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Comments in response to IOU Technical Paper

Additional submitted attachment is included below.

April 9, 2020

Submitted on-line

California Energy Commission
Soheila Pascha, PhD
1516 Ninth Street
Sacramento, California 95814

Docket: 19-AAER-03

RE: Comments to Power Factor docket , 19-AAER-03

Dr. Pasha:

Signify (formerly Philips Lighting), the world leader in lighting products, systems and services, appreciates the opportunity to offer these comments in response to the technical white paper submitted to the docket at the end of February.

Our company name comes from the fact that light is an intelligent language that connects and conveys meaning. Our understanding of how lighting positively affects people coupled with our deep technological know-how enables us to deliver digital lighting innovations that contribute to a safer, more sustainable and smarter world. By transforming light points into data points, we connect more devices, places and people for smarter homes, smarter buildings and smarter cities.

Serving both professional and consumer markets, we sell more energy efficient LED lighting than any other company. By the end of 2018, we delivered ~1.7 billion LED lights globally and we were the first lighting company to surpass the 1 billion milestone as part of the Global Lighting Challenge. As a result, we are on track to deliver 2 billion LEDs ahead of our 2020 target.

Please contact me if you have any questions.

Sincerely,

Anthony Serres
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Our global brands are

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Comments to Paper on Power Factor Energy Savings Opportunities

Ernesto Mendoza

Signify

4/9/20

Comments to Paper on Power Factor Energy Savings Opportunities

This paper describes some concerns and proposes additional considerations to the California Investor Owned Utilities Technical *White Paper on Power Factor Energy Savings Opportunities* (May-Ostendrop, Dayem, Mercier, Xergy, & Rubin, 2020), which was filed as; the California Investor Owned Utilities Comments to the California Energy Commission Power Factor Project, TN# 232241, docket 19-AAER-03.

Issues to be Addressed

1) **Technology Development.** One can read in the Power Factor and Efficiency Tradeoffs for Harmonic Loads section (May-Ostendrop et al., 2020, p. 29) a call for product prototyping and raising efficiency to 95% or higher.

> Additional study, including prototyping and product measurements, will be required to examine the extent to which increased losses from PFC in electronic products might impact savings. In the meantime, however, we can look to the results of the existing analysis to provide a reasonable upper bound on PFC stage losses. Table 5 summarizes the unit and percent energy savings results across low, mid, and high scenarios for select electronic products in this study (those with highest savings). The additional savings from power factor correction are typically a fraction of a percent to a few percent of the product's unit energy consumption, so in order to maintain positive energy savings, PFC devices must themselves consume less than this amount of energy. In practice, this will mean ensuring very high pass-through efficiencies (in excess of 95%).

It seems like including additional electrical phenomena impacting power factor is needed. This section indicates that raising power factor leads to a financial gain. We argue it is user case dependent. It is unclear why High Intensity Discharge (HID) lamps are in the mix. Most Magnetic HID ballast have a power factor higher to 0.9, and most electronic HID ballast have a power factor higher than 0.99. Furthermore; HID is a decaying technology which will be soon not be used for general or street light illumination according to the DOE analysis of the country LED adoption (National Academies of Sciences & Medicine, 2017). A HID ballast with an efficiency higher than 0.95 is outside of the max tech acknowledge in the DOE MH Fixtures energy efficiency rule (DOE_CFR_431, 2014).

2) **Literature review**. The researchers did an extraordinary effort collecting various research articles and other materials; however, it is unclear why they concluded that the current electrical power research body underrepresent power factor correction as a relative untapped opportunity for energy savings. See the conclusions section (May-Ostendrop et al., 2020, p. 34), first paragraph.

> Although under-represented in the literature and only rarely considered as an energy-saving measure, power factor correction stands as a large and relatively untapped opportunity for energy savings in buildings.

Power factor correction and its impact to buildings energy savings is specific to each application. Consider the lighting systems as an example. Commercial general illumination is powered by electronic fluorescent ballast mostly, and by LED drivers recently. Most electronic fluorescent ballast are high power factor (DOE_Framework_Fluoresecent_Lamp_Ballast, 2015). According to the DOE LED adoption report, most buildings are still illuminated by fluorescent systems. LED drivers powering commercial building lighting systems have a power factor greater than 0.99 commonly. It is difficult to say that the potential energy savings from power factor has been underrepresented when considering this user case.

3) **Dearth of Power Factor Data** (May-Ostendrop et al., 2020, p. 34). It is unclear the root of this concern. We agree with the authors claim saying there is no fundamental cost increase to industry or testing houses to report power factor once they are using a power analyzer to characterize the input power of a device.

The DOE requires yearly power factor reporting of several devices included in the scope of the study (DOE, 2014; DOE_CFR_430, 2011; DOE_CFR_431, 2014; DOE_Test_Proceadure_EPS, 2015). Heat pumps power factor may be reported different because their variable modes of operation; however, there are plenty research papers across the globe addressing its impact into the power grid (Berger & Worlitschek, 2018; Love et al., 2017).

4) **Technical approach**. The White Paper (May-Ostendrop et al., 2020) will benefit from integrating additional electrical quantities impacting power quality such as;

- Inter harmonics
- High order harmonics (higher than 2 kHz)
- Load Diversity and aggregation theorems
- Supply voltage distortion
- Power Grid specific modeling

The harmonic currents in the electrical grid are not the integer multiples of 60 Hz only. Among other reasons one need to consider variable speed motors, and power supplies. Switched power supplies operation frequency are not a integer factor of 60 Hz; their massive use result in the injection of inter-harmonics and high frequency harmonics (Aiello, Cataliotti, & Nuccio, 2004; Desmet, Sweertvaegher, Vanalme, Stockman, & Belmans, 2003; Dolara & Leva, 2012).

Electrical load diversity results in harmonics with different phase angles; thus the addition of harmonics of the same order always result in less than the arithmetic sum of the two harmonics, unless they have exactly the same angle (Desmet et al., 2003; Gonzalo, 2014). The supply voltage distortion and the specific grid impedance have an overall impact in the electrical system power factor (IEEE_519, 2014; IEEE_1459, 2010; Liu, Dow, & Liu, 2011).

Overall Proposal

We propose the authors revise the White Paper in the future considering a broader approach to power factor, disaggregating in different user cases, considering inter harmonics, and harmonics of higher order, research reports discussing harmonic aggregation in the service interconnection point, and load diversity. Disregarding these factors results in an overestimation of the power factor correction potential savings estimates, and it will drive demand for components with efficiency higher than 0.95, with no real gain. We are providing some technical analysis and a complementary literature review to support this effort.

Complementary Analysis

The publication of the IEEE standard 1459, *Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, No sinusoidal, Balanced, or Unbalanced Conditions* (IEEE_1459, 2010) has been used by many researchers to investigate an enhanced view of power factor and its implications for the electrical grid (Dolara & Leva, 2012; Duarte & Schaeffer, 2010; Willems, 2010). The enhanced power factor understanding has been equally used to describe the Power Quality of electrical devices, as well as to describe the Economic Impact on the power grid (Muñoz-Galeano, Alfonso-Gil, Orts-Grau, Seguí-Chilet, & Gimeno-Sales, 2015; S. & E., 2009).

Power Factor Enhanced Understanding in General Terms

The power quality of devices and electrical networks are better described in terms of its fundamental metrics of displacement and harmonic factors, as opposed to, power factor (Fiorucci, 2015; Gonzalo, 2014). Thus, the power factor can be described using two alternative algorithms. See Equations 1 to 5.

Equation 1, Power Factor Traditional Description

$$PF = \frac{W}{V.A}$$

Equation 2, Power Factor Alternative Description

$$PF = df * hf$$

Assuming a pure sinusoidal voltage has been provided to the load, the displacement factor is equal to the cosine of the fundamental harmonic phase angle. The harmonic factor is the inverse of the root square of the total harmonic distortion square plus one. See Equations 3, 4, and 5.

Equation 3, Simplified displacement factor

$$df = \cos(\emptyset_1)$$

Equation 4, Simplified harmonic factor

$$hf = \frac{1}{\sqrt{1 + THD^2}}$$

Equation 5, Power Factor Alternative Description Rewrite

$$PF = \frac{\cos(\emptyset_1)}{\sqrt{1 + THD^2}}$$

Equation 5 is the same as the one described in the California Investor Owned Utilities

A detailed explanation about the equivalence of Equations 1 and 5 and its limitations can be found at the *Philips Technical Response for Low Power Mode and PF* (Mendoza, Pacelle, & Haring, 2017), and Standard IEEE 1459 *Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, No Sinusoidal, Balanced, or Unbalanced Conditions* (IEEE_1459, 2010). A more comprehensive description of the power factor is needed when the voltage provided to the load deviates from the sinusoidal. See Equation 6.

Equation 6, Power Factor Alternative General Description

$$\mathrm{PF} = \frac{P}{S} = \frac{P_1 + P_H}{\sqrt{S_1^2 + S_N^2}} = \frac{(P_1 / S_1)[1 + (P_H / P_1)]}{\sqrt{1 + (S_N / S_1)^2}} = \frac{[1 + (P_H / P_1)]\mathrm{PF}_1}{\sqrt{1 + \mathrm{THD}_I^2 + \mathrm{THD}_V^2 + (\mathrm{THD}_I \mathrm{THD}_V)^2}}$$

This equation encompasses the various harmonics power, as well as the total harmonic distortion of current and voltage. Thus, the power factor of a power grid is impacted by the power plant generation voltage distortion. There are various factors that affect the voltage distortion, including load effects, the distribution effects, and the electrical power generator quality. Low harmonic distortion, high power factor devices may be negatively affected by high voltage distortion from the electrical power generator. An electronic preconditioner circuit designed to improve a load power factor may be designed to synchronize the voltage and current phases; however, a voltage harmonic distortion which results in various zero crossings per half cycle may defeat the synchronization circuit (Paschedag & Ferdowsi, 2012).

Another phenomenon of consideration is the harmonics phase diversity, which is a description of how the different harmonics for different electrical equipment may have different phase angles. Various studies have shown the power factor, measured in a building interconnection to the electrical grid, has been impacted way less than what one could from considering the power factor of each individual load (K., J., & M., 2010; Rönnberg, Wahlberg, & Bollen, 2010).

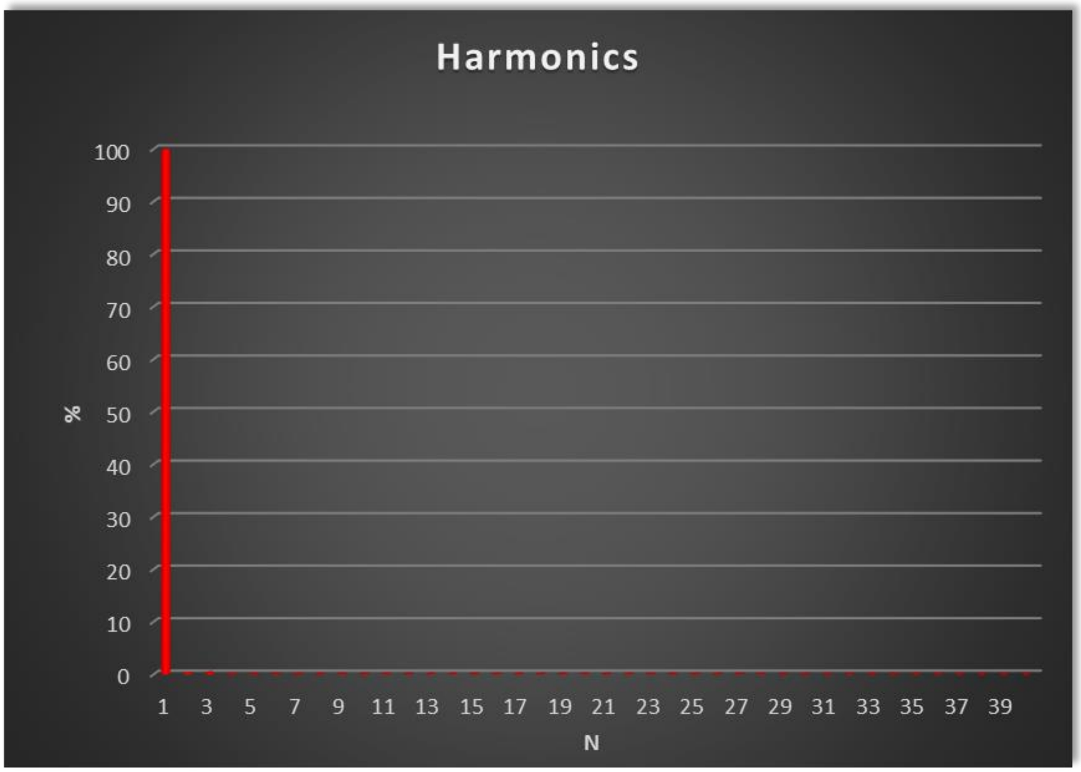
Power Factor Enhanced Understanding in Terms of Lighting Devices

Building lighting applications have been frequently debated (Lam, 2012; Mendoza & Haring, 2018; Milardovich, Prevosto, Lara, & Milardovich, 2017). It is possible to argue that an incandescent lamp is better for the overall electrical grid because it has a power factor of one, and therefore, no harmonic distortion. Figures 1 and 2 show the electrical parameters and current harmonics of a 120V, 100W incandescent lamp.

Figure 1, 100W Incandescent Lamp Electrical Parameters

DATE	1/11/18
TIME	18:05:55
VRMS	119.97
IRMS	0.8312
WATTS	99.7196
VA	99.7554
VTHD	0.338969
ITHD	0.484459
PF	0.999988
EPA	0.00509373

Figure 2, 100W Incandescent Lamp Electrical Current Harmonics

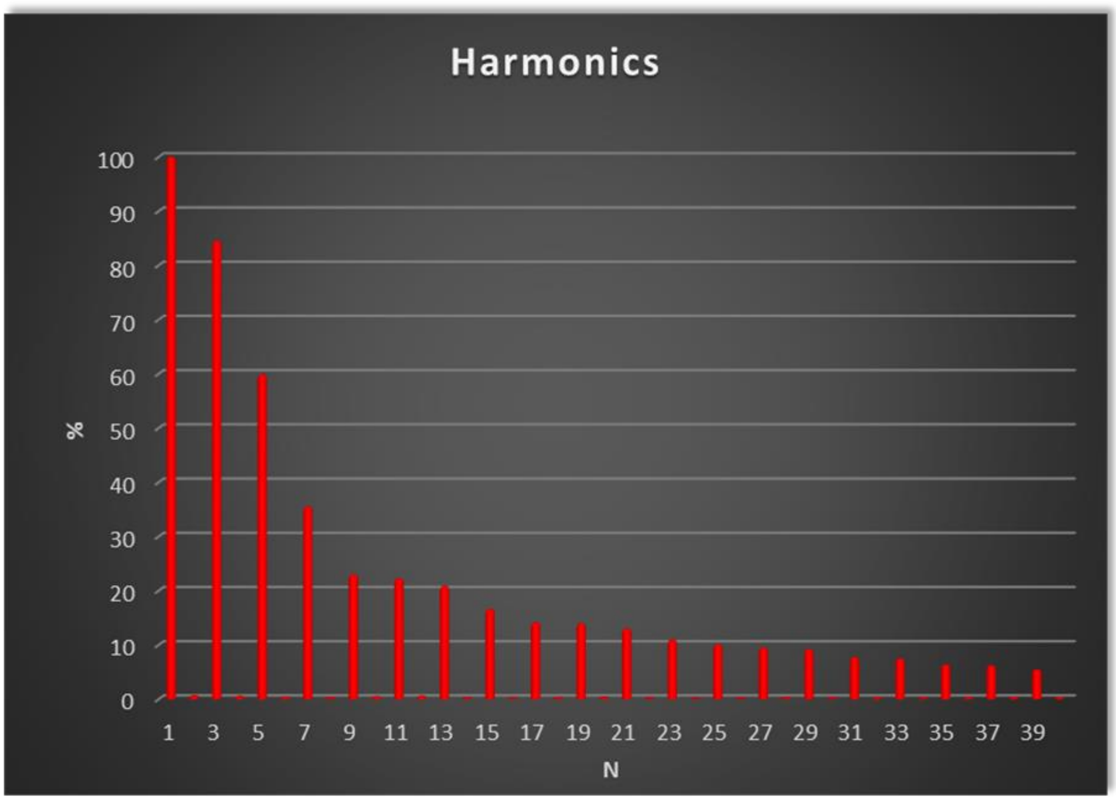


It is useful to consider how the 10 W LED lamp electrical parameters compares with the 100W incandescent lamp electrical parameters, assuming both are used to illuminate similar spaces. Figures 3, and 4.

Figure 3, 10 W LED Lamp Electrical Parameters

DATE	1/11/18
TIME	17:47:58
VRMS	120.073
IRMS	0.143905
WATTS	10.0026
VA	17.282
VTHD	0.332927
ITHD	122.393
PF	0.578888
EPA	0.953422

Figure 4, 10W LED Lamp Electrical Current Harmonics



The 10W LED lamp power factor seems to compare poorly to the incandescent lamp because; the LED lamp has a power factor of 0.57, compared to the power factor of 1 of the incandescent lamp. However, the electrical network will have reduced losses because the electrical current reduces from 0.83Arms to 0.14Arms. A load of 1 KW will be added every ten incandescent lamps, with a current consumption of 8.3Arms. Whereas ten 10 W LED lamps will be consuming 10% of the power, and they will load the circuit with a current of 1.4 Arms.

Comparing Figures 3 and 4 may lead to misunderstanding of the real power factor and harmonic distortion impact when replacing incandescent lamps by LED lamps because they are expressed in percentage. See Figures 5, and 6.

Figure 5, 100W incandescent and 10W LED Lamps Harmonic Currents Comparison %

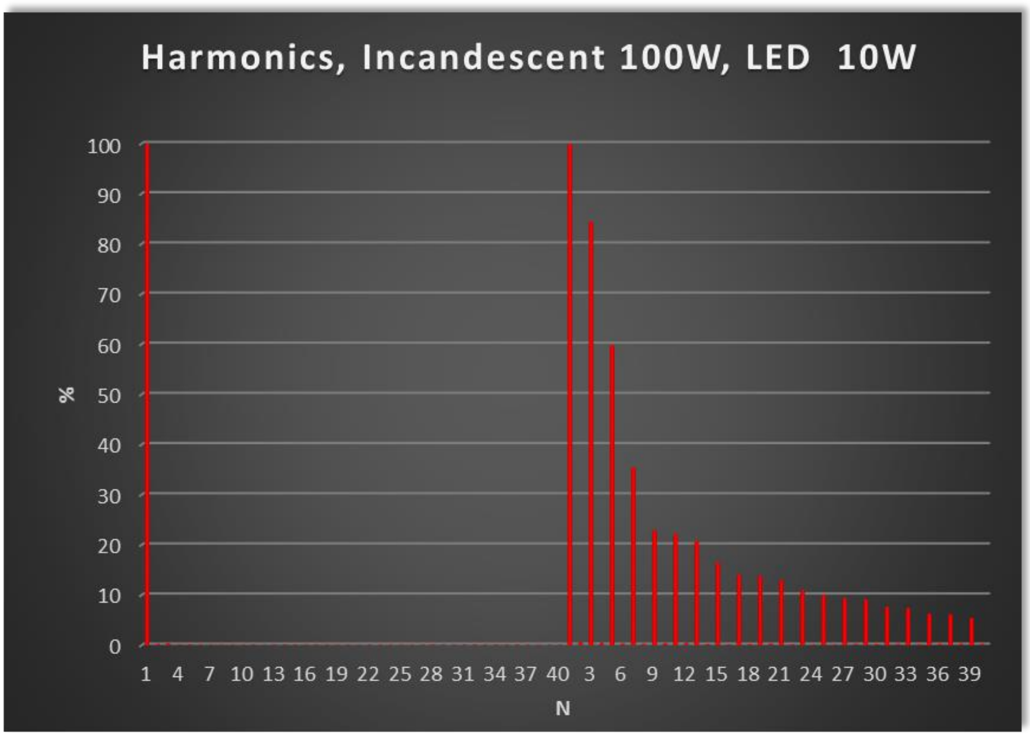
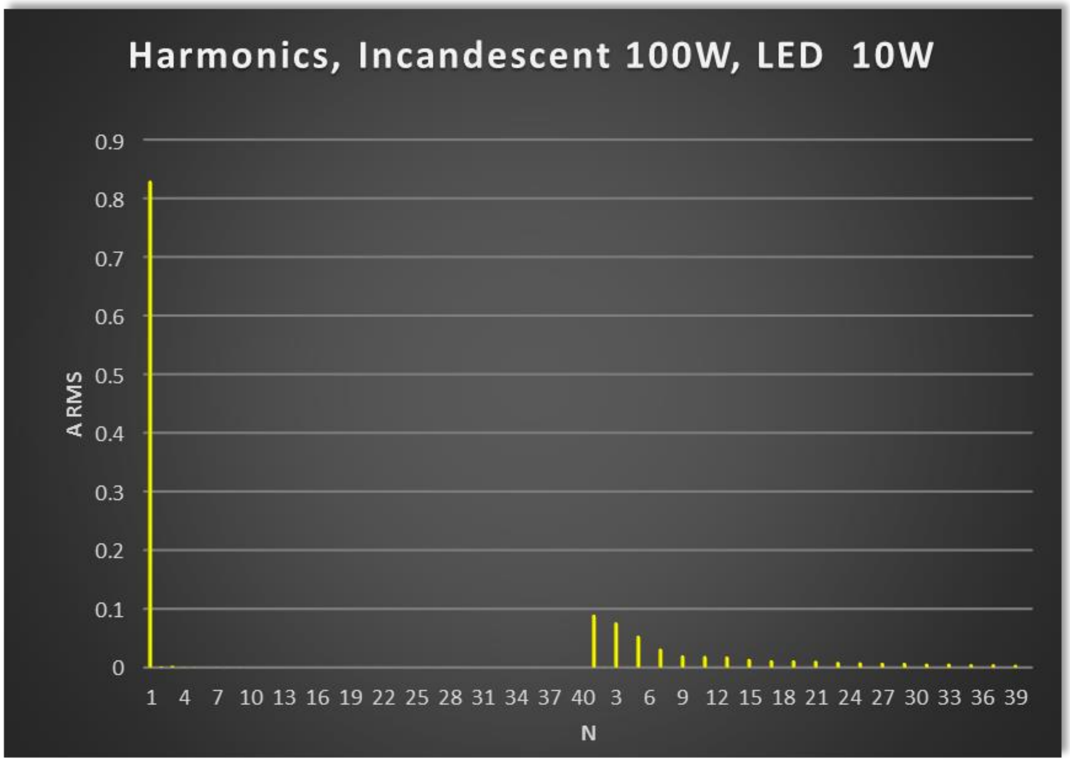


Figure 6, 100W incandescent and 10W LED Lamps Harmonic Currents Comparison Arms



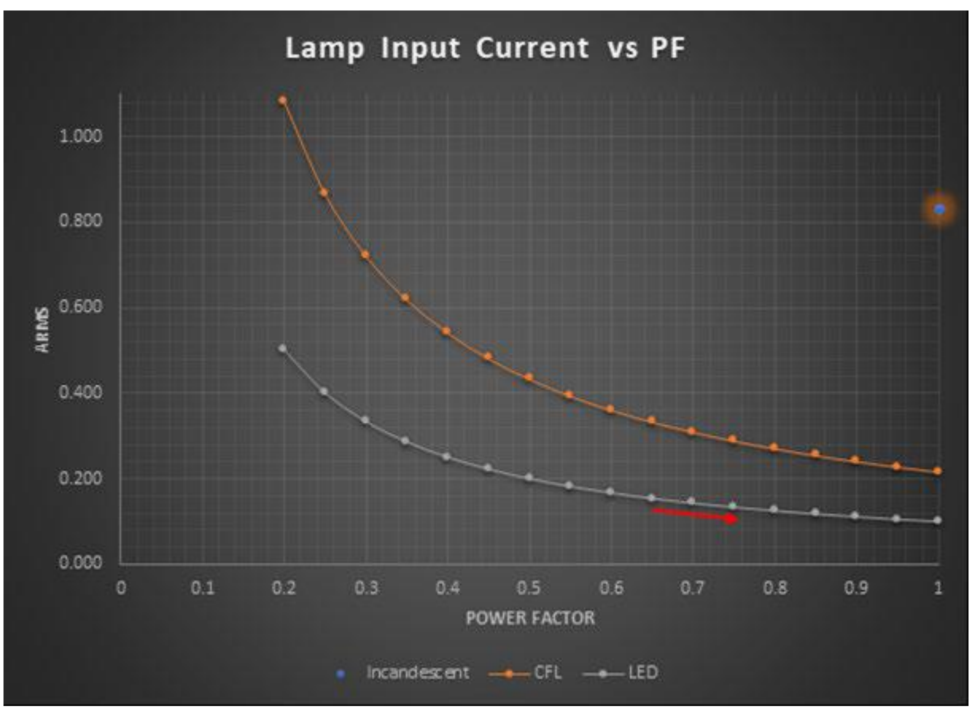
We have shown the harmonics from the incandescent lamp on the left side and the harmonics of the LED lamp on the right side in Figures 5, and 6. The harmonics comparison in RMS current (Arms) is the most useful to understand the real impact on the electrical grid for this use case. Thus, for equal illumination of similar spaces, replacing the incandescent lighting by LED lighting will result in fewer power losses in the system, regardless that the LED lamp has a lower power factor and a higher harmonic distortion. A study expanding this concept to connected IoT electrical systems, harvesting natural light, have been described in the research paper *LED Drivers Energy Efficiency and IoT* (Mendoza, Haring, & Wolfman, 2019) discussed last year at the IES annual conference.

Similar findings have been described in the ANSI Standard C82.77-10 *American National Standard for Lighting Equipment—Harmonic Emission Limits—Related Power Quality*

Requirements (ANSI_C822.77-10, 2020). See Figure 7. This figure describes the relationship of the power factor of an incandescent lamp, 26W CFLi lamp, and a 10W LED lamp to the electrical current expressed in RMS. The horizontal axis is the power factor, and the vertical axis is the electrical current in RMS. The blue / orange dot placed at the top right represents the 100W incandescent lamp behavior. The orange line represents the 26W CFLi, and the gray line represents the 10W LED lamp. It is worth mentioning that most LED lamps in the marketplace today have a power factor closer to 0.71 as opposed to a power factor closer to 0.5; we have used the lowest power factor in the example before to assume the worst case.

One can be tempted to ask for a LED lamp with a preconditioner or other power factor correction circuit to raise it from 0.7 to 1.00 Figure 7 depicts how there is almost no significative electrical current reduction for the LED lamp case, (follow the red arrow).

Figure 7, Various Lamps Power Factor and Electrical Current Relationship



Note, adapted from; ANSI_C822.77-10. (2020). American National Standard for Lighting Equipment—Harmonic Emission Limits—Related Power Quality Requirements

Conclusions

Power Factor expressed as real power divided by apparent power (see Equation 1) is a compound metric that obscures the understanding of potential impacts and savings. An enhanced understanding emerges from expressing power factor in terms of Equation 6, or its simplified form Equation 5, when applicable.

It is difficult to propose a general model describing potential savings from power factor corrections to individual components in the electrical grid. The potential savings are contingent to the specific use case. The example above shows how there are almost no benefits to the grid by increasing the power factor of a 10W LED lamp from 0.7 to 1; whereas, the power factor correction circuit will impact the cost significantly to consumers.

A more comprehensive model of the potential savings from increasing the power factor of individual electrical components is needed. This new model needs to include, among other considerations.

- Inter harmonics
- High order harmonics (higher than 2 kHz)
- Load Diversity and aggregation theorems
- Supply voltage distortion
- Power Grid specific modeling

The above-mentioned additional considerations will result in a more realistic power factor energy savings expectation, and it will prevent demanding electrical grid components with an energy efficiency higher than 0.95.

Bibliography

Aiello, M., Cataliotti, A., & Nuccio, S. (2004). A PC-based instrument for harmonics and interharmonics measurement in power supply systems. *Measurement, 35*(4), 371-380. doi:http://dx.doi.org/10.1016/j.measurement.2004.03.005

ANSI_C822.77-10. (2020). NEMA Publishes ANSI C82.77-10-2014 American National Standard for Lighting Equipment—Harmonic Emission Limits—Related Power Quality Requirements. In. Washington, D.C: American National Standards Lighting Group. In affiliation with National Electrical Manufacturers Association.

Berger, M., & Worlitschek, J. (2018). A novel approach for estimating residential space heating demand. *Energy, 159*, 294-301. doi:https://doi.org/10.1016/j.energy.2018.06.138

Desmet, J. J. M., Sweertvaegher, I., Vanalme, G., Stockman, K., & Belmans, R. J. M. (2003). Analysis of the neutral conductor current in a three-phase supplied network with nonlinear single-phase loads. *IEEE Transactions on Industry Applications, 39*(3), 587-593. doi:10.1109/TIA.2003.810638

DOE. (2014). Appliances and Commercial Equipment Standards. Retrieved from http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/23

DOE_CFR_430. (2011). 10 CFR 430 Energy Conservation Program: Energy Conservation Standards for Fluorescent Lamp Ballast. Agency: Office of Energy Efficiency and Renewable Energy, Department of Energy. Action: Final Rule. In *Final Rule* (Vol. 10 CFR 430, pp. 70558-70629). Washington D.C.: Federal Register Vol 76 N0 219 Monday 14, 2011 Rules and Regulations.

DOE_CFR_431. (2014). Energy Conservation Porgram: Energy Conservation Standards for Metal Halide Lamp Fixtures. In. Washington, DC: United States Department of Energy.

DOE_Framework_Fluoresecent_Lamp_Ballast. (2015). Energy Conservation Standards Rulemaking Framework Document for Fluorescent Lamp Ballasts Docket Number: EERE-2015-BT-STD-0006. In.

DOE_Test_Proceadure_EPS. (2015). **DEPARTMENT OF ENERGY. 10 CFR Parts 429 and 430, [Docket No. EERE–2014–BT–TP–0043], RIN 1904–AD36. Energy Conservation Program: Test Procedures for External Power Supplies** In. Washington D.C.: **U.S**. **DEPARTMENT OF ENERGY**.

Dolara, A., & Leva, S. (2012). Power Quality and Harmonic Analysis of End User Devices. *Energies, 5*(12), 5453-5466. doi:http://dx.doi.org/10.3390/en5125453

Duarte, C. H., & Schaeffer, R. (2010). Economic impacts of power electronics on electricity distribution systems. *Energy, 35*(10), 4010-4015. doi:http://dx.doi.org/10.1016/j.energy.2010.03.037

Fiorucci, E. (2015). The measurement of actual apparent power and actual reactive power from the instantaneous power signals in single-phase and three-phase systems. *Electric Power Systems Research, 121*, 227-242. doi:http://dx.doi.org/10.1016/j.epsr.2014.11.002

Gonzalo, S. (2014). Power factor in electrical power systems with non-linear loads. INELAP

IEEE_519. (2014). IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems. *Institute of Electrical and Electronics Engineers IEEE*.

IEEE_1459. (2010). Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions. In.

K., R. S., J., B. M. H., & M., W. (2010, 26-29 Sept. 2010). *Harmonic emission before and after changing to LED and CFL — Part I: Laboratory measurements for a domestic customer.*

Paper presented at the Proceedings of 14th International Conference on Harmonics and Quality of Power - ICHQP 2010.

Lam, J. (2012). *A dimmable high power factor electronic ballast for compact fluorescent lamps.* (NS28189 Ph.D.). Queen's University (Canada), Ann Arbor. Retrieved from http://search.proquest.com/docview/1513231711?accountid=458 Retrieved from http://linksource.ebsco.com/linking.aspx?sid=ProQuest+Dissertations+%26+Theses+Full+Text&fmt=dissertation&genre=dissertations+%26+theses&issn=&volume=&issue=&date=2012-01-01&spage=&title=A+dimmable+high+power+factor+electronic+ballast+for+compact+fluorescent+lamps&atitle=&au=Lam%2C+John&isbn=9780499281890&jtitle=&btitle=&id=doi: ProQuest Dissertations & Theses Full Text database.

Liu, R., Dow, L., & Liu, E. (2011). *Survey-PEV-Impacts*. Paper presented at the IEEE PES Innovative Smart Grid Technologies Conference, Anaheim, CA.

Love, J., Smith, A. Z. P., Watson, S., Oikonomou, E., Summerfield, A., Gleeson, C., . . . Lowe, R. (2017). The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy, 204,* 332-342. doi:https://doi.org/10.1016/j.apenergy.2017.07.026

May-Ostendrop, P., Dayem, K., Mercier, C., Xergy, & Rubin, E. (2020). A New Factor In Efficiency. Energy Savings Opportunities Through Improved Power Factor *The California Investors Owned Utilities, Feb*.

Mendoza, E., & Haring, R. (2018). *Power Quality, Harmonics, Power Factor, and Standby Power in the Times of Smart Lighting Systems*. Paper presented at the IES Annual Conference 2018. https://www.ies.org/product/ies-2018-annual-conference-proceedings/

Mendoza, E., Haring, R., & Wolfman, H. (2019). *LED Drivers Energy Efficiency and IoT*. Paper presented at the 2019 IES Annual Conference, Louisville, KY. https://www.ies.org/product/ies-2019-annual-conference-proceedings/

Mendoza, E., Pacelle, M., & Haring, R. (2017). Philips Technical Response for Low Power Mode and PF. Docket 17-AAER-12: Low-Power Mode and Power Factor. *Philips Lighting, TN 229071*.

Milardovich, N., Prevosto, L., Lara, M., & Milardovich, D. (2017). On the reduction of the third-order harmonic losses in low–voltage power cables used for feeding large LED and CFL lighting loads. *Advanced Electromagnetics, 6*(3), 46-52.

Muñoz-Galeano, N., Alfonso-Gil, J. C., Orts-Grau, S., Seguí-Chilet, S., & Gimeno-Sales, F. J. (2015). Instantaneous approach to IEEE Std. 1459 power terms and quality indices. *Electric Power Systems Research, 125*, 228-234. doi:http://dx.doi.org/10.1016/j.epsr.2015.04.012

National Academies of Sciences, E., & Medicine. (2017). *Assessment of Solid-State Lighting, Phase Two*. Washington, DC: The National Academies Press.

Paschedag, D., & Ferdowsi, M. (2012, 15-20 Sept. 2012). *Elimination of zero-crossing distortion in a power factor correction circuit.* Paper presented at the 2012 IEEE Energy Conversion Congress and Exposition (ECCE).

Rönnberg, S. K., Wahlberg, M., & Bollen, M. H. J. (2010, 26-29 Sept. 2010). *Harmonic emission before and after changing to LED and CFL — Part II: Field measurements for a hotel.* Paper presented at the Proceedings of 14th International Conference on Harmonics and Quality of Power - ICHQP 2010.

S., P., & E., E. A. (2009). Effect of Neutral Path Power Losses on the Apparent Power Definitions: A Preliminary Study. *IEEE Transactions on Power Delivery*, *24*(2), 517-523. doi:10.1109/TPWRD.2009.2014481

Willems, J. (2010). *The IEEE standard 1459: What and why?*