Comment on “Impact of Load Frequency Dependence on the NDZ and Performance of the SFS Islanding Detection Method”

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***Abstract*—We read with interest an article [1] published in the IEEE Transactions on Industrial Electronics in 2011 and tried to reproduce the results of this article for the needs of our own research. Unfortunately, we were led to think that the load model equations used by the authors contained an inconspicuous but significant mathematical error, leading to erroneous results and conclusion. The present paper brings a correction to some figures and their analysis as well as the paper conclusion. The new results show that the load's frequency dependence has actually no significant impact on the NDZ of the SFS method.**

***Index Terms*—Distributed generation (DG), inverter, islanding detection, Sandia frequency shift (SFS).**

I. Introduction

The article [1] studies the impact of the frequency dependence of load on the Sandia frequency shift (SFS) islanding detection method. However the value of one parameter of the load is used with the wrong unit. As a consequence, the computations are done with a highly over-evaluated parameter which leads to the conclusion that the load's active power frequency dependence has a significant impact on islanding detection. On the contrary, using the right unit, the conclusion would be the opposite: the load's active power frequency dependence does not have any significant impact on islanding detection.

This paper is organized within two sections. Section II explains the origin of the unit error and Section III brings a correction to some figures, their analysis and the conclusion.

II. Explanations of the Unit Error

For calculations and simulations, the authors of [1] propose to use a load similar to a parallel RLC load, except that resistance R is replaced with a load whose active power consumption depends on frequency through:

$$P = \left(P_0 + \Delta P\right)\left(\frac{V}{V_0}\right)^{NP}\left(1 + k_{pf}\left(f - f_0\right)\right) \qquad (1)$$

where, P represents the load active power and ΔP represents the active power mismatch. The exponent term NP represents the load's voltage dependence parameter which is set equal to two. Parameter k_{pf} represents the load's frequency dependence parameter. Parameters V and V_0 represent the system operating voltage and system nominal voltage, respectively. Parameters f and f_0 represent the system frequency and nominal frequency, respectively.

Evidence that is detailed below leads us to think that, because of an error in the units used, the values of k_{pf} used in the paper are not what the authors intended and are thus very different from the range of values that are considered as "reasonable" in the literature. Then the results presented in Figures 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 from the paper [1] are unfortunately incorrect.

As stated in [2] (in part 7.1) and in [3] — which are both cited by [1] — the typical value for k_{pf} ranges from 0 to 3. As clearly specified in [4] which is the original source of these data, k_{pf} is a ratio between the per unit power and the per unit frequency, so the unit of k_{pf} is "pu/pu". However figures 2 to 12 from paper [1] have been produced using the unit "pu/Hz" with a k_{pf} ranging from 0 to 3pu/Hz as shown in the next paragraph. These values are erroneous as, for example, with k_{pf}=1pu/Hz and f-f_0 = -1Hz, the load would no longer consume any power, which is obviously wrong. With this wrong unit, the load's active power frequency dependence is 60 time higher than standard values.

To confirm our hypothesis, we plotted Figure 6 from [1] which is an easy to understand figure as it directly based on (2) — which is the equation (11) from [1] with a correction of a typo on the sign. We plotted it twice, first using the wrong unit "pu/Hz" for k_{pf}, see Fig. 1, and get exactly the same curves as Figure 6 from [1], which confirms our suspicion; then with the correct unit (pu/pu), see Fig. 2, and we can see that the frequency dependency actually barely has any impact on the load characteristics.

$$\Phi_{load} = \tan^{-1}\left(\frac{Q_f}{\left(1 + k_{pf}\left(f - f_0\right)\right)}\left(\frac{f_r}{f} - \frac{f}{f_r}\right)\right) \qquad (2)$$

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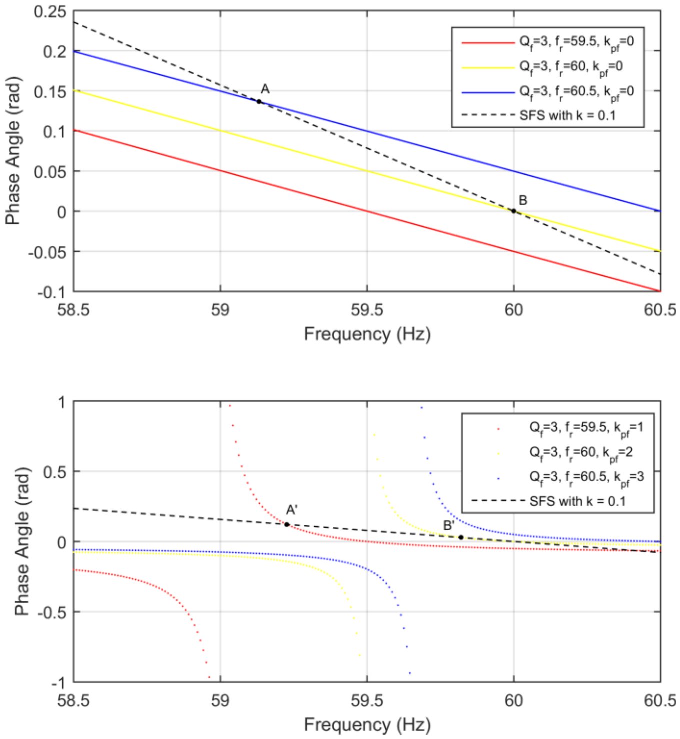

Fig. 1. (New plot of Fig. 6 from [1]) Load characteristic with and without frequency dependence, using "pu/Hz" for k_{pf}.

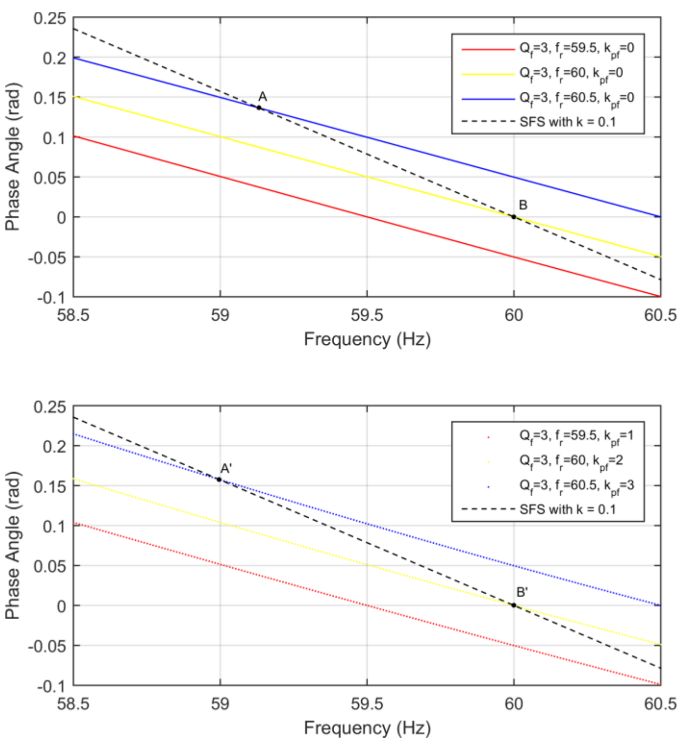

Fig. 2. (Corrected version of Fig. 6 from [1]) Load characteristic with and without frequency dependence, using "pu/pu" for k_{pf}.

III. Correction of Figures and Analyses

A. *Figures based on static equations (=Section III from [1])*

In this section, the figures are based on the equations described in [1], in particular equations (5), (8), (10) and (11). The figures were plotted twice, one with the wrong unit for k_{pf} and one with the correct one. The figures with the erroneous unit always exactly correspond to the figures from the original paper, and so, are not presented here.

The analyses of figures and the conclusion from the original papers are copied-pasted in the present paper, corrected using italic font and enclosed with quotation mark.

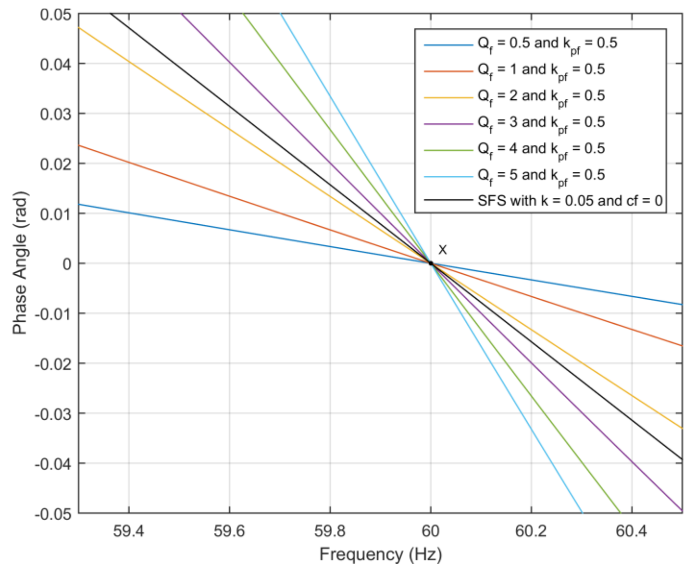

Fig. 3. (Corrected version of Fig. 2 from [1]) Load and SFS phase angle–frequency characteristic for a load with f_r = 60 Hz.

"In *Fig. 3*, the load's quality factor is varied between 0.5 and 5 while f_r and k_{pf} are set fixed at 60 Hz and 0.5, respectively. Based on the phase angle criterion, in order to eliminate the NDZ of the SFS method, the *distributed generator* (DG) phase angle curve should be steeper (higher absolute slope) than the load phase angle curve. For loads with *$Q_f \geq 3$*, the frequency will stabilize within the IEEE threshold values (59.3 and 60.5 Hz) and thus frequency relays will fail to detect islanding. For the case where $Q_f \geq 3$, the frequency will stabilize at 60 Hz (Point X)."

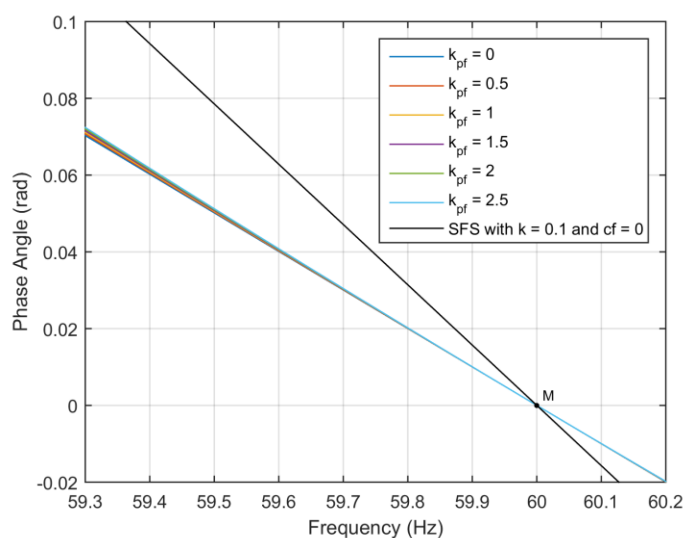

Fig. 4. (Corrected version of Fig. 3 from [1]) Load and SFS phase angle–frequency characteristic for a load with f_r = 60 Hz and Q_f = 3 for various values of k_{pf}.

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"*Fig. 4* shows the load and DG phase angle–frequency characteristic for a DG equipped with the SFS islanding detection method for various values of k_{pf}. […] From *Fig. 4*, it is shown that as the value of k_{pf} *has little impact on the load phase angle–frequency curve and does not affect the islanding detection capability of the SFS method*. […] The analysis shows that the load's active power frequency dependence is a *secondary* factor to consider when designing islanding detection methods."

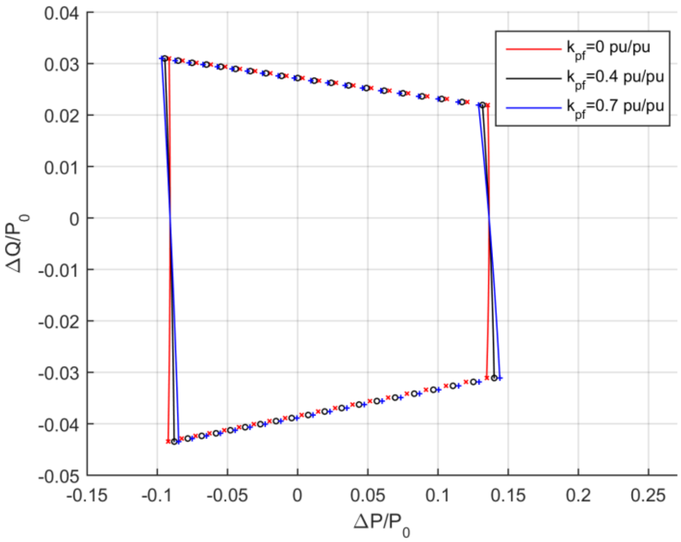

Fig. 5. (Corrected version of Fig. 4 from [1]) NDZ for the SFS method with cf=0 and k=0.05 for different values of k_{pf} with $Q_f = 4$.

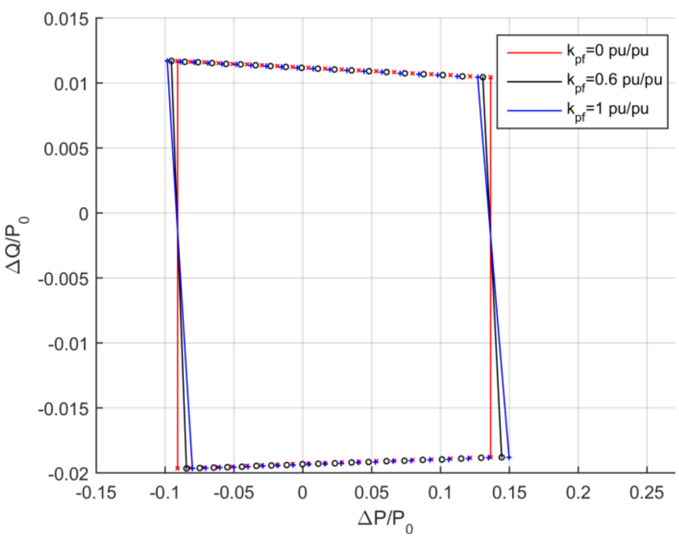

Fig. 6. (Corrected version of Fig. 5 from [1]) NDZ for the SFS method with cf=0.001 and k=0.005 for different values of k_{pf} with $Q_f = 1$.

"Figs. 5 and 6 show the NDZ of the SFS under two different design cases for different values of k_{pf}. For the two presented cases, the NDZ of the SFS method *almost does not* change with the change in k_{pf}. […] Similar conclusions could be drawn for the case where cf = 0.001 and k = 0.005. The SFS method *would not* fail to operate correctly for large active power mismatches as a result of the load's active power frequency dependence.

[…] the presented NDZ shown in *Figs. 5 and 6* correspond to the steady-state performance. The steady-state NDZ is a conservative measure of the NDZ but the actual NDZ (taking into account transient behavior) could be smaller."

"Fig. 2 shows the load curves for various values of f_r with and without frequency dependence. It can be seen that for both points A and B, the SFS curve has a higher (steeper) slope than the load curve and thus both points are considered unstable operating points. The slope of the load curve is almost constant within the 59.3-and 60.5-Hz window. For loads with $Q_f = 3$, the frequency is forced to drift beyond the frequency relay thresholds with k set to 0.1.

On the contrary, the slope of the load curve *does not change much* within the 59.3- and 60.5-Hz frequency window with frequency dependent loads, as shown in *Fig. 2*. For both points A' and B', the slope of the load curve is *smaller* than the SFS curve. Both points are considered *unstable* operating points. […]"

B. Figures based on simulations (=Section IV from [1])

Section IV from [1] provides simulation results to verify the results from mathematical analysis. Two main conclusions were drawn from this section:

- The steady-state NDZ (Fig. 11 from [1]) is very close to the NDZ from the previous Section.
- For the "100ms NDZ" (Fig. 12 from [1]) large active power mismatch are outside the NDZ.

Figures 7, 8, 9, 10, 11, 12 from the original paper are the results of simulations. They are presumably all plotted using the erroneous unit "pu/Hz". However we will not bring any correction to these figures in the present paper as the model used for [1] is not detailed enough to be reproducible. In addition, as for the previous corrected curves, all the curves would presumably be quite close to the case with k_{pf}=0 and would not bring anything new to the results of Section III.A.

C. Conclusion

"This paper analyzes the impact of the load's active power frequency dependence on the islanding detection capability of the SFS islanding detection method. Through mathematical analysis, it was proven that the load's active power frequency dependence has *no* significant impact on islanding detection and the NDZ of the SFS method. […] The analytical results prove that the load's frequency dependence is *a secondary* factor to consider when designing frequency drift islanding detection methods such as the SFS. It is envisaged that other frequency drift islanding detection methods such as the active frequency drift and slip mode frequency shift methods *would not be impacted either*."

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