Enabling Practical Demand Response in Highly-Stressed Grids using Aashiyana

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ABSTRACT

This paper targets the unexplored problem of demand response in highly-stressed grids. We present here a novel building DLC system, Aashiyana, that can enforce several user-defined low-power states. We evaluate distributed and centralized load-shedding schemes using Aashiyana that can, compared to current load-shedding strategy, reduce the number of homes with *no* power by $> 80\%$ for minor change in the fraction of homes with full-power.

1. INTRODUCTION

Demand response (DR) is a smart-grid technology allowing grid to communicate a demand decrease request to meet supply, using indirect (pricing) or direct (through some control) signals. We however argue that most DLC work has focused on *over-provisioned* grid systems of developed countries, with a focus on increasing revenue and reliability [**?**], but remains largely blind to the unique characteristics of *highly-stressed grids* of countries (like Pakistan, Nepal, and India) with a very large and nearly continuous supply-demand gap. As an example, for Pakistan, this gap can be as high as 6GW during summers, but stays around 1.2GW even during the winter months (2011-2012). The (largely national) utilities in these countries enforce periodic events of controlled blackouts, or load-shedding, to relieve this stress. Existing DLC mechanisms allow for control events, like changing HVAC set-points, or possibly for controlling the AC for a few hours a day [**?**]. These mechanism are **inadequate in their magnitude as well as flexibility** for managing the large and continuous gaps that exist in highly-stressed grids.

We believe that the consumers in a highly-stressed grid — being acclimatized to frequent blackouts — are much more amenable to aggressive DLC mechanisms and thus willing to accept a wider-range of load-shedding policies. *We thus propose instrumenting homes with a system that provides utilities with transitions to several* ***low-power states*** *that map to user-specified appliances.*

In this paper we design and evaluate a novel and practical home-level DLC system solution, *Aashiyana*, that can implement several user-configurable power-states of a home. This system is practical as it can retrofit into the existing wiring scheme of homes; is of low cost while controlling most appliances in a home; provides home consumers a flexible way to describe these lower-power states as a compact disconnectivity matrix requiring one-time configuration.

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2. AASHIYANA: A PRACTICAL SYSTEM TO IMPLEMENT POWER CONTROL

Our major focus is to design a system that can enforce a consumption budget at each home, while allowing the users the ability to flexibly configure devices running at each demand reduction level. We next describe the major design decisions and the architectural components of our demand-management solution.

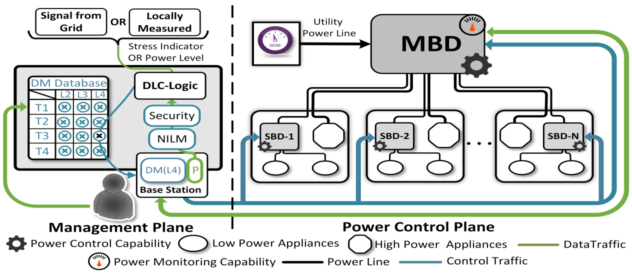


Figure 1: Aashiyana Architecture

2.1 Design Decisions for Aashiyana

We first decided on locating our two control components at the main distribution board and switch boards installed at each home, in light of the traditional wiring structure for Pakistan. These locations provide us sufficient control as the high-power device sockets are accessible from the main distribution board, while individual sockets as well as fixed appliances are accessible from a switch box.

We next decided to restrict the power consumption of our homes to **five levels**. *Level 5 and Level 1* represent the current two binary modes (unrestricted power and full disconnection). *Level 4-2* represent power consumption that is 75%, 50%, and 25% of full rated capacity. We restrict ourselves to just three configurable level, for each level user will provide a matrix of devices that will be disconnected (which we call a *Disconnectivity Matrix (DM)*). Finally, we also decide on using existing building automation and IoT frameworks, like [**?**] to enable an ease of application development and a robust rendezvous mechanism.

We split the architecture of Aashiyana into two planes (Figure 1): Management Plane and the Power Control Plane which we describe next.

2.2 Power Control Plane

The power control plane consists of two different control components, located at switch boards and main distribution board, that enable the enforcement of different power-states of a home.

Main Board Device (MBD), located at the main distribution box, is responsible for controlling room level power and all heavy appliances from one location. Another purpose of the MBD is to monitor the power consumption at each room level to provide monitoring ability to prevent overuse.

Switch Board Device (SBD) is located inside the switch board for each room, which terminates the direct line coming from the main distribution box. It is responsible, much like MBD, to control the wires distributing from this sockets.

Both these components communicate their data to the home management plane through some IoT-based communication technology. We describe this plane next.

2.3 Management Plane

The Management Plane, the brains behind the power-management of Aashiyana, consists of a DLC-logic module as well as Base-station component that enables the communication using the IoT technology (802.15.4, Z-wave, power-line) used by the MBD and SBD.

This plane is first responsible for saving user preferences in the form of a database of DMs for each power-state. A second, and most important, function is to appropriately respond to a grid-stress signal by selecting the appropriate power-state using the DLC-logic present within this plane. Once the power level is selected the appropriate DM is used to send commands to the control plane in order to switch off power to selected points.

The demand-reduction process initiated by the management plane requires an indication of grid-stress which can occur in a fully distributed manner at each home (by, for example, sensing frequency [?]).

3. DLC ALGORITHMS

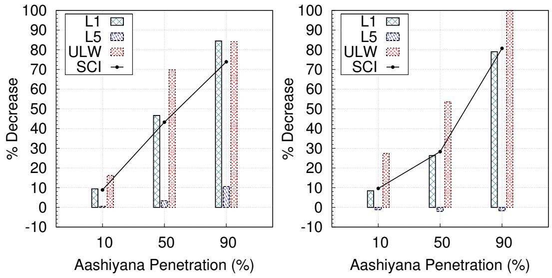
We propose two different algorithms, one central and the other distributed which enforce reduction at an hour-long granularity.

In the iterative distributed algorithm, DLC signal will be stochastically generated within Aashiyana system when grid is under stress and a segment of Aashiyana homes will move to different lower power states. If the power reduction achieved by first iteration of Aashiyana homes is not enough, the utilities will move a segment of non-Aashiyana homes to no power state.

In centralized approach, the utilities refine the current loadshedding scheme by picking a feeder-level group and computing the savings by shutting-off all non-Aashiyana homes. The utility then computes the power savings by reducing the consumption level of Aashiyana homes one at a time, given the demand-supply gap is still positive and move to the next group until the demand is met. Once this decision is made centrally, the control decisions are then communicated directly (and at once) to every home.

4. EVALUATION SETUP AND RESULTS

We evaluated the benefits of our proposed large-scale DLC algorithms using Aashiyana, employing a custom event-driven simulator implemented in C++ having 40,000 home agents. We used REDD and Uk-DALE datasets to stochastically model the power consumption of appliances in a home.



(a) Distributed 20% gap (b) Centralized 20% gap

Figure 2: DLC Algorithm Results: Change (from no AP) in distribution of home-levels with 20% demand supply gap

We limit the generation at 80% of total demand of all homes, which results into a supply-demand gap of 20%

Figure 2 shows the results for our centralized and distributed algorithm averaged over 10 simulation runs. Our fine-grading DLC schemes allow not only a decrease in the number of homes with no power (L1) for a slight decrease, sometime even increase, in homes with full-power (L5). As is quite evident, the fractional decrease of homes in L1 is *always* greater than (by more than 100%) the corresponding decrease in L5. This difference, corresponding to increase in social comfort, is understandably greatest at the highest Aashiyana Penetration (AP) level with the **social comfort index** (SCI[1]) $\approx$ 80 percentage points for 90% AP, thus clearly indicating the benefit of wide-scale adoption. The details evaluation setup and results can be found at a companion tech-report[?]).

5. CONCLUSIONS

We present here a novel and practical DLC system, Aashiyana, that enables several different low-power states for homes within the context of highly stressed grids. We design and evaluate this with practical incentives for the utilities (decreasing social unrest) as well as consumers (low-cost, lower hours with no-power, greater utility), *all without* having to increase the supply side equation. We show that, compared to current load-shedding strategy, for the same supply-demand gap, we can reduce homes with *no* power by $> 80\%$ while not significantly impacting the fraction of homes with full power.

[1]SCI is defined as the magnitude of difference between the fractional decrease in L1 and fractional decrease in L5.