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Response to Invitation to Submit Proposals - 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 Request for Proposals
Phase 2 Pre-Rulemaking
Power Factor
17-AAEER-12

September 18, 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) 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 Submit Proposals for 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 adverse effects of low power factor, the multiple benefits of improving power factor, and the technology pathways for doing so. It also contains a discussion of key considerations for developing an effective power factor roadmap, including: options for scope and framework; a review of existing test methods and regulations; and how a proposed series of research activities might lead to the culminating policy activities of the power factor roadmap.

2. Background

Power factor improvements present a compelling path to large 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 gigawatt hours (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; similar in magnitude to behind-the-meter savings. Therefore, 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.

Beyond increasing energy efficiency, improved power quality for electric utilities has other benefits for the electrical distribution system and for customers. Such benefits include reduced wear and tear on distribution system components and building wiring, and reduction in alternating current (AC) voltage distortion in local building wiring—which can disturb sensitive electrical equipment.

This submission expands upon the Statewide CASE Team's June 16, 2017 Invitation to Participate (ITP) submission through additional supporting data, suggestions on roadmap approaches and activities, and discussion of Statewide CASE Team planned activities to gather data and develop a standards proposal.

Table 1: Overview of the Statewide CASE Team roadmap proposal

Description of Standards Proposal	The Statewide CASE Team continues to support the Energy Commission's pursuit of a power factor roadmap. The roadmap will ultimately lead to a determination of cost-effective power factor opportunities, followed by policy actions in either a vertical or horizontal framework.
California Stock and Sales	The Statewide CASE Team is currently evaluating a range of residential and commercial products with potential power factor impacts, and will provide further stock and sales details as analysis progresses.
Energy Savings and Demand Reduction	The Statewide CASE Team will provide detailed analysis of energy savings potential as part of future submissions and as sufficient data become available.
Economic Analysis	The Statewide CASE Team will provide detailed economic analysis as part of future submissions and as sufficient data become available.
Non-Energy Benefits	A piece of electrical equipment with low power factor requires higher AC current to operate than similar, power-factor-corrected equipment, leading to greater heat and wear on electrical components, such as transformers in buildings, and on the distribution grid. Improvements to power factor reduce AC current requirements in equipment thereby helping to extend the useful life of distribution equipment. Products (such as power supplies and motor drives) with nonlinear loads that exhibit harmonic distortion –which in turn causes low true power factor—produce harmonic emissions that can cause distortion in supply voltages. The result is a reduction in power quality for other nearby equipment. Severe distortion can be problematic for sensitive equipment and can even trip circuit breakers in extreme cases. Correcting for harmonic distortion, especially in end-use products, ensures that these emissions will not disturb local building wiring or the grid itself.
Environmental Impacts	At this time, the Statewide CASE Team is unaware of any adverse environmental impacts that might result from this measure. The Statewide CASE Team will provide more detailed feedback on this topic in future submissions, at which time the potential scope and technological pathways associated with the roadmap and any future regulations will be more clear.
Acceptance Issues	At this time, the Statewide CASE Team is unaware of any acceptance issues specific to the power factor roadmap. The Statewide CASE Team will provide more detailed feedback on this topic in future submissions, at which time the potential scope and technological pathways associated with the roadmap and any future regulations will be more clear.
Federal Preemption or Other Regulatory or Legislative Considerations	The Statewide CASE Team continues to investigate the issue of federal pre-emption with regards to this measure. The Statewide CASE Team's current understanding is that the Energy Commission may investigate any scope of products under its power factor roadmap, as this course of action will not necessarily result in mandatory regulations.

2.1 Addressing Energy Commission Roadmap Guidance Questions

On August 22, 2017, the Energy Commission provided stakeholders with additional questions to be addressed for roadmap topics. Below, the Statewide CASE Team provides responses to several of the questions that relate directly to the power factor roadmap. In many cases, the requested information is already provided in subsequent sections of this document, as indicated in the responses. Responses include the original question numbers from the Energy Commission document.

Table 2: Responses to the Energy Commission's roadmap guidance questions

Energy Commission Question	Statewide CASE Team Response
1. Should power factor and low-power modes be treated together in the same roadmap or should two separate roadmaps be developed? Should the product clusters align if the roadmaps are separated? What are the advantages and disadvantages to your proposed approach?	As stated in the Statewide CASE Team's ITP response and in greater detail in Section 5.1 of this document, we encourage the Energy Commission to maintain flexibility when it comes to the scope and coupling of the low-power mode and power factor roadmaps, and to allow future analyses of technical feasibility and cost-effectiveness to drive these important decisions. Section 5.2 of this document discusses horizontal and vertical frameworks that could be applied to the power factor roadmap. The Statewide CASE Team is still in the process of researching and developing recommendations on such a framework. However, Section 5.5, discusses roadmap scenarios that could result depending on the findings of our research and other stakeholder input.
Questions 3 – 9 are only relevant to the low-power mode roadmap.	
11. What are the benefits of power factor correction and who receives those benefits?	Sections 4.2 and 4.3 of this document provide a summary of the types of benefits that would result from improvements to power factor. Both benefits (energy and non-energy) and beneficiaries (customer or the utility) are described. The Statewide CASE Team is still conducting research and analysis to quantify benefits (primarily energy and demand reductions) that would impact future economic analyses.
12. Are correcting both kinds of power factor, displacement and harmonic distortion, equally beneficial? To whom?	The Statewide CASE Team has not yet comprehensively quantified the power factor improvement opportunities associated with displacement and harmonic distortion. In Section 4 of this document, the Statewide CASE Team summarizes the benefits of power factor improvement, the beneficiaries (the customer versus the utility), and the technologies available to address both power factor types.
13. What research and development is needed to better quantify the benefits of power factor correction?	Section 5.5 provides recommendations on key research questions and activities for the roadmap process overall and, more specifically, quantifications of power factor benefits. Section 5.6 discusses contributions and research activities that the Statewide CASE Team will undertake to address this and other key roadmap questions.

3. Technical Rationale for Improving Power Factor

3.1 Root Causes of Low Power Factor

Power factor issues stem from 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 power factor*, loads draw current out of phase with the voltage supply, resulting in lower power factor. Inductive loads like electric motors and motorized appliances (without electronic speed controls) exhibit displacement power factor issues. Inductive load current lags the supply voltage, as shown in Figure 1 (this can be seen by the offset in the peaks of the waveforms). Electronic loads, which are mildly capacitive, lead the supply voltage somewhat.

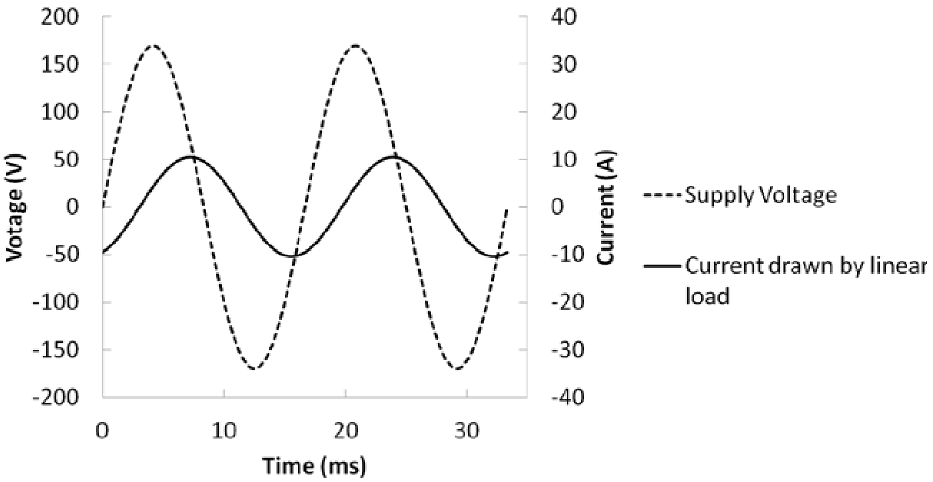

Figure 1: Linear load exhibiting displacement power factor

Source: CEC 2015.

In the case of *harmonic distortion*, loads draw current in a non-sinusoidal manner and cause harmonic currents in building wiring and the grid.[1] As with displacement issues, harmonic distortion results in lower power factor. 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 or segment the waveform in some fashion. An example current waveform for a non-linear load with harmonic distortion issues is shown in Figure 2.

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[1] Harmonics have frequencies higher than the fundamental frequency of 60 Hz, and are usually in multiples of 60 Hz.

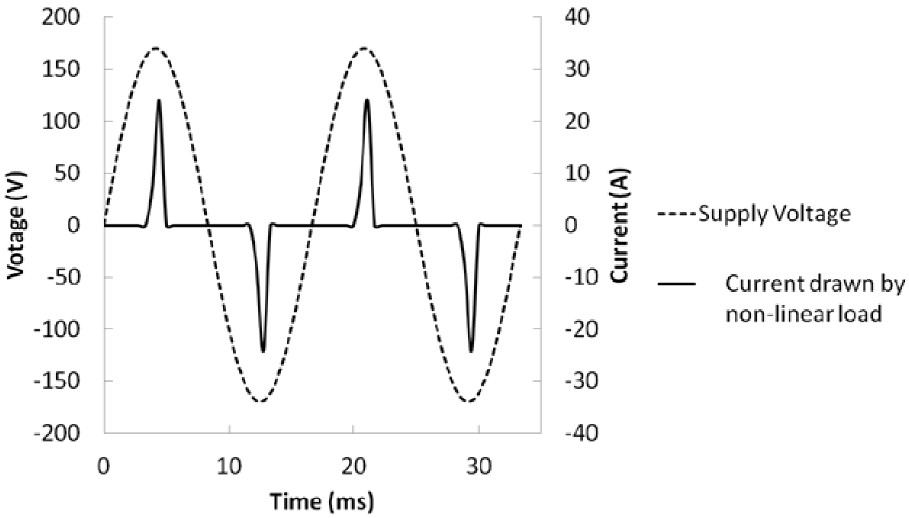

Figure 2: Non-linear load exhibiting harmonic distortion

Source: CEC 2015.

A product's true power factor is the ratio of its real power (*P*) in watts (W) to its apparent power (*VA*) in volt-amperes. True power factor is a function of both displacement and harmonic distortion effects, described by the following relationship:

$$\mathrm{PF} = \frac{P}{VA} = \frac{\mathrm{PF_{disp}}}{\sqrt{1+\mathrm{THD}_I^2}} \qquad \textbf{Eq. 1}$$

where *P* and *VA* are vectors, $\mathrm{PF_{disp}}$ 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; an increase in total harmonic distortion $(\mathrm{THD})_I$ also results in lower power factor. [2]

3.2 How Power Factor Impacts Building Energy Use

Devices with low power factor do not *directly* consume more power than other products. For example, consider two different televisions. Both televisions are metered as stand-alone end uses and draw 100 W, but one has a power factor of 0.5 and the other has a power factor of 0.95. The televisions will draw the same real power, but different amounts of apparent power and, therefore, current. At a system level in the home, the product with the lower power factor (drawing higher current) consumes more power due to increased power losses in the building wiring.

Each conductor, from the grid to the load, presents some electrical resistance and dissipates power according to the following relationship:

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[2] Total harmonic distortion (THD) is a key power quality metric related to power factor. It is the ratio (expressed as a percent) of the current drawn by a device at frequencies higher that the fundamental frequency to the current drawn at the fundamental frequency itself (in the case of the North American grid, 60 Hz). Lower THD values are desirable and indicate a more linear, less distorted load.

$$P_{\text{loss}} = I^2 R$$

Eq. 2

where P_{loss} is the power dissipated in the conductor, R is the electrical resistance of the conductor, and I is the root mean square (rms) load current (illustrated in Figure 3). Changes in load current are amplified due to the square relationship. For example, in the case of the hypothetical televisions, which are non-linear, distorted loads, increasing power factor from 0.5 to 0.95 will reduce load current from 1.7 amperes (amps) to 0.9 amps, which in turn would reduce losses in the building wiring by over 70 percent. For a 75 foot long, 15 amps residential branch circuit with 14 American wire gauge (AWG) conductors, this would result in 0.8 W power savings in the branch circuit.

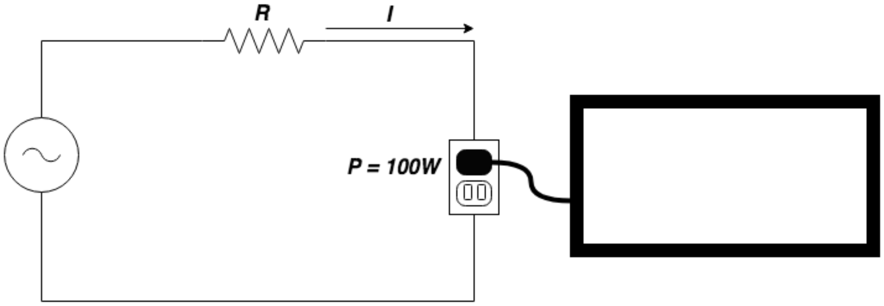

Figure 3: Schematic representing resistive losses in branch circuit for a television

Source: Statewide CASE Team

Energy savings benefits would extend beyond the customer meter as well. The additional current flow to the television with low power factor will cause additional losses beyond the customer's meter on the distribution grid. The customer does not pay for these grid losses directly. Rather, the losses represent part of the cost of providing power and must be recovered through electric rates. In this way, grid-side losses and costs associated with power factor are ultimately borne by the consumer.

3.3 Real-World Power Factor Interactions

In the above example, the power factor of a single load drives the losses throughout a whole branch circuit. In real-world settings, however, usually multiple loads exist on a branch circuit and will interact with each other. Each load will draw different magnitudes of current, exhibit differing degrees of displacement and distortion issues, and have its own duty cycle. The aggregate power factor and current draw on the circuit ultimately determines the magnitude of losses.

This aggregate effect is important; capacitive and inductive loads can work to balance each other's power factor impacts. Some stakeholders have suggested that correcting the power factor of electronic loads may unintentionally result in higher overall power factor at the system level by "unbalancing" inductive loads like motors. The degree to which capacitive loads balance inductive loads depends on several factors related to the loads themselves (e.g., the relative magnitude of load currents, their displacement and distortion), and how the loads are used (e.g., the loads that are present on a circuit and the coincidence of those loads).The Statewide CASE Team plans to investigate how these factors impact aggregate power factor.

4. Benefits, Data Sources, and Technological Availability

4.1 Summary

The Statewide CASE Team continues to develop a comprehensive assessment of the technically achievable potential for power factor-related energy savings across a wide range of products. Research to date has focused most heavily on electronic loads with harmonic distortion, but the Statewide CASE Team is expanding research into larger loads, including appliances, HVAC equipment, and lighting. The results of the Statewide CASE Team's current literature review include the following topics: energy and non-energy benefits, prior energy savings estimates, sources of power factor data on existing products, and available technology to mitigate power factor issues.

4.2 Energy Benefits

Power factor improvements can result in both energy and non-energy benefits on the customer and utility sides of the meter. By offloading unnecessary current from building wiring and the distribution grid, electrical losses can be reduced, leading to energy and utility bill savings (CEC 2006, 2015; Key 1996; Ghorbani 2015).

Several studies have examined and quantified the energy benefits of improved power factor, with a broad range of estimated savings. This range can be attributed to the diverse array of considerations when modeling the savings associated with this measure. Since benefits accrue at the system level (i.e., not directly at the load itself), system assumptions regarding conductor sizing, circuit topology, circuit length, and load coincidence play a role in estimating savings. These benefits can vary widely. In 2006, EPRI estimated that power factor correction in computer power supplies alone could save 2.8 percent of the total electricity consumed by commercial buildings in California, equivalent, at the time, to about 300 GWh per year at full stock turnover (CEC 2006). More recently, EPRI estimated that 240 GWh per year could be saved by requiring *all* residential and commercial loads that draw more than 50 W of power to achieve a power factor of 0.9. Field studies in Indian households have found that improving power factor could reduce annual electricity consumption by 1.8 to 3 kilowatt hours per household (Singh 2010). Scaling these results to California's approximately 10.8 million single-family housing units, this equates to 19 to 32 GWh in annual savings in the residential sector alone.

None of the aforementioned studies include energy benefits on the distribution grid, but existing literature notes the grid-side energy efficiency benefits of improved power factor (de la Rosa 2006; ABB 2007). One recent study (Lombard et al. 2016) analyzed the energy losses associated with harmonic distortion from residential and office loads based on data from South African low-voltage distribution networks (which include the distribution and switching substations on the grid side, down to the load on the customer side), and estimated losses at 0.1 to 0.5 percent of total power. A recent simulation study (Ghorbani 2015) of distribution feeder circuits estimated that harmonic distortion accounted for as much as 20 percent of the feeder's total distribution losses. This would also translate into fractions of a percent total losses; combined transmission and distribution losses average about 5 percent, and feeder circuits themselves account for a subset of these losses (EIA 2017).

The Statewide CASE Team continues to develop its own set of assumptions and model framework to evaluate technically achievable energy and demand savings potential.

4.3 Non-Energy Benefits

Improvements to power factor can provide a host of non-energy benefits. These may not be permissible in cost-effectiveness assessments, even when benefits can be monetized; these benefits, however, are included here for comprehensiveness.

Utility rates for some larger facilities include fees for kVA (apparent power) or power factor, in addition to demand or energy charges. These facilities may realize additional economic benefits by lowering average monthly power factor and kVA.

Reduced resistive losses also result in lower heat dissipation in conductive elements, which can extend the useful life of components like transformers (de la Rosa 2006). Finally, in the case of non-linear loads with harmonic distortion, eliminating harmonic currents at the source can mitigate a variety of power quality-related issues that can cause electrical equipment to malfunction, such as telecommunications interference (de la Rosa 2006). Table 3 summarizes power factor improvement benefits.

Table 3: 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	Broadly applicable: • Increased current-carrying capacity (ampacity) of existing electrical circuits and avoided unnecessary circuit breaker trips. • Reduction of kVA charges for large customers (if applicable). • Extended life of system components, such as breakers and stepdown transformer, by reduction in electrical currents and resulting heat generation. Harmonic distortion only: • Reduced harmonic currents on building's neutral wires, decreasing overheating risk, particularly in older facilities with traditionally sized neutral wires. • Avoided flicker in fluorescent lighting. • Reduced audible noise on telephone landlines.	Broadly applicable: • Extended life of system components, such as transformers, by reduction in electrical currents and resulting heat generation. Harmonic distortion only: • Reduced distorted supply voltages (a side-effect of severe harmonic distortion) and improved overall power quality.

4.4 Power Factor of Existing Products

A variety of studies on the energy efficiency of end-use equipment help provide a picture of prevailing power factor values in different equipment types. Table 4 summarizes approximate power factor ranges by equipment type, using sources identified by the Statewide CASE Team. This is not a definitive, representative sampling of equipment power factors, but rather a starting point for scoping analyses. The Statewide CASE Team will continue to develop a robust power factor dataset to inform future roadmap and policy discussions, and welcomes input from other stakeholders who may have additional, valuable information to contribute to existing datasets.

The power factor of existing products can vary dramatically and is especially small in low power modes in electronics, where values as low as 0.03 have been reported, as shown in Table 4. This suggests that there is ample opportunity for improvement across many product types. Determining existing products' power factor benchmarks with improved accuracy— in a way that authentically captures current market conditions—requires additional data collection.

Table 4: Power factor ranges for selected end-use equipment categories

Power Factor Issues Present	Product Category	Power Factor Low Power Modes	 Active Modes	Sources
Displacement and/or distortion	Laundry Equipment	TBD	0.1 - 1	1,3,4,7
	Refrigerators and Freezers	TBD	0.7 - 1	1,7
	Other Kitchen Appliances	TBD	0.8 - 1	1,3,4,5,7
	HVAC Equipment	N/A	0.5 - 1	2,4
	Other Large Motor Loads	N/A	0.6 - 0.9	6
Distortion only	Computers and Office Electronics	0.03 - 0.2	0.5 - 0.9	1,2,3,7
	Television and Home Entertainment	0.03 - 0.2	0.2 - 0.9	1,2,3,7
	Other Electronics	0.03 - 0.2	0.3 - 0.6	1,2,3,7
	Lighting (non-incandescent)	TBD	0.5 - 0.9	11

Sources:

1. CEC (2015).
2. Unpublished measurements by Xergy Consulting (2016).
3. NRDC (2017).
4. Pippatanasomporn et al. (2014).
5. Sweeney et al. (2014).
6. The Engineering Toolbox (2017).
7. Ghorbani and Mokhtari (2015).

4.5 Known Technological Pathways and Technology Availability

The technological solutions to address power factor issues vary depending on the underlying cause. Introducing reactive elements (like capacitors) to counteract the phase shift of inductive elements (like motors) can mitigate displacement issues. This approach, when applied to mitigate the impact of large inductive loads like large motor banks, places large capacitors between the AC source and the offending load (Figure 4). The Statewide CASE Team is still investigating the extent to which these techniques are already applied to large motor installations, as there may be a motor size threshold above which displacement power factor is already well mitigated (for example, in central HVAC plants in larger commercial facilities). In smaller motors, such as those used in appliances and smaller packaged HVAC systems, opportunities exist to mitigate displacement power factor by integrating capacitors directly with end-use equipment.

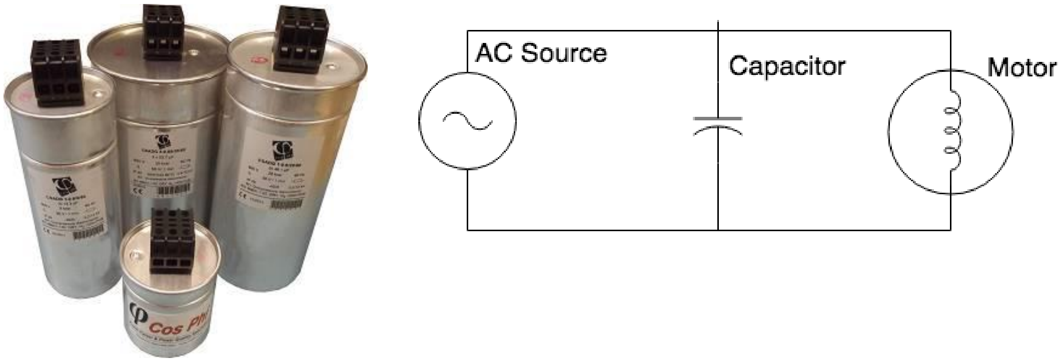

Figure 4: Capacitors for use in facility-scale power factor mitigation (left) and schematic of capacitor placement (right)

Source: (left photo) Cos Phi 2017; (right drawing) Statewide CASE Team

Distortion power factor must be addressed using electronic filters (usually integrated into the end product) to smooth the product's current waveform.[3] 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 end product.

Figure 5 shows example active PFC ICs. Some designs, like Power Integrations' HiperPFS, claim to be able to achieve good pass-through efficiency even while operating at load fractions as low as 20 percent,[4] suggesting the potential to address power factor concerns in certain low power modes.

Figure 5: Example PFC components designed for consumer electronics applications from Power Integrations (left) and Texas Instruments (right)

Source: (left photo) Power Integrations; (right photo) Texas Instruments

Larger distorted loads, such as large commercial variable-speed motor drives, may require stand-alone harmonic filters, which can mitigate the distortion of an entire motor bank. These units typically apply to equipment drawing tens of amps via three-phase power. Equipment already addressed by stand-alone

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[3] Active power factor correction designs use active circuitry to control the shape of the current waveform such that it matches the shape of the supply voltage.

[4] https://ac-dc.power.com/products/hiper-family/hiperpfs-4/.

harmonic filters may not be suitable for the scope of this roadmap. Future analyses should establish a threshold of equipment ratings above which product-level power factor correction would not be feasible or economical.

Figure 6: Stand-alone harmonic filter equipment for use in industrial and large commercial facilities with large distorted loads

Source: Eaton (2015)

As the Energy Commission evolves the scope for its power factor roadmap, careful consideration of the different technological pathways and associated costs appropriate to different loads is critical. Table 5 summarizes two general approaches available today to address power factor at the device level, depending on the type of power factor issue present (other solutions available at building- or grid-scale would not be appropriate to Title 20).

Table 5: 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.[5]
Passive Power Factor Correction	Harmonic Distortion	Passive electronic components (capacitors, diodes, inductors) filter some, but not all, harmonics.	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).
Active Power Factor Correction	Harmonic Distortion	Solid-state electronic component(s) integrated into a device's power supply that actively filters out harmonic currents.	

5. Roadmap Considerations

5.1 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. The key criteria specifically discussed during the presentation included cost-effectiveness, technical feasibility, and energy savings. 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, for some product types it may be advantageous to decouple the scopes of the power factor and low power modes roadmaps to maximize cost-effective, feasible savings for both efforts. For other product types, for example products that draw relatively little, cost-effectiveness may only be achieved if the power factor and low power mode roadmaps are coupled. 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 W in nameplate power rating), such as those addressed in certain industry standards (see Section 5.4.). Although power factor improvements may generate smaller savings through low-power loads like consumer electronics and office equipment, such devices represent significant aggregate loads in buildings—about 20 percent of residential electricity consumption according to the Energy Commission's research (CEC 2010). Thus, the power factor savings potential of these devices could be commensurately large.

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[5] The Statewide CASE Team generally considers small motor loads here, such as those in appliances and residential-scale HVAC. Large motor loads, such as those used in large commercial HVAC installations, are often corrected collectively with a bank of appropriately sized capacitors or harmonic filters. Such approaches fall beyond the scope of Title 20, although may be applicable to Title 24 codes.

5.2 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 mitigate 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. Further refinement of that target to 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) may be appropriate. Such an approach is most compatible with the parallel low power modes roadmap.

A 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 study estimated statewide energy savings for 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 Energy Commission used 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. Because low power modes, in addition to active power modes, are under consideration for power factor targets, the Statewide CASE Team recommends adding a low load measurement point that is representative of low power mode load conditions.

The Statewide 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 coverage scope.

5.3 Existing Test Methods

Power factor is a key physical property of any AC electrical load; it is simply the ratio of real power in W to apparent power in VA 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 Energy Commission's regulations for televisions that draw more than 100 W requires active mode power factor reporting during specific operational modes.

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 to 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— 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). The standard only applies to products drawing up to 16 amps per phase. A separate IEC standard, IEC 61000-3-12, addresses measurement of larger harmonic loads drawing current up to 75 amps per phase (IEC 2011).

The Statewide CASE Team is only aware of two test methods that provide general conditions 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.

5.4 Existing Mandatory Energy Regulations

The IEC 61000-3-2 and 61000-3-12 standards referenced above also establish limits for harmonic distortion for a variety of equipment. The European Commission's adoption of these standards has resulted in mandatory limits across the European Union. Such limits are not legally binding in the United States (U.S.); thus, power factor problems have not been comprehensively mitigated in end-use products and opportunities for improvement still exist. For example, desktop computer power supplies currently available in U.S. markets may or may not include power factor correction technology. Contrary to European norms, the inclusion of this feature in U.S. products is driven more by voluntary energy efficiency requirements, such as 80 PLUS or ENERGY STAR.

Although power factor requirements and reporting criteria do appear in various vertical product specifications[6] and some mandatory efficiency regulations,[7] the Statewide CASE Team is not aware of any energy efficiency standards that comprehensively or horizontally address the issue of power factor.

5.5 Roadmap Considerations and Scenarios

The Statewide CASE Team envisions power factor roadmap activities culminating in a milestone policy determination, followed by potential policy action, as depicted in Figure 7.

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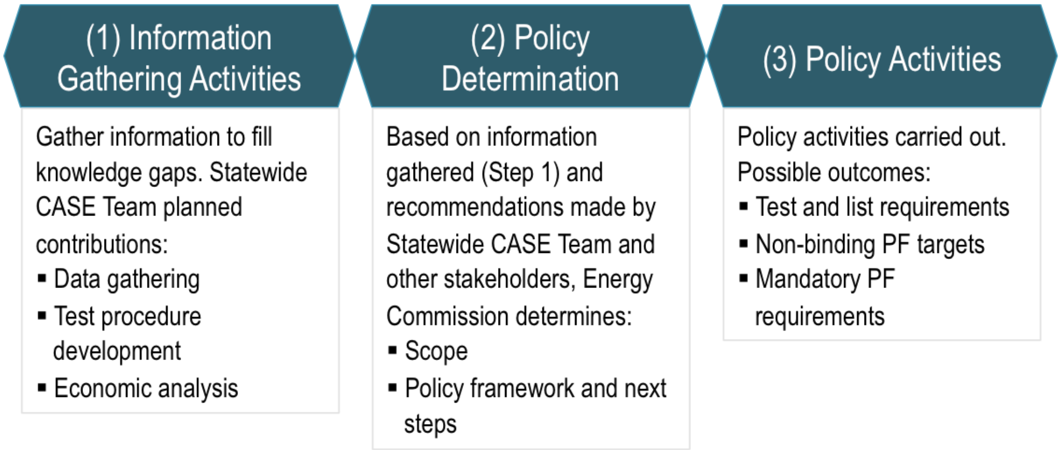
[6] Examples include ENERGY STAR specifications for computers, enterprise servers, and uninterruptible power supplies

[7] Such mandatory regulations include European Commission Ecodesign regulations for computers, and servers; Energy Commission regulations for computers, fluorescent lamp ballasts, televisions and signage displays



(1) Information Gathering Activities

Gather information to fill knowledge gaps. Statewide CASE Team planned contributions:
- Data gathering
- Test procedure development
- Economic analysis

(2) Policy Determination

Based on information gathered (Step 1) and recommendations made by Statewide CASE Team and other stakeholders, Energy Commission determines:
- Scope
- Policy framework and next steps

(3) Policy Activities

Policy activities carried out. Possible outcomes:
- Test and list requirements
- Non-binding PF targets
- Mandatory PF requirements

Figure 7: Proposed activity sequence for power factor roadmap and beyond

Source: Statewide CASE Team

The initial roadmap phase would span the Energy Commission's Phase 2 rulemaking. The roadmap phase should address, at a minimum, the following three fundamental questions:

1. Which scope of products presents the most cost-effective power factor savings opportunities?
2. Can power factor improvements be made cost-effectively in the absence of other energy-saving measures, or must they be bundled with other efficiency improvements to achieve cost effectiveness?
3. Power factor requirements have historically applied to on mode operation in higher power devices (e.g., greater than 75 W), but can requirements be cost-effectively extended to lower power applications as well?

The Statewide CASE Team recommends the following research activities during the roadmap phase to address these and other questions:

- **Background research**: continue to document the existing body of research on power factor improvement and energy savings potential from literature, gather third-party data sources, and estimate technically achievable energy savings potential.
- **Test method development**: document all applicable test procedures for individual end uses that can be used to capture power factor, and/or develop a generalized test method that can be used to capture power factor across a larger scope of products.
- **Data gathering**: conduct laboratory testing of end-use products using identified test method(s) to establish baseline and cost-effectively achievable power factor levels.
- **Savings validation**: conduct lab and/or field testing to validate energy savings benefits from a systems perspective.
- **Economic analysis**: identify technical pathways to address power factor in key end uses, develop cost assumptions, and model lifetime benefits (including grid- and customer-side energy and non-energy benefits that can be reasonably monetized).

The outcomes of these roadmap activities will dictate the recommended scope and framework of any policy action, which will in turn dictate the policy mechanisms suitable for capturing cost-effective savings opportunities. Four plausible but hypothetical scenarios that could result from roadmap research, depending largely on the answers to the key questions above, are outlined in **Table** 6. The Statewide CASE Team stresses that these scenarios are provided to help envision the potential directions that a power factor roadmap and resulting policy options could take. They should not be construed as conclusions or recommendations.

Table 6: Power factor roadmap scenarios

Scenario	Roadmap Outcome	Follow-on Policy Options
1. Harmonic loads	▪ Harmonic loads are identified as the largest cost-effective savings opportunity. ▪ Common technological pathways make it possible to demonstrate cost-effectiveness across a diverse range of products, from electronics to variable-speed-control motorized appliances.	The Energy Commission develops mandatory requirements for clusters of products with similar underlying power electronics components, addressing harmonic distortion in a horizontal manner.
2. Inductive loads	▪ Inductive loads like appliances and HVAC equipment present the best savings opportunity. ▪ Crosscutting technological pathways can be demonstrated, but can only be made cost-effective when combined with other energy efficiency improvements.	Due to the way motorized products are currently regulated,[8] the Energy Commission may be prevented from developing broad horizontal power factor requirements. Instead, vertical power factor requirements are established for select motorized equipment.
3. Low power modes in electronic products	▪ Power factor issues are unaddressed at low load fractions and present large savings potential. ▪ Technological and/or cost challenges prevent immediate feasible and cost-effective savings.	The Energy Commission develops horizontal power factor test and list requirements in conjunction with low power mode roadmap and establishes long-term voluntary targets, reserving the right to revisit mandatory requirements if milestones are not achieved.
4. Mix of large harmonic and inductive loads	▪ A combination of large loads, each with unique power factor causes and technological pathways, yields the greatest savings potential. ▪ The disparate nature of the products makes a cross-cutting, horizontal approach unattainable.	The Energy Commissions develops a plan to revisit vertical product standards as possible with power factor requirements.

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[8] Since motorized products are already governed by federal standards, the Energy Commission may be federally pre-empted from establishing separate power factor requirements for these products. The Statewide CASE Team is still investigating this matter.

5.6 Statewide CASE Team Contributions

The Statewide CASE Team believes that a product efficiency roadmap like power factor should be driven by data in a manner consistent with “traditional” Title 20 rulemakings, and is committed to providing robust research, data, and analysis to inform the power factor roadmap process.

Table 7 presents the Statewide CASE Team’s planned sequence of activities to support the power factor roadmap process. The Statewide CASE Team’s next planned research activity is a comprehensive analysis of power factor savings opportunities across a range of residential and commercial products. This activity is notably more complex than modeling conducted in other measures, because energy is saved in building electrical systems rather than in the end products themselves. This system interaction requires assumptions in addition to those commonly developed at the product level (for example, branch circuit lengths and wire gages). The purpose of the analysis will be to identify technically achievable and cost-effective statewide savings at an order-of-magnitude level, and to inform discussions around the appropriate product scope and framework for any future power factor requirements.

With a potentially tighter scope of products in mind, the Statewide CASE Team will further develop a test procedure or suite of test procedures suitable for measuring power factor in the most promising products. The Statewide CASE Team intends to conduct product testing and prototyping to establish: (1) more accurate assumptions on prevailing typical and best-in-class power factor in various products, and (2) detailed understanding of cost-effective power factor improvement pathways.

Roadmap activities would conclude after cost-effectiveness analysis and the development of a comprehensive CASE Report.

Table 7: Sequence of Statewide CASE Team proposed activities

Comprehensive analysis of power factor opportunities	🟦	🟦							
Test plan and test method development			🟦	🟦					
As-assembled testing					🟦				
Technical pathways & prototyping					🟦	🟦			
Cost effectiveness analysis							🟦		
CASE Report development								🟦	🟦

6. 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 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. Although low power modes and power factor have been presented alongside each other in the staff roadmap ITP, 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, for some product types it may be advantageous to decouple the scopes of the power factor and low power modes roadmaps to maximize cost-effective, feasible savings for both efforts. For other product types, for example products that draw relatively little, cost-effectiveness may only be achieved if the power factor and low power mode roadmaps are coupled. The Statewide CASE Team plans to conduct additional analysis to inform scope considerations

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 categories 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 Statewide 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 single 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.

Similarly, mandatory standards have been developed around the IEC 61000-3-2 standard, but these only apply in the European market for products with nameplate power ratings above 75 W. The Statewide CASE Team has not yet seen evidence to suggest that harmonic distortion has been fully mitigated for the same scope of products sold in the U.S. market. Furthermore, there may be opportunities for energy savings by addressing power factor in products that fall below this 75 W threshold. Again, we encourage the Energy Commission to allow the data on technical feasibility and cost-effectiveness drive decisions around any regulatory scope, and to consider a broader range of products than the European standards.

Finally, we have outlined several potential scenarios for the roadmap that may result depending on the outcomes of testing, technical feasibility analysis, and cost-effectiveness assessments. Each scenario may portend a different scope, framework, and mix of technological pathways. We have also provided a clear sequence of planned activities that the Statewide CASE Team plans to undertake during the roadmap, including test method development, technical and economic analysis, savings validations, and ultimate CASE report development.

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