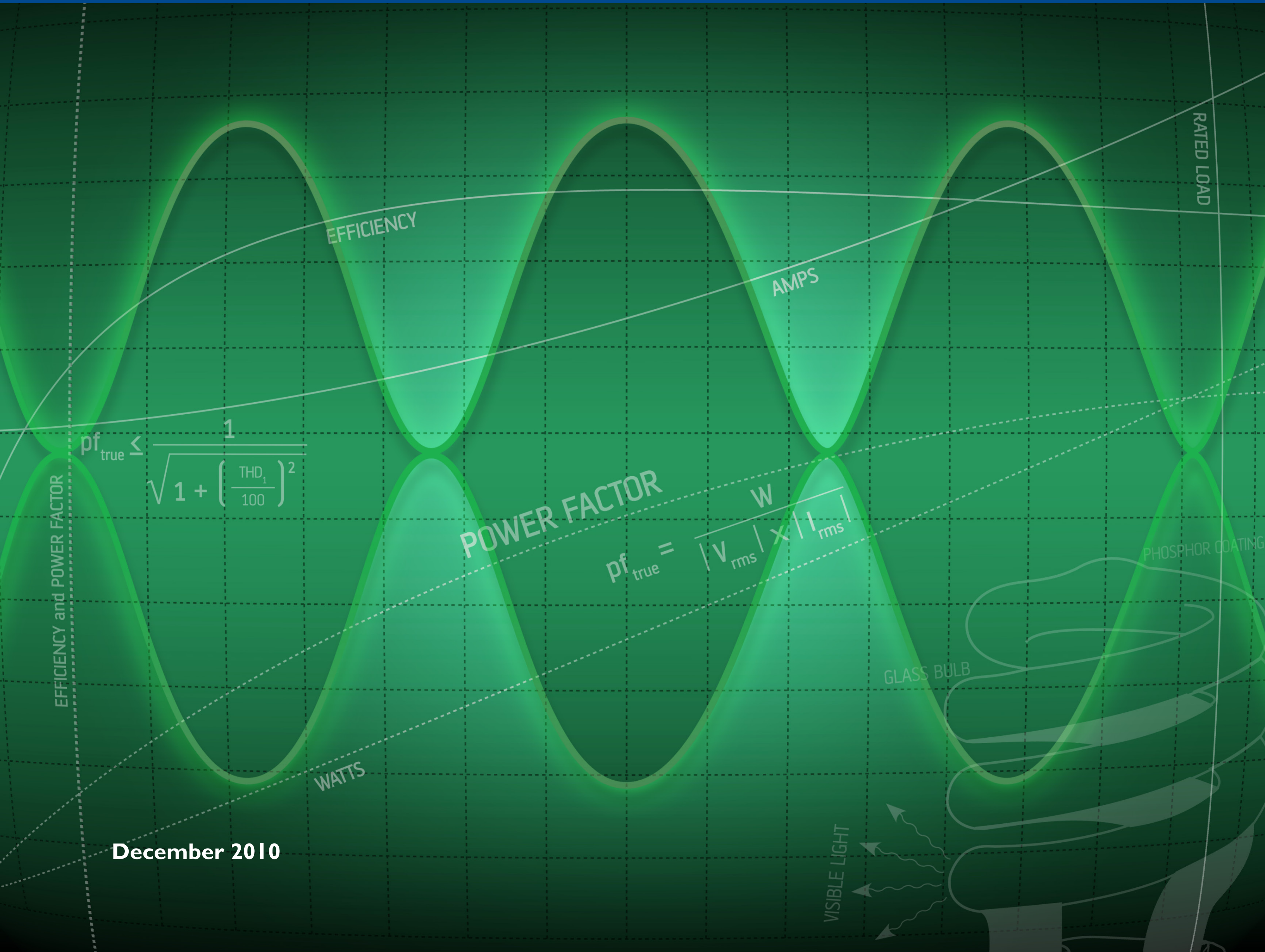
USAID | ASIA

FROM THE AMERICAN PEOPLE

POWER FACTOR:
POLICY IMPLICATIONS FOR THE SCALE-UP OF CFL PROGRAMS



December 2010

POWER FACTOR:
POLICY IMPLICATIONS FOR THE SCALE-UP OF CFL PROGRAMS

December 2010

This report is made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this report are the sole responsibility of the International Resources Group (IRG) and do not necessarily reflect the views of USAID or the United States Government. IRG prepared this report as part of its work under the ECO-Asia Clean Development and Climate Program. Contract No. EPP-1-100-03-00013-00: Task Order 9.

TABLE OF CONTENTS

LIST OF TABLES, FIGURES AND BOXES

ACRONYMS

AC	Alternating Current
ALC	Asia Lighting Compact
CFLs	Compact Fluorescent Lamps
DSM	Demand-Side Management
ECO-Asia CDCP	Environmental Cooperation-Asia Clean Development and Climate Program
ELC	European Lamp Companies Federation
FAQ	Frequently Asked Questions
GHG	Greenhouse Gas
HPF	High Power Factor
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronic Engineers
ICHQP	International Conference on Harmonics and Quality of Power
LEDs	Light Emitting Diodes
LPF	Low Power Factor (also known as NPF)
NEMA	(US) National Electrical Manufacturers Association
NPF	Normal Power Factor (also known as LPF)
NUTEK	Swedish National Board for Industrial and Technical Development
PELP	Poland Efficient Lighting Project
PF	Power Factor (or pf)
RERED	Renewable Energy for Rural Economic Development
THD	Total Harmonic Distortion
VA	Volts Amps (a measure of electric power)
VAR	Volt-Ampere Reactive
W	Watts

ACKNOWLEDGMENTS

This report was funded by the United States Agency for International Development's Regional Development Mission for Asia (USAID/RDMA) through its Environmental Cooperation-Asia Clean Development and Climate Program (ECO-Asia CDCP).

The principal authors of the report were Erik Page of Erik Page & Associates, and My Ton, Team Leader, Energy Efficient Lighting, ECO-Asia CDCP. The report was reviewed by Khan Ram-Indra, Program Development Specialist, USAID/RDMA and Dr. Peter du Pont, Chief of Party, ECO-Asia CDCP.

The authors would like to thank the following experts for providing valuable information, comments, and feedback on the draft report: Professor Math Bollen (Sweden), Stewart Craine (Asia & Pacific), Ian Connor (UK), Kathryn Conway (USA), Kevin Gauna (USA), Stuart Jeffcott (China), Edmundo Klophaus (Hong Kong, China), Casper Kofod (Denmark), Dilip Limaye (USA and India), Professor Martin Lundmark (Sweden), Johan Wijntjens (Netherlands), Marten Willemsen (China), and Ed Yandek (USA).

EXECUTIVE SUMMARY

INTRODUCTION

The question of whether utilities and policymakers should be concerned about the power factor (PF) of compact fluorescent lamps (CFLs) has been discussed ever since the lamps were first introduced to the market as replacement for incandescent lamps.[1] Thirty years later, the same questions remain. The basic argument has been whether or not the potential benefits to the electric grid of requiring high power factor (HPF) CFLs outweigh the potential costs and risks that such requirements would produce.

Ultimately, the choice to require HPF CFLs or LPF (low power factor, also known as normal power factor – NPF) is left to policymakers. However, the information currently available to policymakers regarding this issue tends to take the form of complex technical papers, and by their nature, these papers do not address all of the relevant policy considerations, leaving policymakers ill-equipped with a clear basis on which to make policy decisions. This can result in policy implementation that may be unnecessarily cautious, expensive, and may not maximize the potential benefits that may accrue from the expansion of CFL usage in Asia and elsewhere.

This report reviews and summarizes the current findings regarding the topic of CFL power factor; and explores and identifies related policy considerations, in order to allow policymakers to make well-informed decisions that address their specific policy goals. The report does not take sides, but rather explores the arguments above and to present science and economic-based recommendations based on the best currently available information.

METHODOLOGIES AND COVERAGE

In order to identify the relevant policy considerations, the ECO-Asia CDCP research team conducted a literature survey to identify and review papers, articles and other material regarding CFLs PF from both technical perspectives and economic perspectives. The team collected and reviewed policy positions, discussions of power factor impacts on transmission grid power quality and capacity, technical trade-off, assessment of local conditions, and programmatic as well as economic issues.

The literature review covered available documented research results from the last 15 years, from both laboratory research, experimentation, and simulation, as well as from actual field installation and measurements. In addition, the research team conducted interviews with researchers and policy experts.[2] **Section 2** of this paper contains summaries of all these research results, while **Section 3** reviews and analyzes the policy positions of stakeholders. For policymakers wishing to have a more in-depth understanding of power factor issues, a technical glossary is included, as well as a number of "frequently asked questions" and answers. **Section 4** identifies and discusses policy considerations.

---

[1] CFLs require electronic circuits, or "ballasts," to properly and efficiently operate the lamps. The electronics in a CFL's ballast interact with the grid differently than an incandescent lamp, which does not require any additional circuitry and exhibits different electrical characteristics to the grid. How each electrical and/or electronic device interacts with the grid is an interplay of their electrical characteristics and power consumption.

[2] This paper is primarily focused on large-scale installation of CFLs.

CONSIDERATIONS FOR POLICYMAKERS

The move to more efficient lighting technologies in general – and the move from incandescent lamps to CFLs in particular – remains one of the most impactful and cost-effective energy savings and carbon mitigation strategies available. This move to more efficient technologies also carries the promise of reducing the strain on many over-burdened grids by reducing peak-load demands.

The key barriers to CFLs achieving their savings potential are widely documented, and include higher initial purchase price (compared to incandescent lamps), fit (size), and reliability. The choice on whether or not to require HPF CFLs has the potential to affect all of these barriers.

The choice on CFL power factor should be an informed one, based on the specific policy goals, and a thorough understanding of all of the issues involved. In addition to potential impacts on the power quality of the electric grid, there are a number of other issues that policymakers may wish to take into account regarding power factor choice: the (beneficial) effect of CFLs on the grid capacity, the specific grid conditions where the CFLs will be introduced, the technical (and economic) trade-offs regarding CFL power factor correction, and the related economic considerations with regard to price elasticity of HPF CFLs. These are briefly summarized below:

- **Grid Capacity:** Increasing the market penetration of CFLs, regardless of power factor level, to replace incandescent lamps will result an increase in the available capacity of the utility (and of the transmission and distribution grid). In general, a CFL can reduce the current that the utility previously has to deliver to a socket to maintain the same light output by at least one half.
- **Technical trade-offs:** The addition of a power-conditioning circuit to bring the PF from 0.5 (normal PF) to 0.9 (high PF) for CFLs consumes a small amount of additional power and generates a small amount of heat. Both of these have the potential to adversely affect long-term CFL performance. Lamp reliability can also be affected as a new potential ballast failure point is introduced.[3] The addition of power conditioning circuitry can also lead to increases in lamp size from the added electronics, and typically adds an estimated 15-25% to the cost of the CFL.[4]
- **Suitability for local conditions:** The dynamics and capacities of electrical grids vary greatly from region to region. Because of this, it is difficult to make sweeping statements about how LPF devices can be expected to affect electrical grids.[5] A technical review of the expected effect on the local grid should be considered before making decisions that relate to power factor requirements. This type of evaluation can help inform policymakers about expected risks and benefits of their policy decisions. This review is particularly important where the grid infrastructure is operating near or at capacity, and can be useful in determining if it would be more cost-effective to address the power quality issue at the source with HPF CFLs or on the distribution network with power conditioning equipment, which can address the issue of power quality of all devices.
- **CFL price elasticity:** Policymakers may want to consider how to address the expected additional cost for HPF CFLs. Studies have indicated that consumer demand for CFLs is very closely tied to initial cost and that this relationship is highly elastic. Identifying the incremental costs of high-PF CFLs can help to determine if additional funds are best spent on the HPF requirement, on power-conditioning equipment for the electrical network, or on moving forward with a larger number of less costly LPF CFLs.

---

[3] A failure of the CFL's power conditioning circuit does not result in the CFL reverting to a LPF condition; rather, it leads to a complete lamp failure.

[4] Note: 15-25% is the typical range that has been provided to ECO-Asia CDCP by industry experts.

[5] For example, in the case of "mini" or "micro grids" – an isolated electric distribution network set up to deliver electricity to households in a village, where lighting makes up a large portion of the evening load, there can be HPF benefits.

SUMMARY AND RECOMMENDATIONS

With regard to impacts of LPF CFLs, the following points can be made based on the data that have been reviewed:

- **Research results to date do not support the need for HPF CFLs:** It can be concluded with relative certainty that the totality of the research to date, and especially field research, has not proved that HPF CFLs are needed or even beneficial.
- **HPF CFL decision is not clear-cut:** The decision whether or not to require HPF CFLs is much more nuanced. It should involve considerations of policy, technical, market and economic factors.
- **A policy goal should be central to any power factor decisions:** Of all of the policy considerations identified, the policy element should be central, since it is this element that defines what the program or nation is attempting to accomplish. With clear policy goals, the technical, market and economic analyses can help define the most appropriate policy and regulatory pathways for power factor correction.

In summary, current data indicate that a high power factor CFL does not deliver any additional value to either the grid-operator or the end-user under most conditions, other than in cases of isolated, micro, or mini grids with high peak lighting loads. Utility managers and regulators should not simply specify HPF CFLs under the assumption that HPF CFLs are "better" than LPF CFLs. There are trade-offs in choosing HPF or LPF, and these should be made based on a realistic evaluation.

Therefore, when making regulatory or procurement decisions relating to CFL power factor, it is necessary to clarify and prioritize policy goals, evaluate local electrical infrastructure conditions, and local market conditions. By following these recommended steps, the positive and negative impacts of the policy or program impacts can be fully evaluated and used to maximize policy or program benefits while minimizing program drawbacks both on the grid and in the market.

SECTION I

INTRODUCTION

The question of whether utilities and policymakers should be concerned about the power factor of compact fluorescent lamps (CFLs) has been discussed ever since the lamps were first introduced to the market as replacement for incandescent lamps.[6] Thirty years later, the same questions remain. The basic argument has been whether or not the potential benefits to the electrical grid of requiring high power factor CFLs outweigh the potential costs and risks that such requirements would produce.[7]

These questions are now more timely than ever, as some of the concerns that have been voiced are no longer confined to the impact of a few hundred CFLs, but rather to large-scale procurement and deployment in the scale of millions – the types of bulk procurement programs are currently being carried out in many parts of the world.[8] CFLs have only recently reached the sharp upward slope of their market growth curve, and this growth is likely to continue as numerous programs to phase out incandescent lamps are implemented world-wide.[9]

This report explores both the scientific and economic issues relating to the power factor of CFLs, and utilizes currently available information to help inform decision-making related to large-scale deployments of CFLs. The ECO-Asia CDCP team examined documented results from both laboratory and "real-life" or field installation of CFLs to assess the potential impacts of substituting CFLs for incandescent lamps.

Generally speaking, the electric grid operates most efficiently when the collective load – that is, all of the connected and operating devices such as lamps, appliances, motors, etc. – on the grid has a power factor of 1.0 and does not vary with time. When the PF of the grid is lowered, utilities must add equipment to the grid (in the form of additional generating capacity or compensating devices) to compensate for the lower PF of the connected load, thus raising the grid's overall PF and/or allowing the grid to operate at less than unity levels. The argument for high PF (HPF) CFLs from this perspective is that they would alleviate the costs incurred by additional grid-connected PF compensation equipment and/or lowered grid efficiencies.

The counter-argument to HPF CFLs is that operationally there is a much more complex set of interactions of various connected loads on the system grid, and low power factor (LPF) CFLs, which are also sometimes referred to as "normal power factor" (NPF) CFLs, do not have a noticeable negative effect on the grid. While it is technically possible to raise the PF of CFLs from approximately 0.5-0.6 (the current level of most CFLs) to 0.9 or above (considered "high") with the addition of power conditioning components, lighting manufacturers estimate that these

---

[6] CFLs require electronic circuits, or "ballasts," to operate. The electronics in a CFL's ballast interact with the grid differently than an incandescent lamp, which does not require any additional circuitry and exhibits different electrical characteristics to the grid. How each electrical and/or electronic device interacts with the grid is an interplay of their electrical characteristics and power consumption.

[7] Please refer to the report glossary and FAQ sections for additional discussions on power factor.

[8] For example: "Bangladesh Sets a World Record: 5 Million Compact Fluorescent Lamps (CFLs) in One Day!: Lessons Learned from the first round of the EE Lighting Program & Carbon Finance Operation under Bangladesh RERED project." Presentation by Ashok Sarkar and Zubair Sadeque of the World Bank, 8 July 2010.

[9] This discussion is limited to applications of CFLs, however, the arguments can also be extended to the use of low-power (<25W) LED-based lighting devices.

changes add 15-25% to the cost of the CFL.[10] In addition to the higher costs associated with HPF CFLs, there can be other negative consequences. Adding components to CFL ballasts to improve PF have the following potential drawbacks:

- Shortened lamp life due to potential failures of the added components
- Failures of other lamp components due in part to heat generated by the added power conditioning components
- Increased ballast size to accommodate additional components

Higher costs, decreased reliability, and increased lamp size are all factors that can contribute to slower consumer adoption of CFLs as incandescent replacements.[11] Proponents of LPF CFLs have argued that requirements for HPF CFLs can slow growth in CFL markets, and may not only lead to missed opportunities for energy and carbon savings, but could ultimately be detrimental to electric grids that are short on capacity because of the increased presence and power demands from power-hungry incandescent lamps (which have a PF of 1).

Thus, one of the reasons that the power factor of CFLs remains a contentious issue is that it is neither purely a technical question nor a policy question – rather, it is a policy question that requires a strong understanding of technical issues. For example, the appropriate action on if and how to regulate CFL PF may be quite different depending on how the policymakers prioritize such policy goals as:

- Reducing greenhouse gas (GHG) emissions
- Increasing energy savings/adoption of energy efficient lamps
- Building a market for CFLs and other energy efficient products
- Increasing the capacity and/or efficiency of the electric grid
- Increasing the reliability of the electric grid.

Ultimately, the choice to require HPF CFLs is left to policymakers, as the appropriate actions that should be taken are dependent on the specific policy goals rather than simply universally valid engineering, economic, or scientific facts. However, the information currently available to policymakers regarding this issue tends to take the form of complex technical papers, leaving them ill-equipped with clear basis on which to make policy decisions. This can result in policy implementation that may be unnecessarily cautious, expensive, and may not maximize the potential benefits that may accrue from the expansion of CFL usage in Asia and elsewhere.

This paper aims to review and summarize the current findings regarding the topic of CFL power factor, explore and identify the related policy considerations, in order to allow policymakers to make the most informed decisions that address their specific policy goals. The objective of this paper is not to take sides, but to explore the arguments above and to present science and economic-based recommendations based on the best currently available information.

The literature review covered available documented research results from the last 15 years, from both laboratory research, experimentation, and simulation, to actual field installation and measurements. In addition, the policy positions/opinions of various stakeholders were also reviewed, as well as interviews conducted with researchers and policy experts. **Section 2** of this paper contains summaries of all these research results, while **Section 3** contains the policy positions of stakeholders. For policymakers wishing to have a more in-depth understanding of power factor issues, a technical glossary is included, as well as a number of "frequently asked questions" and answers. A discussion of the identified policy considerations is included in **Section 4**.

---

[10] It is assumed that this is at retail. 15-25% is the typical range that has been provided to ECO-Asia CDCP by industry experts.

[11] It should be noted that high cost, low reliability, and larger-than-incandescent sizing have all been identified in many markets as significant market barriers to the wide-spread adoption of CFLs.

Box 1. Background on Power Factor

Note: This section is offered for policymakers who wish to have more nuanced understanding of the technical issues involved. It is intended to provide a fundamental technical background on power factor and informs policymakers on the issues related to the LPF vs. HPF debate. The policy decisions are discussed in section 5 of this paper, and can be reviewed without delving deeply into the technical issues covered herein.

- Power Factor (pf) – the ratio of the real power of a load to the apparent power; a measure of the degree to which the voltage waveform and the current waveform are in phase with one another in an electrical circuit. The true power factor (pf_{true}) can also be expressed as:

$$pf_{true} = \frac{W}{|V_{rms}| \times |I_{rms}|}$$

W = *Power*

V_{rms} = *Root mean squared Voltage*

I_{rms} = *Root mean squared Current*

- Leading Power Factor – A circuit in which the current waveform precedes ("leads") the voltage waveform. CFLs can produce circuits with leading power factors.
- Lagging Power Factor – A circuit in which the current waveform follows ("lags") the voltage waveform. Motors or transformers can produce circuits with lagging power factors.
- Harmonics – electric voltages or currents that appear on the electric grid as a result of circuit loads. These voltages and currents are generally considered undesirable because they alter (or "distort") the current and/or voltage waveforms that are provided by the electric utility.
- Total Harmonic Distortion (THD) – the ratio of the sum of all the harmonics of a system to that of the fundamental frequency (a sine wave on standard AC electrical grid). The relationship between current THD and Power Factor (pf_{true}) is given by the following equation:

$$pf_{true} \leq \frac{1}{\sqrt{1 + \left(\frac{THD_I}{100}\right)^2}}$$

This means that if a CFL has a THD below 35%, it's true power fact cannot be lower than 0.95.

- Power Quality – a term used to describe both the reliability of the electrical system (number and duration of outages) and the quality of the voltage supply (voltage fluctuations, harmonics, etc).
- Load – a device that is connected to the output of an electrical circuit.
- Linear Loads - loads that do not change the shape of the current waveform from its original sine wave shape.

The current waveform can be shifted to lead (i.e. magnetic fluorescent ballasts) or lag (i.e. motors) the voltage waveform, but the sine wave shape is maintained.

- Non-Linear Loads – loads that change the shape of the current waveform from its original sine wave shape. This typically occurs because the load utilizes a switching action during its normal operation. Electric ballast and switch-mode power supplies (efficient power supplies used to power most modern electronic equipment) are non-linear loads.
- Real (or Active) Power – the energy that is transmitted to a load to do work, expressed in Watts.
- Reactive (or Non-Active) Power – the energy that is transmitted to a load but rather than doing work, it is stored in the load in an electrical or magnetic field. Reactive power is expressed in Vars.
- Apparent Power – the vector sum of real and reactive power. Apparent power is expressed in VA and is relevant to utilities because they must deliver both real and reactive power (i.e. apparent power) to the loads that are on the distribution network.
- Mixed Loads – An electrical circuit that has loads with a variety of load shapes (i.e. a "mix" of linear and/or non-linear loads of a variety of shapes). Most real-world electrical distribution systems consist of mixed load applications. Mixed loads tend to counteract some of the harmonics that would otherwise be present if the loads on the circuit were all of one type of load shape.

Box 2. FAQs regarding PF

Does low power factor mean higher energy usage?

One common misunderstanding that clouds the power factor debate involves the relationship between power factor and energy use. Some erroneously believe that a drop in PF leads to a proportional increase in energy use. For example, the assumption that a 25W CFL with a PF = 0.5 really uses twice as much power to operate as a 25W CFL with a PF = 1.0. This is not true: both CFLs use the same amount of power at the device, namely 25W.

This misunderstanding is likely based on the fact that current does increase proportionally with drops in PF. This does have real impacts on a utility's capacity, though, as they must meet the current demands of the grid's connected load. And the PF 0.5 CFL in our example will require twice the current delivered as the PF 1.0 CFL. But this additional current is not used in the device – it is stored in the device as an electric or magnetic field and then returned to the grid for use by other loads. Thus, for any given wattage, the HPF and LPF devices should theoretically use the same amount of energy and have the same greenhouse gas impacts.

What is the relationship between the power factor of a device and the power factor of the grid?

Ultimately, it is the power factor of the grid and its branch circuits, not those of the individual devices connected to the grid, which are of concern to the utilities. Utilities can increase the power factor of the grid by either installing power factor correction devices (at grid substations or at user sites) or by limiting the connected load of low power factor devices (i.e., HPF requirements for CFLs). It should be noted, though, that because of phase angle differences in the loads on the grid, and the issues of cancellation of leading PF and lagging PF previously discussed, grid or circuit power factor cannot be easily estimated by "adding up" the PF from the devices connected to the grid. This difficulty in knowing which loads will be used together and how these mixed loads will add up is a key element underlying the LPF vs. HPF debate. There are an infinite number of possible mixed load combinations, making it difficult to model the "true" effect of LPF CFLs on the grid.

How do CFL power factor regulations vary worldwide?

Currently, India is the only country that requires HPF for CFLs.[12] The world's largest CFL markets (including North America, Europe and China) not only allow LPF in their mandatory (i.e., minimum qualification) standards, but also LPF CFL in their CFL subsidy programs. Australia and China both had required HPF but ultimately eliminated these requirements, based on the international experience. More recently, several countries that have conducted CFL programs with the support of the World Bank and/or the Asian Development Bank have required HPF in their CFL specifications for these tenders.

Is there a correlation between HPF CFLs and product quality?

The presence or absence of power factor correction circuitry itself is not a good indicator of overall CFL quality. Because HPF CFLs can be better for "power quality" than LPF CFLs, some may take this to mean they are inherently a higher quality product and thus will have longer lives and/or better lighting service. This is not necessarily true. In fact, the presence of the power conditioning circuit introduces additional circuitry to the CFL ballast, which could either become a failure point itself or speed the failure of other components in the ballast by introducing additional heat into the ballast compartment. But ultimately, the *power quality* of a CFL is a poor proxy for the product quality of the CFL. CFL *product quality* is best assessed by reviewing established testing and verification mechanisms, such as those established by the Asia Lighting Compact (ALC).

---

[12] A formal policy paper regarding India's position on PF is not available.

SECTION 2

WORLD-WIDE RESEARCH ON CFL POWER FACTOR EFFECTS TO DATE

The issue of power factor impacts on the electrical grid has been studied by many parties in the past, and have been used to inform the discussions of whether there are benefits to justify the added costs associated with adding power factor correction circuitry to CFLs. This section summarizes results from available laboratory research on CFL power factor, as well as field studies the effect of LPF CFLs on the grid.

2.1 RESULTS FROM LABORATORY RESEARCH

A number of studies have investigated the effect that LPF CFLs have on the supply power in controlled laboratory settings and/or through computer simulations. Generally speaking, these studies have looked in detail at the waveform and harmonic characteristics of LPF CFLs in order to project how these devices might affect the grid if they were to be distributed in large quantities. The following are summaries of several of these studies.

- **Egypt, 2004 [1]**. In 2004, the Institute of Electrical and Electronics Engineers (IEEE) published a simulation study comparing incandescent to CFL loads. This study did not consider potential mixed load cancellation effects but simply looked at the combined effect of incandescent loads compared to those of CFL loads on the utility infrastructure. This study estimated that system losses are increased by 29% by the use of CFLs due to the increase in system harmonics, which counteracts some of the savings that the CFLs offer.

  The authors suggest that in order to limit harmonics from CFLs, the power of CFLs on the grid should be limited to that of the incandescent loads which they are replacing – which should not present a major practical issue given that CFLs are generally ¼ the power of their incandescent equivalent.

- **New Zealand, 2006 [2]**. One of the most widely referenced studies used to support the case for HPF CFLs is a 2006 study by Parsons Brinckerhoff Associates conducted for the New Zealand Electricity Commission. The study considered two theoretical cases: one in which 5 LPF CFLs were installed per household in 400,000 homes in the Auckland area and another case in which HPF CFLs were installed instead. A cost-benefit analysis was conducted to evaluate "the incremental cost of upgrading from LPF CFLs to [HPF] CFLs versus the cost of capacitive compensation and harmonic filtering equipment." The study authors estimated that:

  "The initial incremental cost of installing HPF-CFLs instead of LPF-CFLs is approximately 10 times less than the cost of capacitive compensation equipment which might become necessary to counteract the degradation in power factor caused by using LPF-CFLs."

  Based largely on this estimate, the authors offered a number of recommendations towards encouraging or requiring that CFLs are HPF. Following this study's release, New Zealand did consider requiring HPF for all CFLs but ultimately decided against this requirement.

- **Slovenia, 2008 [3]**. Another study was recently published by IEEE describing a simulation model developed specifically to evaluate the effect of widespread replacement of incandescent lighting with LPF CFLs. This study evaluated the waveforms of several commercially available CFLs, developed a computer model that simulated these waveforms, and developed several simulated scenarios in which the CFLs replaced incandescent lamps. While the scenarios presented in this paper were rather limited, the authors did note both positive and negative expected results from the conversion. The authors concluded that:

  "The pro of using the CFLs are reduced network active power losses and the con is the increased number of issues regarding harmonic currents which can be effectively compensated only by using active compensators."

  While the models showed that the mixed load condition in which the CFLs operated acted to mitigate the harmonics from the CFLs, harmonics were still present at levels that would require active compensation.

- **Switzerland, 2009 [4]**. A 2009 study was commissioned by the Swiss government to investigate whether "widespread replacement of incandescent lamps by [CFLs] can reduce the voltage quality of the mains supply and lead to an increased load on the lines." The study's main findings were that risks to the Swiss electrical system were minimal and the authors recommended against imposing any new regulations on CFLs – including specifically recommending against power factor correction. The authors also noted that the "lower energy requirements [CFLs] create lower supply losses than comparable incandescent lamps."

- **Australia, 2010 [5]**. Another laboratory study looking the harmonic characteristics of a cross-section of modern CFLs was conducted in 2010 by research from the University of Wollongong in Australia. Like many previous studies, this study pointed out that the electric utility can expect to see capacity demand reductions from the replacement of incandescent lamps with CFLs, but demand reductions will be less than the 75% savings on active power the CFL offers because of the CFLs' lower power factor. The study also noted that the proportion of residential harmonic load attributable to CFLs was significant given the combining factors of increased CFL penetration and improving harmonic characteristics of other residential devices. The study authors concluded the following:

  "Analysis of the performance of a range of other domestic electronic loads has shown that the current harmonic performance of some equipment has improved on first generation models. This means that the CFL with its highly distorted current waveform cannot be ignored as a significant harmonic load in spite of its low power rating. Analysis has shown that 10 CFLs operating simultaneously have the potential to be the single largest residential harmonic load."

- **Sweden, 2010 [6]**. This paper presents an investigation of the impact on a number of power-quality parameters due to the change from incandescent lamps to energy saving lamps like CFL and LED. The measurements were conducted in a full-scale laboratory model with ordinary household equipment connected, thus simulating an ordinary domestic customer. Measurements by the researchers showed that the replacement of incandescent lamps by LED and CFL resulted in a reduction in active power consumption, a reduction in peak current, and a reduction in distribution-system losses – all positive impacts on energy consumption and on the power-system. The measurements also showed that the replacements by CFLs and LEDs resulted in an increase of the amount of reactive power produced by the load. This increase has an overall impact on the grid, but this impact is too small for it to be any real value.

- **Sweden, 2010 [7]**. This paper presented measurements performed in the laboratories with an experimental setup of 48 fluorescent lamps powered by high-frequency ballasts. In this research, the authors investigated the impact of distortion in the frequency range between 2 and 150 kHz is on end-user equipment and on equipment in the grid. This research was initiated in response to indications of rising disturbance levels and anecdotal but consistent information on equipment damage. The authors found that there are two identified types of signals generated by this type of lighting loads: recurrent oscillations and high frequency components. It concluded that the high frequency components do not seem to add in the same way as the recurrent oscillation, indicating that this part of the disturbance to the grid is going between the lamps rather than upstream as in the case with the recurrent oscillation.

- **Columbia, 2010 [8]**. This paper was presented at the 2010 International Conference on Harmonics and Quality of Power (ICHQP) in Bergamo, Italy, September 2010. It shows the results of a computer simulation of two distribution feeders that supplies energy to customers who use CFLs and High-Power Light Emitting Diodes. An IEEE 13 node test feeder and a real distribution circuit were used for the simulations, with the resulting voltage and current distortion analyzed. This paper concluded that:

  According to the simulations, in a balance distribution circuit the substitution will not cause serious changes in voltage signals. Since most of the real distribution networks are balanced, it is expected that the mass replacement from incandescent bulbs to LEDs and CFLs will not affect seriously the voltage distortion indices.

- **Iran, 2010 [9]**. This paper, presented at the same conference in 2010, studied the effects of using CFLs on the power distribution system elements on both the generation and the consumption sides. It studied the technical and practical issues of mass utilization of CFLs in power systems, with a focus on different devices that are installed, and how the CFL harmonics affect the equipment on both feeding and consuming sides. Although there are some research works that study this effect on individual system elements, such studies have not integrated the analysis of different devices. Different classes of equipments are introduced and analyzed using their mathematical model in this research.

  The authors concluded that mass usage of CFLs in different power systems must be planned carefully in order to avoid any unexpected negative effects on the other equipments in the system. The paper identified the most vulnerable equipments of the power system to overall system fluctuations are the ones which contain solenoids, such as transformers and measurement equipments, especially on the feeding side. It recommended that extra care and calculations are required in different power systems for a safe use of CFLs. It noted that some electronic devices can be more affected by harmonic distortion in general, and may need to be either equipped with protective filters or be replaced by more advanced ones.

2.2 RESULTS FROM FIELD STUDIES

In addition to the laboratory and simulation studies discussed above, a number of field studies of LPF CFLs have also been conducted. These field studies provide added insights into the issue by observing how the grid actually is affected by the addition of LPF CFLs, rather than projecting how the grid might be affected, as the laboratory studies and simulations do.

It is important to note that the field studies do have certain limitations – chief among them being that they only show how the specific electrical system monitored reacted to the presence of the LPF CFLs during the period of testing. Thus there are limitations in using results from a field test in one location to speculate about system performance in locations with very different electrical conditions.

But, by looking at various field studies at a variety of field locations, as well as the results from laboratory studies, overall conclusions can be made. Interestingly, the field tests that have been conducted and reported on by and large have failed to find evidence of the types of harmonic issues that many of the simulation studies above had predicted. The following are summaries of several relevant field studies with references to the complete studies.

- **Sweden, 1997 [10]**. In the late 1990s NUTEK conducted a field study looking for signs of power quality effects from CFLs in residential applications in Sweden. Metering equipment was installed at a residential service feed for one residence as well as a residential substation that serviced 17 homes. Power conditions were then monitored before and after six LPF CFLs were installed in each home. The study found that the effects from the installed CFLs were minimal. In their conclusions the study authors noted the following:

  "High harmonic distortion is the main reason that utilities hesitate to advocate increased use of CFLs. They focus mainly on the high relative current distortion. It is true that for CFLs, the relative current distortion expressed in percent of the fundamental may exceed 100%. However, since fundamental current is very low (ca 110 mA for a 11W lamp), the values of harmonic currents are very low too. […] The results indicate, that the harmonic generated by the CFLs in residential districts have only a minor effect on power quality of the supply network."

- **Poland, 1997 [11]**. A similar but much larger field study was conducted in Poland around the same period through the Poland Efficient Lighting Project (PELP). In this study 33,000 CFLs were installed in three targeted municipalities with the intent of identifying any measureable power quality effects through substation metering. CFL density was estimated to increase by up to 10 CFLs per household in some of the municipalities, but the evidence of power quality issues was again found to be minimal. The study authors state:

  "Based on findings from the PELP DSM Pilot, data suggest that CFL installations, even in concentrated levels, do not contribute significantly to voltage distortion in electricity distribution networks. Moreover, only slight increases in current distortion and neutral wire currents were observed and no increase in reactive power in the substation feeders was recorded."

- **Sweden, 2010 [12]**. This paper, presented at the 2010 International Conference on Harmonics and Quality of Power (ICHQP) in Bergamo, Italy, September 2010 reported on the results of measurements performed at a medium-sized hotel in the north of Sweden. The harmonic emission and other parameters were measured before, during and after a replacement of all incandescent lamps with energy saving lamps, both compact fluorescent lamps (CFLs) and light emitting diodes (LEDs). It concluded that:

  The reduction in total power factor is shown to be almost exclusively due to the reduction in active power. The reactive power consumption is not noticeably different before and after the replacement. The contribution of the current distortion to the total power factor is less than 1%. The reduction in active power and rms current before and after the replacement is due to a combination of seasonal effects and the energy saving by the CFLs and LEDs. Comparing the daily energy consumption for 2009 and 2010 shows a visible reduction in energy consumption. The changes in harmonic spectrum before and after the replacement are small, show increases as well as decreases and no impact is visible of the replacement of incandescent lamps by energy savings lamps with a power factor of 0.5 to 0.6.

- **California, 2010 [13, 14]**. California has not conducted any field studies specifically looking at the effect of LPF CFLs, but it is worth considering because of the de-facto experiment California has undertaken by installing a large number of LFP CFLs. Between 2006-2008, approximately 100 million LPF CFLs were installed in residential applications in California though utility rebate programs. This large program was in part responsible for pushing CFL penetration rates in California residences to over 20%, or an average of over 10 CFLs per home. While this program did not explicitly evaluate grid power factor degradation or other issues related to CFL harmonics, no such issues are known to have been reported on from this major initiative. In fact, California utilities are currently ramping up for another three-year program of equal or greater size to further increase CFL penetration and this new program again relies almost exclusively on LPF CFLs.

- **Worldwide, 2010**. The de-facto experiment described above for California has also occurred in many countries around the globe. Very large installations of LPF CFLs have been carried out in both developed and developing regions of the world without any of the problems predicted by some simulation studies being documented. This does not necessary mean that none of the problems predicted by the simulation studies have occurred or could occur. But, again, it is worth highlighting that the overall worldwide trend continues to be an aggressive push towards replacing incandescent sources with LPF CFLs. This is true in developing countries such as China, which has recently installed nearly 200 million CFLs in the last two years with plans to install another 150 million over the next year, as well as places which have already effectively "banned" the incandescent lamp, such as Cuba. This is also true for many developed countries (Australia, EU, USA) that are phasing in "bans" but do not have any planned HPF requirements in place as part of this conversion. All of these countries have had growing penetrations of LPF CFLs in the years leading up to the establishment of these incandescent phase-out programs. One might infer that had utility sector grid operators and regulators in any of these countries seen evidence that LPF CFLs presented significant costs or risks to their grid infrastructures, they would not have allowed these regulations to move forward.

SECTION 3

POLICY POSITIONS ON CFL POWER FACTOR

A number of important stakeholders involved in this issue have published policy papers describing their positions regarding power factor. These have included lamp manufacturers, utility organizations, and environmental groups. Several of the key policy positions of these groups are described below.

- **US National Electrical Manufacturers Association (NEMA) [15]**. NEMA's Lamp Section published a position paper (LSD 8-1999) entitled "Power Quality Implications of Compact Fluorescent Lamps in Residences." NEMA discusses the power factor and harmonic current considerations of a broad distribution of LPF CFLs and argues that the risks are minimal. NEMA bases this conclusion on a number of factors including the relatively small load of the CFLs (even when aggregated), the fact that current is actually cut in half when a LPF CFL replaces an incandescent of equivalent light output, and the fact that no field studies have ever documented any actual real-world problems. The authors concluded:

  "Currently available CFLs do not pose a power quality problem for users or utilities. Experience indicates that utilities should not hesitate to fully recommend both low and high power factor screw-in CFLs for residential customers and incentive programs, realizing that most user/consumers will continue to prefer the lower priced non-PF corrected models. Taken together, the benefits of such CFLs strongly outweigh any perceived near term risks from power quality issues."

- **European Lamp Companies Federation (ELC) [16]**. The ELC recently published a position paper titled "Mains Power-Quality Effects by Electronic Lighting Equipment." This paper provides a detailed technical appendix to support the position that existing safeguards, including the international harmonics standard IEC 61000-3-2, adequately address the concerns posed by LPF CFLs and that additional requirements would be counterproductive.

  "The internationally accepted IEC 61000-3-2 "Limits for harmonic current emissions" standard safeguards the Power-Quality of the mains sufficiently. Electronic lighting equipment that complies with this standard will not increase the "mains-voltage distortion" and "PEN overload" risks in wiring systems, which are designed to comply with traditional current ratings. The proposed tightening up of the requirements has more disadvantages than advantages."

SECTION 4

CONSIDERATIONS FOR POLICY MAKERS

The move to more efficient lighting technologies in general – and the move from incandescent lamps to CFLs in particular – remains one of the most impactful and cost-effective energy savings and carbon mitigation strategies available. This move to more efficient technologies also carries the promise of reducing the strain on many over-burdened grids by reducing peak-load demands. The key barriers to CFLs achieving their savings potential are widely documented, and include higher initial purchase price (compared to incandescent lamps), fit (size), and the prevalence of lower quality CFLs on the market.[13]

As stated earlier, the choice to require HPF CFLs is ultimately left to policymakers. However, the appropriate action should be an informed choice, based on the specific policy goals, and a thorough understanding of all of the issues involved. In addition to the issue of impacts on the power quality of the electric grid, which was covered by the studies reviewed in the preceding section, there are a number of other issues that policymakers may wish to take into account: the (beneficial) effect of CFLs on the grid capacity, the specific grid conditions where the CFLs will be introduced, technical trade-offs of power factor correction, and the related economic considerations with regard to price elasticity of HPF CFLs. These are covered below.

4.1 NET CAPACITY EFFECT

In discussing this often technical and complex topic of power factor, one basic point should not be neglected: when an LPF CFL replaces an incandescent lamp of equivalent light output, it results in a drop of the current drawn by approximately 50%. To put it another way, a CFL can reduce the current that the grid previously has to deliver to a socket to maintain the same light output by at least one half (see example in **Table 4-1** below). [14]

Table 4-1. The current draw of a 100W incandescent and a 25W LPF CFL

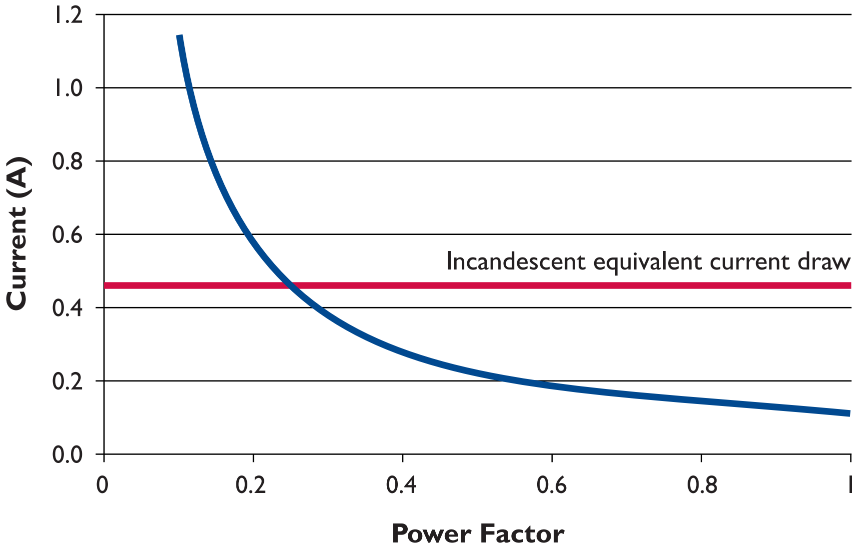
	Incandescent	LPF CFL	HPF CFL
Power (W)	100	25	25
Voltage (V)	220	220	220
Power factor	1.0	0.5	0.9
Current (A)	0.455	0.227	0.126

---

[13] Confidence in Quality: Harmonization of CFLs to Help Asia Address Climate Change. USAID, Regional Development Mission, Bangkok, Thailand. October 2007.

[14] Note: even when an LPF CFL replaces another CFL, the current draw should be expected to stay roughly the same since nearly 100% of the CFLs in place are LPF.

Figure 4-1. Current draw of a 25W CFL as a function of power factor (Voltage = 220V)



As such, increasing the penetration of LPF CFLs on a grid to replace incandescent lamps will result in an increase, not a decrease, of the available capacity of the utility. It just will not increase it as dramatically as a HPF CFL would. **Figure 4-1** illustrates that CFL power factor would need to drop below 0.3 before the current draw of an equivalent incandescent is approached.

4.2 TECHNICAL TRADE-OFFS

According to experts, high power factors in CFLs are achieved by adding additional power conditioning circuitry to the standard CFL electronic ballast. The addition of a power conditioning circuit adds an estimated 15-25% to the cost of the CFL, according to lamp manufacturers. While these additional circuits can be designed to very efficiently rectify the distortion waveform, this process is not 100% efficient – thus these circuits consume a small amount of power and generate a small amount of heat. Both of these effects can adversely affect long-term CFL performance.

The power used by the power conditioning circuit increases the total power draw of the CFL, leading to a small drop in overall lamp efficacy (generally by less than 3%). Lamp life can also be affected as a new potential ballast failure point introduced. A failure of the CFL's power conditioning circuit does not result in the CFL reverting to a LPF condition; rather, it leads to a complete lamp failure.

The extra heat generated by the circuit can shorten the operating lives of other ballast components – the degrees of impacts depend on the designs and components of the HPF circuits that are added and the size of the ballast housing. Heat, or more accurately, lamp ballast operating temperature, has an inverse relationship to ballast longevity – as can be illustrated by the industry "rule of thumb" that electronic ballast life can be assumed to double for every 10° C drop in ballast temperature. Lastly, the addition of power conditioning circuitry can lead to increases in lamp size - particularly the less expensive methods which utilized traditional electrical components such as coil transformers rather than integrated electronic circuits.

For these reasons, HPF CFLs remain a very small fraction of the overall market – typically only deployed where specifically mandated by local regulations or bulk procurement requirements. Of the approximately 4 to

5 billion CFLs that are currently produced world-wide annually, less than 1% is thought to be HPF.[15]

4.3 ASSESSING LOCAL CONDITIONS

The dynamics and capacities of electrical grids vary greatly from region to region. This includes both the dynamics of the types of loads that are found on the electrical grid as well as the grid infrastructure itself. Many electrical networks in developed countries have evolved over many decades to appropriately manage both the capacity and the harmonic currents of the loads that can be expected on these networks. Active power factor compensation equipment is often intrinsically included in these grids. Conversely, many power systems in developing regions are operating closer to their capacity limits and lack the type of active power factor compensation that is typical in developed regions.

Because of these and other differences, it is difficult to make sweeping statements about how LPF devices can be expected to affect electrical grids. The effects of LPF devices are likely to vary depending on the dynamics of the local electrical grid. A technical review of the expected effect on the local grid should be conducted before making decisions that relate to power factor requirements. This type of evaluation can help inform policymakers about expected risks and rewards of their policy decisions. This review is particularly important in developing regions where the grid infrastructure is operating near or at capacity.

Simply assuming that in such a situation LPF devices should be avoided because they draw more current than a similar HPF device is not an appropriate technical review of local conditions. This simplistic approach can ignore significant unintended consequences of LPF requirements. A much more nuanced and inclusive approach is recommended. This approach should truly look at the benefits and risks of allowing LPF devices, one based on the local electrical infrastructure, its planned development, and local economic factors (such as the availability of HPF devices, including CFLs).

This assessment should also include a determination of the specific power quality issues faced by the distribution system, the existing (and planned) power factor correction equipment on the network, as well as estimates (if available) of the main load on the network that contribute to power quality issues. This information can all be useful in determining if the CFLs planned to be distributed through the program might be expected to cause power quality concerns for the network – and if they do, if it would be more cost-effective to address the issue at the source with HPF CFLs or on the network with additional power conditioning equipment.[16] Only after clearly identifying these risks and benefits that exist locally can grid operators, regulators and policymakers make informed decisions about the most appropriate actions with respect to grid impacts.

4.4 PRICE ELASTICITY CONSIDERATIONS

If policymakers are convinced that HPF requirements are necessary for their grid, careful consideration should be made of how the expected added cost for these CFLs should be covered. Studies have indicated that consumer demand for CFLs is very closely tied to initial cost and that this relationship is highly elastic. That is, relatively modest increases in CFL cost can lead to relatively major drops in product sales. For example, a 2001 study of the Indian CFL market found that even a 10% increase in CFL price was likely to result in a 20% decrease in product sales. So, without proper planning, it is possible that a utility program that promotes HPF CFLs as part of a program to maximize reductions in loads on the grid could actually have the

---

[15] Testing for Quality: Benchmarking Energy-Saving Lamps in Asia. USAID, Regional Development Mission, Bangkok, Thailand. April 2010.

[16] Because this is a very technical topic, it may be appropriate to involve experts from the utility sector that have the most complete understanding of the grid infrastructure. But care should be taken to clearly define the role that the utility sector experts are playing in any such exercise since the utility sector may have different policy priorities (such as grid infrastructure) than those identified by programs or nations policy goals (such as GHG mitigation and maximum carbon savings).

unintended consequence of stifling CFL market penetration and, in turn, work against the goal of grid load reductions.[17] An example of how price differences between LPF and HPF CFLs could affect a CFLs program's energy savings and greenhouse gas reductions is included in the appendix of this report.

HPF CFLs are generally 15-25% more expensive than LPF CFLs. This is a generalization based on the world market and differences are likely to occur from region to region. If it was determined through an analysis of the specific power quality issues faced by the distribution system that some power factor correction is required, it is important to get an accurate picture of the potential cost adder for specifying HPF for CFLs. For example, if the program involves bulk procurement, then it may be necessary to request quotations for CFLs that include HPF requirements as well as those that do not – this is the only way to truly isolate the cost of including this requirement.

With this cost isolated, it will be easier to determine if these funds are best spent on the HPF requirement, on power conditioning equipment for the electrical network, or on moving forward with a larger number of less expensive LPF CFLs. Also, it is important to look at the market's ability to sustainably support the program after the program has completed. For example, if a CFL program introduces a large number of HPF CFLs onto the market, but all the CFLs available in retail channels are LPF, it is reasonable to assume that the benefits to the grid that were expected to be realized by including a HPF requirement will over time be eroded as HPF program CFLs are replaced with LPF retail CFLs.

---

[17] For example, at the end of a price support program, HPF lamps price could return to the previous market levels, which are generally higher than LPF lamps.

SECTION 5

SUMMARY AND RECOMMENDATIONS

Prior studies on the effect of LPF CFLs on the power grid's power factor and harmonics have had mixed results. Some laboratory studies and computer simulations have suggested that harmonic disturbances from CFLs are likely at higher CFL penetration rates. Other laboratory studies and simulations have downplayed these risks. The differences in conclusions offered in some of these studies can perhaps be traced to either differences in assumptions for the models and/or differences in local grid conditions from the field studies, further discussed below.[18]

The great bulk of field data, including studies specially designed to document grid impacts from LPF CFLs as well as more general observations of large CFL distributions, have failed to find any significant detrimental effects from LPF CFLs.[19] The particular electrical conditions that exist on the grid being evaluated (such as the type and quantity of power condition equipment present and the other loads on the grid) play a key role in determining the net effect of LPF CFLs on the grid. Furthermore, the interactions between power system equipment and loads can be quite complicated and difficult to model or evaluate – especially in real-world scenarios where mixed loads are almost always present. For these reasons it is difficult for studies to accurately generalize about the effect CFLs will have on the grid when local conditions may vary so greatly.

With regard to impacts of LPF CFLs, the following points can be made based on the data that have been reviewed:

Prior research has not proved that HPF CFLs are needed or even beneficial: One thing that can be concluded with relative certainty is that the totality of the research to date, and especially field research, has not proved that HPF CFLs are needed or even beneficial.

Use of HPF CFLs requires policy, technical, and market considerations: Ultimately, the decision whether or not to require HPF CFLs is much more nuanced that one might first expect. It involves policy, technical, market and economic factors. These may include:

- Policy: the program or national priorities for GHG reductions, energy savings and electric grid reliability.
- Technical: the load and harmonic characteristics of the electric grid as well as a future forecast of grid capacity; analysis of how a large displacement of incandescent lamps with LPF CFLs would likely impact the grid.
- Market: the maturity and structure of the CFL market and the expected impact on CFL sales costs if HPF CFLs are passed on directly to consumers.
- Economic: the cost-benefit of analysis to the electric utility and the society as a whole from addressing HPF upstream (grid infrastructure) vs. downstream (HPF CFLs)

---

[18] Some reviewers have suggested that some harmonic models seem to have not provided an accurate prediction of the resulting harmonic distortion.

[19] For example, in the case of "mini" or "micro grids" – an electric distribution network set up to deliver electricity to households in a village, where lighting makes up a large portion of the evening load, there can be HPF benefits.

Policy element is central to HPF decision: Of all of the above considerations, the policy element should be central since it is this element that defines what the program or nation is attempting to accomplish. With the policy goals defined, the technical, market and economic analyses can help define the most appropriate policy and regulatory pathways for power factor correction.

Utility managers and regulators should not simply specify HPF CFLs under the assumption that HPF CFLs are "better" than LPF CFLs. There are trade-offs that are made with choosing HPF or LPF, and these trade-offs should be made based on a realistic evaluation of local grid conditions as well as local market factors. A high power factor CFL does not deliver any additional value to grid-operator nor end-user under most conditions, other than in cases of isolated, micro, or mini grids with high peak lighting loads. Further, the selection of a quality CFL should be based on results of performance parameter tests. Finally, if the decision to require HPF CFLs is made, it is recommended that additional incentives should be considered (depending on program design) to offset the incremental cost increase, and to mitigate any price-driven sales stagnation in the market.

When making regulatory or procurement decisions relating to CFL power factor, the following steps are recommended:

1. **Clarify and prioritize policy goals.** The appropriate actions to take with respect to CFL power factor requirements can vary based on the overall policy objectives. In addition, other relevant or concurrent programs with potential to impact the grid and its power quality should also be considered.
2. **Evaluate local electrical infrastructure conditions.** This assessment should include a determination of the specific power quality issues faced by the electrical transmission and distribution system, the existing (and planned) power factor correction equipment on the network, as well as estimates (if available) of the main load on the network that contribute to power quality issues.
3. **Evaluate local market conditions.** It is also important to look at the market's ability to sustainably support CFLs or other energy-efficient products after a policy has been implemented or promotion program has completed.

By following these recommend steps, the positive and negative impacts of the policy or program impacts can be fully evaluated and used to maximize policy or program benefits while minimizing program drawbacks both on the grid and in the market.

SECTION 6

REFERENCES

[1] **Sadek, Abbas, El-Sharkawy, and Mashaly, 2004**, Impact of Using Compact Fluorescent Lamps on Power Quality, IEEE, 0-7803-8575-6/04

[2] **Parsons Brinckerhoff Associates, 2006**, Installation of Compact Fluorescent Lamps Assessment of Benefits, Commissioned by the Electricity Commission of New Zealand.

[3] **Matvoz D. and Maksic M, 2008,** Impact of Compact Fluorescent Lamps on the Electrical Power Network, IEEE, 978-1-4244-1770-4/08.

[4] **Durrenberger G. and Klaus G, 2009**, Rebounce Effects of the Grid of Energy Saving Lamps, Commissioned by the Swiss Federal Energy Agency.

[5] **Elphick, S. and Smith, V., February/March 2010**, Results of Laboratory Tests and Analysis to Quantify the Electrical Behaviour of the Modern CFL, Transmission and Distribution Magazine.

[6] **S. K Rönnberg, M.H.J. Bollen, M Wahlberg**, Harmonic emission before and after changing to LED and CFL – Part I: laboratory measurements for a domestic customer. Paper presented at the International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, September 2010.

[7] **E.O.A. Larsson, M.H.J. Bollen**, Measurement result from 1 to 48 fluorescent lamps in the frequency range 2 to 150 kHz, Paper presented at the International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, September 2010.

[8] **A. M Blanco, E.E Parra**, Effects of High Penetration of CFLs and LEDs on the Distribution Networks, Paper presented at the International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, September 2010.

[9] **A.H. Jahanikia, M. Abbaspour,** Studying the Effects if Using Compact Fluorescent Lamps in Power Systems, Paper presented at the International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, September 2010.

[10] **Gothelf, N., 1997**, Power Quality Effects of CFLs – A Field Study, Right Light 4

[11] **Bredenkamp, B., 1997**, Effects of CFLs on Power Quality of Electricity Distribution Networks, Commission by the Efficient Lighting Initiative (ELI).

[12] **S.K. Rönnberg, M. Wahlberg, M.H.J. Bollen**, Harmonic emission before and after changing to LED and CFL – Part II: Field measurements for a hotel, Paper presented at the International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, September 2010.

[13] **The Cadmus Group, 2010**, Compact Fluorescent Lamp Market Effects Final Report, Commissioned by the California Public Utilities Commission.

[14] **KEMA, Inc, 2010**, Final Evaluation Report: Upstream Lighting Program, Commissioned by the California Public Utilities Commission.

[15] **National Electrical Manufacturing Association (NEMA), 1999**, Power Quality Implications of Compact Fluorescent Lamps in Residences, LSD-8-1999.

[16] **European Lamp Companies Federation**, Mains Power-Quality Effects by Electronic Lighting Equipment, May 2009.

APPENDIX

Table A-1 below illustrates the effect and tradeoffs a requirement for HPF can have on overall program costs and impacts. In this table, three scenarios are considered for a utility program in which 10 million CFLs are to be distributed:

1. A program which offers LPF CFLs
2. A program which offers HPF CFLs, but which subsidizes the incremental cost of moving from LPF to HPF CFLs
3. A program which offers HPF CFLs, but which does NOT subsidize the incremental cost of moving from LPF to HPF CFLs.

While there are considerations and variables to consider, this example is intended to show that in certain scenarios, if the incremental costs of HPF CFLs are not covered, the effect for both consumers and the utilities can be negative. In the table, the "without subsidy" savings generated less financial and energy savings for the consumer and less lead reductions for the utility because of a drop in CFL demand based on higher CFL costs. The table assumes that the 20% increase in CFL cost generates a 20% drop in CFL demand – or half the drop in sales that the Indian CFL price elasticity model would have predicted. It should be noted that the results of this model are highly dependent on the benefit that the utility reaps from load reductions (i.e., avoided costs of new generating capacity) as well as from reductions in harmonics – both of which are specific to local conditions.

With the assumptions used in the table, it can be seen that the benefits to the utility (or other program funder) are significantly greater in the HPF with subsidy over the HPF without subsidy scenario – even though this scenario requires a larger initial investment. In cases where budgets are fixed, program implementers should still consider cost-to-sales connection when designing programs.

Assumptions	
Price Elasticity	100%
Cost Adder for HPF	20%
Electricity Cost ($/kwH)	0.1
Baseline CFL Sales	10,000,000
Delta Watts (incan-CFL)	65W
CFL life	6,000
LPF CFL Cost	$ 1.00
tCO_2 per kWh	0.000681
Utility Benefit for 1 kwh reduction	$ 0.02
Utility Benefit for 1 kwh of HPF vs LPF	$ 0.001

Table A-1. Utility programs scenarios with LPF CFLs, subsidized HPF CFLs and non-subsidized CFLs

	LPF	HPF with subsidy	HPF without subsidy
ENERGY SAVING			
1 CFL saves X kwh over life	390	390	390
Annual Sales	10,000,000	10,000,000	8,000,000
ALL CFLs energy saving over life	3,900,000,000	3,900,000,000	3,120,000,000
CONSUMER COSTS			
CFL cost to consumer	$ 10,000,000	$ 10,000,000	$ 9,600,000
Value of CFL energy savings over life	$ 390,000,000	$ 390,000,000	$ 312,000,000
Total Consumer Benefit	$ 380,000,000	$ 380,000,000	$ 302,400,000
UTILITY COSTS			
CFL subsidy	$ -	$ 2,000,000	$ -
Utility benefit from kwh	$ 78,000,000	$ 78,000,000	$ 62,400,000
Utility benefit from HPF	$ -	$ 3,900,000	$ 3,120,000
Total Utility Benefit	$ 78,000,000	$ 79,900,000	$ 65,520,000
SOCIETAL BENEFIT			
Cost Savings	$ 458,000,000	$ 459,900,000	$ 367,920,000
Energy Savings	3,900,000,000	3,900,000,000	3,120,000,000
CO_2 Reduction (tons)	2,655,900	2,655,900	2,124,720

United States Agency for International Development
Regional Development Mission for Asia
Athenee Tower, 25th Floor
63 Wireless Road, Lumpini, Patumwan
Bangkok 10330 Thailand