out in the experiments because they were performed at the 10 W level.

Overall the system may be acceptable in a laboratory setting for coarse estimation or where it used for closed-loop approximate power control, but really not convincing as a reliable and accurate method for metering.