Autonomous Hybrid Priority Queueing for Scheduling Residential Energy Demands

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Abstract. The advent of smart grid technologies has opened up opportunities to manage the energy consumption of the users within a residential smart grid system. Demand response management is particularly being employed to reduce the overall load on an electricity network which could in turn reduce outages and electricity costs. The objective of this paper is to develop an intelligible scheduler to optimize the energy available to a micro grid through hybrid queueing algorithm centered around the consumers’ energy demands. This is achieved by shifting certain schedulable load appliances to light load hours. Various factors such as the type of demand, grid load, consumers’ energy usage patterns and preferences are considered while formulating the logical constraints required for the algorithm. The algorithm thus obtained is then implemented in MATLAB workspace to simulate its execution by an Energy Consumption Scheduler (ECS) found within smart meters, which automatically finds the optimal energy consumption schedule tailor made to fit each consumer within the micro grid network.

1. Introduction

Smart grid is an evolved electrical grid system which is emerging as convergence of information technology and communication technology with power system engineering. Unlike the conventional electricity grid that is unidirectional in nature, smart grids allow for a bidirectional channel of communication between the utility and its consumers, enabling them to quickly respond to dynamically changing energy demands. One of the biggest advantages offered by a smart grid system is the implementation of demand response management programs to reduce power outages and other grid disturbances due to network overload. [1]

Demand Response (DR) refers to “changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [2]. DR, by enabling the interaction between the various consumers and encouraging their response, determines short-term impacts that this has on the power
markets, which leads to cost saving not just at the consumer end but also for the power utility company. Moreover, it results in increasing stability of the power grid network due to the reduction in peak demand in the long run. [3] The overall objective of DR systems is to plan out when and how to schedule the various demands of the consumer while at the same time integrating customers’ needs with the retailers’ goals.

In most programs that have been proposed over the years, the focus has been on overall users’ demands rather than individual devices within a household present in the residential smart grid network. Two different methods are used in these programs to achieve demand management: optimization and game theory. In the case of optimization, the consumers’ resources are managed based on optimization models created with different utility functions as the objective, like Peak to Average Ratio (PAR) minimization, or energy cost minimization. In the case of game theory, an energy consumption scheduling game is formulated, where the players are the users and their strategies are the daily schedules of their household appliances and loads. [4,5]

Shift-able devices are those loads whose operation can be shifted in time (e.g., HVAC, washing machine, dishwasher) as opposed to fixed devices whose power consumption and time of usage cannot be altered (e.g., TV, light) [6]. In this paper, we aim to factor in the individual appliances’ demand for each user in the micro grid and propose a load scheduling system wherein each device would be assigned a user defined priority when it is placed in the queue. The hybrid queuing algorithm used for this purpose ensures that all users in the grid get an equal and fair share of the available generated power at all times and that no single user gets placed in the queue indefinitely. The main objective is to optimally reschedule the working of shift-able devices to light load hours in order to alleviate the stress on the power generation network which in turn improves the system performance over time. In addition to benefitting the end consumer, the proposed method also alleviates burden on the power utility network in terms of reduction in the cost of generation during peak load hours as well as investment in infrastructure is delayed due to flatter peaks [7, 8].

The paper is organized as follows. Section 2 discusses the methodology and the nuances underlying the algorithm’s working action. Section 3 describes the experimental setup established for testing and simulation of the algorithm in the MATLAB environment and presents the salient findings. Section 4 reiterates the results with concluding remarks for the future scope of work.

2. Methodology
The hybrid priority queuing (HPQ) algorithm aims to define the scheduling of all time shift-able devices used by consumers in a residential micro grid in order to achieve peak shaving and also reduce the cost of generation for the power utility company. The objective function is formulated to minimize the cost of power generation and also to ensure equal share of the generated power to all users. Implementing just weighted fair distribution or weighted fair queuing is not sufficient and this issue has been addressed in our algorithm by considering the priority metric.

The cost of generation has been divided based on the type of load. The loads fall into three categories, base load, intermediate load and peak load. Base load is the amount of power generated for which the cost of generation is cheapest, this is followed by the intermediate load and finally peak load, which is the maximum kilowatts that a power utility generates in a day for which the cost of generation is highest. The objective function is then subjected to the constraint of base load. The algorithm checks the current demand of the fixed devices. If this demand falls below the base load, then the shift-able devices will be allowed to leave the queue until base load level is reached and the devices can start operating in order of the HPQ schedule. If not, the devices will not be allowed to leave the queue and their operation is delayed until enough power is available.

Before the queuing is done, priorities are assigned to various devices in the form of weights, which will be a user decided value. For instance, if User 1 has two devices to be placed in the queue, a washing machine and a dryer, then the user can assign a higher weight, W1, to the washing machine and lower weight, W2 to the dryer in accordance with his/her preference. This priority parameter plays a key role in the queuing algorithm. These weights can be updated by the user by means of an Energy
Consumption Scheduler (ECS) present in smart meters which enables the user to communicate with the smart grid. Since the user priority can keep changing according to change in preferences, the calculations are constantly performed in real time and the queues are updated accordingly.

There are two queues which are used in the algorithm, a super-queue and a sub-queue. The size of both depends on the power available in the grid for distribution, as well as the demand for this generated power. All users are given a slot in the queue on a first come first serve basis. The sub queue offers the added advantage of ensuring that priority queuing is done not only among the devices of the same user but also with the devices of all the users in a residential smart grid network (refer to Figure 1). This aspect that is often overlooked in most priority scheduling schemes has been given consideration while designing our algorithm.

The procedures are composed of the following five steps:

**Step 1:** A 1x2 matrix containing the parameter for user identification and priority of the device that has to enter the queue, is initialized. For instance, if User 2 wants to place a device of highest priority in the queue, then the matrix initialized is \([A_2, W_1]\).

**Step 2:** If the queue is full, then the operation of the device is delayed. If not, then the device is placed in the queue and updated with a third parameter indicating its position in the queue. Now the 1x2 matrix becomes a 1x3 matrix of the form \([A_2, W_1, P_1]\), assuming the device in the above example is first to enter the queue.

**Step 3:** If the user already has other devices placed in the queue earlier, then the weights of these devices is checked. If the weight of the device that currently has to be placed in the queue has more weight than the device that was already placed in the queue, then the positions of the two devices are swapped, ensuring that the device of higher priority gets to operate first irrespective of the order in which it entered in the queue. If this is not so, then it moves on to step 4.

**Step 4:** If the mini queue is full, then as in the previous step, the operation of the device is delayed; else the matrix is updated with the mini queue position value, giving a 1x4 matrix of the form \([A_2, W_1, P_1, M_1]\) where \(M_1\) indicates the position of the device in the mini queue.

**Step 5:** If the user already has another device in the mini queue, then the device of higher priority is swapped with the device of lower priority. The device of lower priority is then sent back to the normal queue. This ensures that one user does not get to take over the mini queue indefinitely.

If this is the first device from a user to enter the mini queue, then the weight of this device is compared with that of other devices in the queue. If this device has more weight, then the mini queue value is swapped in such a way that all devices are placed in the order of their weights so that the device of highest priority leaves the queue first. If not, then the device gets to operate when sufficient power is available for use.

### 3. Results and Analysis

The Hybrid Priority Queue Algorithm was implemented in a MATLAB workspace to evaluate and assess its functionality in different operational conditions. To this end, MATLAB based simulations were conducted for two hypothetical scenarios (Run 1 and Run 2) and the effect of HPQ scheduling was gauged.

The following assumptions were made to the design of the workspace environment for its simplification:

- In tandem with the classification of demand loads in economics of power generation, there are three slabs for cost of power generation as well (Base Load, Intermediate Load and Peak Load), with a pricing ratio (cost per unit power generated) of 1:2:5 respectively.
- The total load is expressed as the summation of fixed loads and shift-able loads.
- Each appliance load has a running time of one hour and a fixed power consumption of 200W.
- The HPQ Scheduling (if implemented) is to distribute shift-able loads over a 24-hour cycle.
Figure 1. Flowchart of the Hybrid Priority Queue Algorithm
Figure 2. Load-Duration Curves obtained under different simulation scenarios in MATLAB.

The colored regions represent the different slabs for cost of power generation (viz. in proportion to the operational load on the grid). The black curve represents the power supplied to the grid while the white and blue curves represent the total and fixed loads respectively.

Based on the aforementioned assumptions, two run conditions were formulated; Run 1 being representative of a load-duration curve with a singular region (peak) in the peak load operation zone (refer to Figure 2a). Contrastively, Run 2 represents a scenario in which there are multiple regions (peaks) in the peak load operation zone (refer to Figure 2c). For the sake of diversity, Run 1 has 19 shift-able device loads, while Run 2 has 10 shift-able device loads.

When the default load-duration curves of each run are compared to the ones obtained after HPQ Scheduler implementation (refer to Figures 2b and 2d), it is evident just from visual inspection of the graphs that:

- In both cases, the HPQ algorithm is able to shave off the loads in the peak load operation zone to base load operation zones
- The shaved loads are all shift-able device loads which have been rescheduled to operate in base load operation zones.
• The scheduler accommodates the consumer demand requirements well within the stipulated 24-hour cycle. In fact, within the limited sample size of the simulation runs, the scheduling was achieved within a range of 10 hours of wait time/delay; and the variance in delay period imposed on different users was only 2%.

4. Conclusion
The paper set out with the objectives of designing a consumer centric device-load scheduler that could at the same time optimize the energy-generation costs incurred to the power utility companies. And the HPQ Algorithm has done just that. It is able schedule shift-able devices from peak load operation zones to base load operation zones thereby effecting a significant cost-saving to the utility company; in the simplified simulation scenarios, it was to extent of 33% - wherein the cost of unit power generation decreased from 52 to 40. In addition to this, it is achieving the scheduling in a fair manner by imposing nearly equal delay times to the different consumers.

While there are still many nuances and niceties that would need to factored in, and sorted out before this algorithm is consumer market-ready, it still presents a new outlook a ubiquitous problem; and it’s an outlook with a lot of promise and potential. The future scope of work in this regard would be its implementation in real-time systems or its simulation with real data sets obtained from a HEMS.

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