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Response to Invitation to Participate - Power Factor

Additional submitted attachment is included below.

Power Factor

Codes and Standards Enhancement (CASE) Initiative
For PY 2017: Title 20 Standards Development

Response to the California Energy Commission's Invitation to Participate
Phase 2 Pre-Rulemaking
Power Factor
17-AAEER-12

June 16, 2017

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1. Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (the Energy Commission or CEC) efforts to update California's Appliance Efficiency Regulations (Title 20) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and SoCalGas® – sponsored this effort (herein referred to as the Statewide CASE Team). The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve the energy and water efficiency of various products sold in California. The information presented herein is a response to the Energy Commission's Invitation to Participate (ITP) Phase 2 Pre-Rulemaking for the power factor roadmap.

The Statewide CASE Team strongly supports the Energy Commission's decision to develop a roadmap to address power factor in a variety of products. This response contains a review of the benefits of improving power factor, the Statewide CASE Team's recommendations on defining scope, background information on available technologies, example policy frameworks, and a review of existing test procedures and mandatory regulations.

2. Review of Power Factor Opportunity and Benefits

Power factor improvements represent a large opportunity for statewide energy savings. A 2014 Energy Commission-funded study conducted by the Electric Power Research Institute (EPRI) concluded that power factor improvements could achieve statewide savings of 241 GWh per year at full stock turnover; however, EPRI only considered behind-the-meter savings that would occur in buildings themselves (CEC 2015). The Statewide CASE Team's analysis suggests that upstream, grid-side power factor energy savings can be very significant—of similar magnitude as the building-level savings—and the Statewide CASE Team encourages the Energy Commission to consider these energy benefits in addition to customer-side benefits in evaluating the statewide impacts and cost-effectiveness of potential power factor improvements. Power factor is an important element of overall power quality that can have implications for consumers' electricity bills, their equipment, and the grid. It is a unique energy savings opportunity and Title 20 roadmap topic, because it yields benefits at the system level rather than directly at the load itself. Whereas a high-efficiency motor or general service lamp consumes less real power at the point of load, a product with high power factor can consume the *same* real power at the point of load, but results in fewer upstream electrical losses in building wiring, distribution wiring, and transformers.

For electric utilities, improving power quality has other benefits for the electrical distribution system and customers beyond energy efficiency alone (qualitatively summarized in Table 1), including reduced wear and tear on distribution system components and building wiring, and a reduction in high-frequency ac currents in building wiring, which can disturb sensitive electrical equipment.

Table 1. Summary of Power Factor Improvement Benefits

Type of Benefit	Building-Level Benefits	Grid-Level Benefits
Energy benefits	• Fewer losses in building wiring lead to reduced electric consumption and utility bill savings.	• Reduced losses in distribution lines and transformers.
Non-energy benefits	• Reduced harmonic currents on building's neutral wires, decreasing overheating risk. • Reduced electromagnetic noise on circuits, beneficial to certain sensitive equipment.	• Extended life of system components, such as transformers, by reducing electrical currents and resulting heat generation.

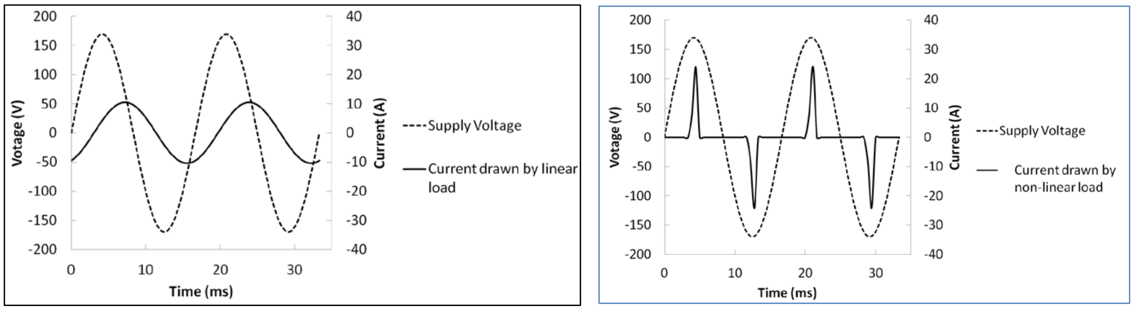
3. Scope

At this early stage in the roadmap process, the Statewide CASE Team encourages the Energy Commission to examine power factor opportunities broadly across a variety of end uses that meet the key criteria mentioned in the May 11, 2017 Energy Commission staff ITP presentation: cost-effective, technically feasible, and not federally preempted. Low power modes and power factor have been presented alongside each other in the staff roadmap ITP, but they need not have the same scope. Cost-effective and feasible savings opportunities for power factor may differ significantly from those identified for low power modes. Therefore, it is important that the scope of the power factor and low power modes standards be decoupled to maximize cost-effective, feasible savings for both efforts. The Statewide CASE Team plans to conduct additional analysis to inform scope considerations.

In a similar way, the Energy Commission need not limit its scope to larger loads (more than 75 watts in nameplate power rating) such as those addressed in certain industry standards (see Section 7. Mandatory Energy Regulations). Although power factor improvements may generate smaller savings through low-power loads like consumer electronics and office equipment, such devices represent significant aggregate load in buildings—about 20 percent of residential electricity consumption, according to the Energy Commission's research (CEC 2010)—and so their power factor savings potential could be commensurately large.

4. Root Causes and Technology Availability

Power factor issues are manifested in two root causes, which depend, on the types of end uses being powered and how they interact with the power system. In the case of *displacement*, loads draw ac current out of phase with the ac voltage supply, leading to lower power factor. Electric motors and motorized appliances exhibit displacement power factor issues. In the case of *harmonic distortion*, loads draw ac current in a non-linear, non-sinusoidal manner and cause harmonic currents (waveforms with frequencies higher than the standard 60 Hz) in building wiring and the grid. As with displacement issues, harmonic distortion results in lower power factor as well. Harmonic distortion is typically generated by the power electronics used in switch-mode power supplies, variable frequency drives, and other non-linear, electronically controlled equipment that operate at high frequencies. Current waveforms for both displacement and harmonic distortion are depicted in Figure 1.



a) Displacement   b) Harmonic distortion

Figure 1. Displacement (a) and harmonic distortion (b) current waveforms (CEC 2015)

A product's true power factor is simply its ratio of real power in watts (*P*) to apparent power in volt-amperes (*S*). It is a function of both displacement and harmonic distortion effects and is related by the following expression:

$$\mathrm{PF} = \frac{P}{S} = \frac{\mathrm{PF}_{\mathrm{disp}}}{\sqrt{1 + \mathrm{THD}_I^2}}$$

Eq. 1

Where: $\mathrm{PF}_{\mathrm{disp}}$ is the power factor due to displacement effects only and THD_I is the total harmonic distortion of the current for the end device. A decrease in displacement power factor causes a corresponding decrease in true power factor, but an increase in THD (overall harmonic content for the load) will result in lower power factor as well.

The technological solutions to address power factor issues vary depending on the underlying cause. Displacement issues can be mitigated by introducing reactive elements like capacitors to counteract the phase shift of inductive elements like motors. Distortion power factor must be addressed using electronic filters to mitigate the electrical "noise" on the line. A variety of vendors, including Power Integrations, ON Semiconductor, and Texas Instruments, manufacture power factor correction (PFC) integrated circuits (ICs) for this purpose. Such PFC ICs scale in size and cost according to the overall power ratings of the product.

As the Energy Commission evolves the scope for its power factor roadmap, it will be important to carefully consider the different technological pathways and associated costs appropriate to different loads depending on the underlying root causes of power quality issues.

Table 2 summarizes two general approaches available today to address power factor at the device level (other solutions available at building- or grid-scale would not be appropriate to Title 20).

Table 2. General Technologies to Improve Power Factor

Technology	Type of Power Factor Addressed	Description	Applicable End Uses
Capacitors	Displacement	Integrated capacitors counteract the displacement power factor introduced by inductive elements like motors.	Motor-driven loads without electronic controls.
Harmonic filtering or power factor correction	Harmonic distortion	Solid-state electronic component(s) integrated into a device's power supply that actively filters out harmonic currents.	Suitable for any electronic device with a switch-mode, ac-dc power supply or motorized devices with variable frequency drives (i.e., non-linear loads).)

5. Framework

Power factor improvement targets could be developed under two general policy frameworks. Under a vertical framework, the Energy Commission would enumerate a list of individual products that present maximum cost-effective savings from power factor improvement. Targets might need to be established separately for individual product categories based on the root cause of their power quality issue (i.e., displacement vs. harmonic distortion), the cost-effective technological pathway to ameliorate power factor, and the operational mode(s) that generate the greatest savings. In practice, a vertical framework might simply entail developing a long-term strategy to update individual product regulations with power factor requirements.

Under a horizontal framework, product power factor would be addressed through a single, generally defined target that could be applied to a large group of similar products or perhaps several "clusters" containing large numbers of similar products (e.g., one set of targets for product categories dominated by displacement power factor issues and another for product categories dominated by harmonic distortion issues). Such an approach is most compatible with the parallel low power modes roadmap.

The challenge with this approach would be to define power factor targets in a way that can be generally applied to many products, without needing to enumerate specific test conditions and operational modes for each individual product. A 2015 Energy Commission-funded research project provides an example of how this might be implemented. The project team based statewide energy savings estimates on power factor targets corresponding to the 50 and 100 percent load points for a product's power supply (CEC 2015). This approach is analogous to the framework that the 80 PLUS program, ENERGY STAR® program, and the CEC use to set efficiency targets for computer internal power supplies. In this way, targets can be applied broadly and horizontally to various loads containing power supplies, without explicitly defining test conditions and operational modes for individual product classes.

The CASE Team continues to analyze the suitability of horizontal and vertical frameworks to the power factor topic and recommends that the Energy Commission remain open to a range of framework approaches. The optimal framework for this topic will likely be dependent on the ultimate scope of coverage.

6. Test Methods

Power factor is a key physical property of any ac electrical load; it is simply the ratio of real power in watts to apparent power in volt-amperes drawn by a load. As such, it is often a required reporting variable in energy efficiency test methods for ac equipment and can easily be captured by any high-quality digital power analyzer. However, the Statewide CASE Team is unaware of a single test method that can be generally applied to all electrical loads to measure power factor. Some product-specific test procedures require reporting of power factor, usually under active mode conditions. For example, the CEC's television regulation requires reporting of active mode power factor during specific operational modes for televisions that draw more than 100 watts.

Standards organizations like the Institute of Electrical and Electronics Engineers (IEEE) have developed generalized test standards that capture power factor for broad classes of electrical components, such as 112-2004 and 114-2010 for polyphase and single-phase induction motors, respectively (IEEE 2004; IEEE 2010). Such test standards are only applicable to the motors themselves and not necessarily the complete motorized appliance in which they are housed.

The International Electrotechnical Commission (IEC) standard 61000-3-2 provides more detailed guidance on the measurement of THD[1]— a key component of true power factor—as well as a set of product-specific test conditions for measuring THD for devices such as televisions, audio amplifiers, vacuum cleaners, washing machines, air conditioners, and microwaves (IEC 2014). IEC 61000-3-2 does *not* explicitly address the measurement of displacement power factor issues that arise from inductive loads like motors. IEC 61000-3-2 is also limited in that it only applies to loads with less than 16 amperes per phase between 75 and 600 watts of rated input power.

The Statewide CASE Team is only aware of two test methods that provide general test methods for power factor measurement that could be applied horizontally to many products: (1) the Generalized Test Protocol for Calculating the Energy Efficiency of Ac-Dc and Dc-Dc Power Supplies (Mansoor et al. 2012) and (2) Department of Energy's (DOE) external power supply test method (DOE 2015). These test methods guide users in measurements of internal and external power supplies, respectively, across a range of test points that vary as a fraction of the power supply's rated load. With the use of these test methods, one could measure the power factor of any product with a power supply at standardized load conditions. Even these methods have limitations, as they only directly apply to products with power supplies (a simple, motorized appliance could not be measured).

Depending on the ultimate scope and framework for the power factor roadmap, the Energy Commission would need to provide additional testing guidance for in-scope products, potentially piecing testing requirements together from several test procedures like those discussed above.

7. Mandatory Energy Regulations

The IEC 61000-3-2 referenced above also establishes limits for harmonic distortion for equipment in the 75 and 600 watts input range; however, as the standard itself is not legally binding in the

[1] Total harmonic distortion is a key power quality metric very closely related to power factor. It describes the fraction of the current or voltage waveform in frequencies above the nominal/base frequency of 60 Hz.

United States, power factor problems have not been comprehensively mitigated for in-scope products and opportunities for improvement still exist. For example, desktop computer power supplies today may or may not include power factor correction technology, but the decision is driven more by voluntary energy efficiency requirements, such as 80 PLUS or ENERGY STAR, than with IEC guidance.

Although power factor requirements and reporting criteria do appear in various vertical product specifications (ENERGY STAR specifications for computers, enterprise servers, and uninterruptible power supplies) and mandatory regulations (European Commission Ecodesign regulations for computers, and servers; the Energy Commission regulations for computers, fluorescent lamp ballasts, televisions and signage displays) the Statewide CASE Team is not aware of any energy efficiency standards that comprehensively or horizontally address the issue of power factor.

8. Conclusion

The Statewide CASE Team strongly supports the Energy Commission's intention to develop a power factor roadmap. Power factor improvements can yield substantial statewide energy savings, both in buildings and utility electrical distribution systems. When assessing the benefits of power factor improvements, the Statewide CASE Team encourages the Energy Commission to consider the full scope of energy and non-energy benefits, such as reduced risk of overheating in buildings' neutral wires and longer lifetimes for distribution transformers.

In defining the roadmap scope, the Statewide CASE Team encourages the Energy Commission to initially consider all products that are not federally preempted, and then take a data-driven approach to narrow its focus. Accordingly, the Statewide CASE Team encourages the Energy Commission to initially evaluate opportunities to improve both displacement power factor and harmonic distortion, and consider the range of technological pathways appropriate to each situation. It is important that the scope of the power factor and low power modes roadmaps be decoupled to afford flexibility in identifying the best mix of cost-effective and feasible savings opportunities may differ significantly.

Two potential policy frameworks could be applied to the power factor roadmap. Under a vertical framework, the Energy Commission would enumerate a list of individual products that present maximum cost-effective savings from power factor improvement and establish separate power factor targets for each product. Under a horizontal framework, product power factor would be addressed through a single, generally defined target that could be applied to a large group of similar products or perhaps several "clusters" containing large numbers of similar products (e.g., one set of targets for product categories dominated by displacement power factor issues and another for product categories dominated by harmonic distortion issues). The CASE Team continues to analyze the suitability of horizontal and vertical frameworks to the power factor topic and recommends that the Energy Commission remain open to a range of framework approaches. The optimal framework for this topic will likely be dependent on the ultimate scope of coverage.

A variety of test methods currently exist that could collectively address power factor measurements for diverse equipment types. Although no one generalized power factor test method exists, the Energy Commission could utilize established procedures to assemble the necessary test conditions for a diverse range of roadmap products.

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