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HPLEMS: Hybrid Plug Load Energy Management Solution

Sunil Kumar Vuppala\textsuperscript{a,b,*}, Kiran Kumar H S\textsuperscript{a,*}

\textsuperscript{a}Infosys Labs, Infosys Limited, Bangalore-560100, India
\textsuperscript{b}International Institute of Information Technology (IIITB), Bangalore-560100, India

Abstract

Energy efficiency is a key goal for today’s enterprises in their efforts towards achieving their sustainability goals, meeting stakeholder needs and concerns, and addressing environmental regulations for a greener tomorrow. Energy efficiency efforts in office and commercial buildings have so far focused on HVAC and lighting, which together constitutes about 60-70% of the energy consumption. With most companies having achieved a fair degree of optimization in HVAC usage, they now are turning their attention to plug loads, which constitutes about 30-40% of the enterprises’ energy consumption. Study conducted within Infosys and other entities shows roughly 40% of energy consumed by plug loads is wasted. By effectively managing plug load consumption, it is possible to save much of this wastage. However, there are not many plug load energy managements solutions in the market today that can cost effectively address the issue at hand due to a variety of challenges. In this paper, the challenges involved in plug load energy management and multiple options for addressing these challenges are discussed. Based on graded solution method, suitable technology for an appliance type can be identified with a payback period of less than 2 years.

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1. Introduction

Enterprises today are under increasing pressure from within, from the Society to reduce energy consumption as a result of increased energy costs, and also due to growing concerns about impact of energy consumption on global climate change. Energy efficiency efforts in office and commercial buildings have so far focused on heating, ventilation and air conditioning (HVAC) systems and hard-wired lighting. However, of late, the energy impact of plugged-in equipment in office buildings is garnering greater attention.

* Corresponding authors. Tel.: +91 7760982950; fax: +91-80-28520362
E-mail addresses: sunil_vuppala@infosys.com, Kiran_hs@infosys.com
Pluggable devices in enterprises such as printers, copiers, desktop computers, coffee machines and vending machines consume between 30% - 40% of a building’s total energy consumption [1]. In a large enterprise, manual monitoring and control (switch on/off) of these plug-in devices is a difficult exercise, which is fraught with inefficiencies. Building managers in enterprises today have difficulty in identifying distribution of energy consumption and consumption pattern of plug loads. It is hard to identify whether a plug-load consumption is appropriate (i.e., usage is unreasonable) and optimal (e.g., device is still ON when it is not supposed to be - for e.g., after work hours and on weekends). Where the energy consumption is not managed optimally, energy wastage can creep in, resulting in excessive consumption and higher energy cost and higher carbon footprint. This calls for an automated monitoring and control approach including centralized management of all plug-loads.

The objectives of the paper are:

- To identify key requirements and challenges of plug load management
- To suggest suitable technology options for plug load management for large number of appliances with a payback period of less than 2 years
- Reduce energy consumption by up to 40%, by minimizing energy wastage

1.1. Paper Structure

The rest of the paper is organized as follows. Section 2 outlines an overview of existing smart plug based solutions from the literature. The requirements and challenges are highlighted in section 3. The HPLEMS structure and features are discussed in section 4. The deployment setup and analysis of results are discussed in section 5. Section 6 captures conclusion and future directions. Please note that the terms ‘plug-in device’, ‘appliance’ and ‘device’ are used interchangeably in the paper.
2. Literature Survey

There is a need for energy management of plug-in appliances to achieve enterprise sustainability goals. Authors in [2] estimate that nearly 60% of desktop computers, around 30% of printers, copiers and other office equipment remain powered on even after work hours, and on weekends. The authors in [3] illustrate energy wastage issue with plug load appliances during and after work hours. To take decisions and actions at enterprise level, it is important to monitor granular level of energy consumption along with building management systems (BMS). The National Renewable Energy Laboratory (NREL) in the United States has suggested a baseline for plug and process loads (PPLs) [4].

The authors in [5] explain real time demand response model in a commercial building. Even though PLEMS [2] bridges the gap by enabling intelligence through feedback based adaptable policies to monitor and control appliances, this cannot be applied to all appliances. The authors in [6], [7] work towards minimizing home energy bill by carrying out home energy management system through scheduling of appliances in peak and off peak hours. The authors in [8] discuss techniques for optimizing energy costs in office buildings which are connected to the smart grid. In this, operation of appliances can be scheduled as per user policies. Authors in [9] emphasize the need for plug load energy management technologies to participate in demand response and achieve the objectives of smart grid. To make these into reality, plug load management solutions based on smart plugs are necessary. The requirements based on literature survey, business needs and various challenges to meet these requirements are highlighted in the next section.

3. Requirements and Challenges

3.1. Requirements:

An effective IT solution for management of plug loads in commercial buildings or enterprises must address the following requirements:

- Identify energy consumption and usage patterns of different plug-in devices over a period of time to assess their usage behavior.
- Identify potential energy wastage during working hours, non-working hours, peak hours, and beyond energy threshold limits.
- Compare energy consumption of plug-in devices against organizational benchmarks at zone, floor, building, campus, and enterprise-wide level.
- Reduce energy consumption / wastage during working hours, non-working hours, peak hours, and beyond energy threshold limits.
- Switch on / off critical and non-critical devices during peak hours and non-peak hours.
- Participate in demand response programs with utility companies to spread load distribution better and reduce energy bills as far as possible.
- Monitor and control energy consumption of plug-in devices across the organization / campus from a central location.
- If the device is seen switched off when it is supposed to be on, it may be due to a fault – such as equipment breakdown, loose connection, short-circuit, grounding, breakdown of components inside, etc. By monitoring the device in real time, it is possible to locate the faulty device and fix it effectively.
• Eliminate the need to switch off devices manually, thereby saving significant manual costs involved and re-directing staff efforts to other productive uses in large enterprises.
• Reduce carbon footprint through reduced energy consumption.
• Make devices available and operational when end-users need it most, thereby increasing end-user satisfaction.
• Low initial investment and simple to use.
• Ability to scale-up the solution to accommodate a large number of plug-in devices.

3.2. Challenges:

These requirements present significant challenges for both development and commercialization of plug load management solutions.

3.2.1. Identification of appropriate plug in devices:

Not all plug-in devices can give significant energy savings. It is important to identify high energy consuming devices which can significantly contribute to the building’s energy cost and carbon footprint. It may also not be necessary to continually monitor and measure energy consumption of all plug-in devices. It may be necessary to initially assess/audit the energy consumption pattern of the plug-in devices, and determine which plug-in devices need to be monitored and controlled, and which do not.

3.2.2. Initial investment:

Upfront investment needed has to be low in order for the solution to be attractive to the customer. This can be achieved through various means:

a. Some governments offer rebates and incentives for purchase of energy efficiency equipment and solutions for customers. Such schemes need to be taken advantage of and promoted in sales and marketing efforts, so the customer can also take advantage of such rebates and incentives, thereby reducing the burden of upfront investment.

b. By offering the solution on rental basis so that the customer can pay for the solution in installments, rather than pay a heavy price upfront.

c. By offering the solution with no upfront investment, but charging the customer only for the savings achieved.

3.2.3. Return on investment and payback period:

The solution should provide a reasonably good return on investment (ROI) through plug-load energy savings achieved. In addition, the payback period has to be within 2-3 years for it to be attractive to the buyer. Not all plug-in devices offer significant ROI, or reasonable payback period. It is important to determine the ROI and payback period of every type of plug-in device that needs to be managed and apply plug load energy management solution on only those devices that qualify the ROI and payback period criteria acceptable to the customer.
3.2.4. Choice of technology and solution capabilities:

Selection of the right technologies and offering solution capabilities in tune with customer needs at the right price point is very important. At times, one technology or one type of solution for managing all types of plug-in devices will not be appropriate. The technology or solution capabilities may not fully address the need, or the price of the technology/solution may be high, the ROI or the payback period may not be within reasonable limits, etc. As such, it is essential to identify appropriate technology/solution options for different types of plug-load management needs.

Even though building managers appreciate the value of these plug load solutions, the cost benefits and ROI play a crucial role for commercialization of the solution. These challenges are addressed in the next sections.

4. Hybrid Plug Load Energy Management Solution Structure

Plug Load Energy Management Solution [2] is an automated solution for monitoring and control of plug-in devices. It can measure energy consumption of plug-in devices connected to it. It helps building managers to understand energy consumption pattern of plug-in devices over a period of time, usage during non-working hours, usage during peak hours, and also usage beyond reasonable values. In addition, the solution allows for comparison of energy consumption of plug-in devices against internal limits (e.g., KWh per occupant) or industry benchmarks. After conducting energy audit and identification of consumption pattern, it may not be required to monitor energy consumption of all appliances continuously due to variation in potential savings and cost involved.

4.1. Hybrid Plug Load Energy Management Solution:

Hybrid Plug Load Energy Management Solution (HPLEMS) offers ‘graded’ plug load energy management capabilities based on the device/appliance and the network setup. Smart plugs, Wireless switches, SNMP technology and Desktop Computer Terminator applications are various technology options that form part of HPLEMS.

**Smart Plug** is a device/plug that monitors energy consumption of a plug-in device/appliance and also controls (on/off) power supply to the appliance wirelessly. The PLEMS discussed in [2] is based on these smart plugs, and can be used for appliances such as large water heaters, stoves, etc. Energy measurement on a continuous basis for sophisticated energy analysis is possible in order to gain new insights about consumption patterns, trends, relationship between energy consumption of appliances, etc. that will help in strategic decision making. But this is a higher cost solution and may not be justified for use with all types of appliances.

**Wireless Switch** is a device that controls (on/off) power supply to an appliance wirelessly without monitoring the energy consumption. Wireless power switches or wireless thermostats supporting WiFi / Zigbee [10] communication standards can be used to turn on/off plug-in devices. They will be suitable to control plug-in devices (such as e.g. coffee machine, water heater, water cooler, etc.) after the energy baseline of plug-in devices in a building has been completed. Using this option, continuous monitoring of energy consumption is not possible, but time-based adaptable policies can be applied from a central server to control the operation of connected plug-in devices.
SNMP is an internet standard protocol using which appliances can be remotely shut down using SNMP manager application. SNMP based monitoring and control is possible for IP based plug-in devices such as printers, fax machines, copiers, multi-function devices (MFDs), network switches, etc. that support SNMP protocol and a MIB variable to allow an SNMP manager to shutdown the appliance. Hardware devices such as smart plugs are not required with SNMP. Instead, SNMP based element/network manager software to initiate remote shutdown operation is needed.

Desktop Computer Terminator is a Java based application software using which desktop computers can be shut down locally or remotely at pre-set times.

Occupancy Sensors can be integrated with HPLEMS for automated control of appliances. For example, if an employee is not at his/her desk, devices such as computer monitor, fans and lights can be switched off. Building entry/exit turnstiles or employee swipe card readers can also give employee attendance, and in/out data. Energy consumption, employee attendance and occupancy data can be used together to intelligently turn on/off office appliances. The overall structure of the HPLEMS is described in the fig-1.

Based on the requirements mentioned in the previous section, business needs can be categorized into various levels in increasing complexity. These business needs are to be met with appropriate technology option and associated pros and cons. These are highlighted in the table-1.

4.2. Summary of graded offerings

Summary of the graded plug load management offerings based on business needs is described in table-1.
<table>
<thead>
<tr>
<th>Level</th>
<th>Business Need</th>
<th>Technology</th>
<th>Approach and Solution</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take simple actions to control usage of appliances to save energy consumption</td>
<td>None</td>
<td>Conduct energy audit to identify energy consumption pattern of various appliances and educate staff; Manually turn on/off appliances during/after usage period based on audit findings</td>
<td>Zero cost solution</td>
<td>No automated control; No centralized control; No energy analysis</td>
</tr>
<tr>
<td>2</td>
<td>Simple mechanism to turn off IP devices to save energy consumption</td>
<td>SNMP</td>
<td>Conduct energy audit; Use SNMP mechanism to turn off the IP device/appliance using a remote SNMP Network Manager.</td>
<td>No additional hardware is required; centralized, automated control of IP devices; Low cost solution</td>
<td>Can be used only to control IP devices. Turning on IP device may not be possible. No centralized control; No energy measurement or energy analysis</td>
</tr>
<tr>
<td>3</td>
<td>Automate operation of appliance/device to save energy consumption</td>
<td>Occupancy sensors, Timer devices</td>
<td>Conduct energy audit; Deploy occupancy sensors and timers on appliances to turn them on/off during/after usage period as per audit findings.</td>
<td>Automated control of appliances. Low cost solution.</td>
<td>No centralized control; No energy measurement or energy analysis. No energy measurement on a continuous basis; No energy analysis.</td>
</tr>
<tr>
<td>4</td>
<td>Automate operation of appliance from a centralized location to save energy consumption</td>
<td>Wireless switches, thermostats; Policy based appliance control</td>
<td>Conduct energy audit; Use wireless switches and wireless thermostats and policy based control to turn on/off appliances during/after usage period</td>
<td>Medium cost solution. Automated and policy based control and centralized control.</td>
<td>No energy measurement on a continuous basis; No energy analysis.</td>
</tr>
<tr>
<td>5</td>
<td>Identify energy consumption trend, perform simple energy analysis, and automate operation of appliance</td>
<td>Smart plugs Energy measurement and control software (PLEMS)</td>
<td>Deploy smart plugs to monitor energy consumption of appliances. Use time based, usage based, peak load based and other policies to turn on/off appliances during/after usage period/limits.</td>
<td>Energy measurement for simple analysis and reporting. Automated and policy based control and centralized control.</td>
<td>High cost solution; No sophisticated energy analysis.</td>
</tr>
<tr>
<td>6</td>
<td>Get new insights about energy consumption patterns of appliances, identify consumption trend, automate operation of appliance</td>
<td>Smart plugs Analytics Energy measurement and control software (PLEMS)</td>
<td>Deploy smart plugs to monitor energy consumption of appliances. Use <strong>analytics</strong> to gain new insights about usage patterns and identify potential energy savings opportunities, forecast energy needs into the future, etc. Use policies to turn on/off appliances during/after usage period.</td>
<td>Energy measurement for sophisticated energy analysis to gain new insights about consumption patterns, trends, Automated policy based control.</td>
<td>Higher cost solution.</td>
</tr>
</tbody>
</table>
5. Pilot Deployment

5.1. Setup

HPLEMS was deployed on a pilot basis in an office building and the following results were observed. Smart plugs [11, 12] were used for appliances such as vending machines and large TV screens. Based on the load of the appliance, 15A and 30A versions of the smart plugs were used. Energy audit for all the appliances was conducted using smart plugs to identify the energy consumption patterns. As a second step, an analysis of different technology options was made.

During the above analysis, applicability of both smart plugs and wireless switches were explored for appliances such as water heater, coffee machines, water cooler, etc. To get lower payback period, suitable HPLEMS technology was suggested as in table-2. After thorough analysis, it was found that wireless switches are economically viable rather than smart plugs for coffee machines and water heaters. These wireless switches and smart plugs communicate with the HPLEMS server via a gateway device. SNMP was used to switch off printers when a policy was violated. Desktop Terminator Application program was utilized to switch off desktop computer monitors and computers.

5.2. Analysis

Based on the results of the above analysis, the list of appliances and applicable HPLEMS technology option suitable for different types of plug-in appliances (to achieve a payback of <=2 years) is shown in the table below. The costs are mentioned both in Euros ("€") and Pound sterling/GBP ("£").

<table>
<thead>
<tr>
<th>Appliance Name</th>
<th>Annual Energy Cost Savings per device in Euros (&quot;€&quot;)</th>
<th>Annual Energy Cost Savings per device in GBP (&quot;£&quot;)</th>
<th>Applicable HPLEMS Technology Option</th>
<th>Payback Period ( &lt;= 'n' years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Function Device</td>
<td>€78.7</td>
<td>£67.5</td>
<td>Smart Plug</td>
<td>2 years</td>
</tr>
<tr>
<td>Wide Format Printers</td>
<td>€11.0</td>
<td>£9.50</td>
<td>SNMP</td>
<td>2 years</td>
</tr>
<tr>
<td>Laser Printer</td>
<td>€9.65</td>
<td>£8.28</td>
<td>SNMP</td>
<td>2 years</td>
</tr>
<tr>
<td>Tele Presence Server</td>
<td>€70.05</td>
<td>£60.07</td>
<td>Smart Plug</td>
<td>2 years</td>
</tr>
<tr>
<td>Tele Presence Screen</td>
<td>€11.33</td>
<td>£9.71</td>
<td>None</td>
<td>2 years</td>
</tr>
<tr>
<td>Water Heater</td>
<td>€38.29</td>
<td>£32.83</td>
<td>Wireless Switch</td>
<td>2 years</td>
</tr>
<tr>
<td>Water Cooler</td>
<td>€27.67</td>
<td>£23.70</td>
<td>Wireless Switch</td>
<td>2 years</td>
</tr>
<tr>
<td>TV Screen</td>
<td>€51.90</td>
<td>£44.48</td>
<td>Smart Plug</td>
<td>2 years</td>
</tr>
<tr>
<td>Coffee Vending Machine</td>
<td>€46.16</td>
<td>£39.58</td>
<td>Smart Plug</td>
<td>2 years</td>
</tr>
<tr>
<td>Coffee Maker (large commercial)</td>
<td>€46.68</td>
<td>£40.00</td>
<td>Smart Plug</td>
<td>2 years</td>
</tr>
<tr>
<td>Coffee Maker</td>
<td>€23.83</td>
<td>£20.42</td>
<td>Wireless Switch</td>
<td>2 years</td>
</tr>
<tr>
<td>Desktop Computer (CPU)</td>
<td>€16.38</td>
<td>£14.05</td>
<td>Terminator</td>
<td>2 years</td>
</tr>
<tr>
<td>Laptop</td>
<td>€12.12</td>
<td>£10.40</td>
<td>Terminator</td>
<td>2 years</td>
</tr>
<tr>
<td>Microwave Oven</td>
<td>€14.53</td>
<td>£12.46</td>
<td>None</td>
<td>--</td>
</tr>
<tr>
<td>Personal Space Heaters</td>
<td>€11.36</td>
<td>£9.74</td>
<td>None</td>
<td>--</td>
</tr>
<tr>
<td>Video Phone</td>
<td>€10.16</td>
<td>£8.71</td>
<td>None</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 2 Application of HPLEMS technology options in enterprise environment
To achieve a payback period of less than two years, smart plug is recommended to use for those plug-in devices which have an annual energy cost savings of above €45 / £37. If energy cost savings are above €25 / £20, wireless switch is suggested. SNMP/Desktop Computer Terminator application is suggested for use if the energy cost savings are at least €8 / £7. Detailed method to choose appropriate technology option is depicted in flow chart (fig-2). It is not be possible to apply HPLEMS for small appliances such as microwave ovens, video phones, etc. as they do not consume much power, and consequently do not justify the investment in energy efficiency.

On average, for one unit (kWh) of electricity, 743 gm of carbon dioxide [13] will be emitted. One unit saved is equal to one unit generated. Based on analysis of pilot deployment, average carbon footprint reduction per plug-in device is observed to be 150 kg CO₂-equivalent per year, and average energy saving potential per plug-in device is 900 kWh per year (33%). Average reduction in price paid for carbon emissions per plug-in device per year is €2.7 / £2.3.
6. Conclusion

Key requirements and challenges in plug load energy management are highlighted in this paper. The paper also proposes a comprehensive Hybrid Plug Load Energy Management Solution suitable for large number of energy consuming appliances with significant energy saving potential. An energy audit can establish the actual energy consumption pattern of various plug load appliances. Then based on proposed method, suitable plug load management technology option can be identified by considering the business need and type of appliance with a payback period of less than 2 years. This solution addresses the challenge of return on investment for most of the devices within 2 years by choosing the right kind of technology. Reduction of energy consumption by up to 40% is witnessed by adopting HPLEMS for plug load appliances.

HPLEMS allows customers to participate in demand response programs [14] announced by utility companies and be part of the smart grid [15] activities. Customers can achieve energy conservation by participating in demand response programs along with the energy management activities using graded HPLEMS solution offerings. In future, the impact of extending HPLEMS for plug-in devices in residential sector needs to be analysed.

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