# Orchestrating Duke's 'Virtual Power Plant'

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## ABSTRACT

Duke Energy recently announced the results of its McAlpine smart-grid program. The company is testing a "virtual power plant" at a substation in Charlotte, N.C. which includes a 50-kilowatt solar array, a 500-kilowatt zinc bromide battery and about 100 households equipped with a home energy management system. In this paper we examine the design and implementation of this program, look at actual results and consider the vision to firm-up renewable resources, micro dispatch demand-side resources in place of supply-side equivalents, orchestrate the efficient control of end-use loads and improve customer satisfaction though enhanced energy management and budgetary control.

## Introduction

During the summer of 2009, Duke Energy conducted a pilot "MicroGrid" program for its residential customers served by the McAlpine Creek substation in south Charlotte, North Caroline in an effort to implement new smart grid technology.

This MicroGrid consists of an array of 213 solar panels providing approximately 30 kilowatts of electricity, enough to power five homes when the panels are operating. Electricity from these panels can be sent directly into the distribution lines serving the McAlpine Creek test area or used to charge a 500-kilowatt zinc bromide storage battery.

In addition to the PV panels and battery, Duke Energy has been installing new smart meters at 8,100 customer homes and new digital communications technology on utility poles and power lines throughout the McAlpine area. This new technology will improve reliability, reduce outage duration, and provide customers with usage data and the ability to customize their energy usage.

Beyond the smart meters, about 100 McAlpine area households also received a residential energy management (REM) system. These systems collect real-time information on the electricity usage of the major end-uses of the house, and supply this information to both the customer and Duke Energy.

The data from all these demand resources – the PVs, the battery, the smart grid, and the REM systems, are sent in real-time to Integral Analytics Integrated Distributed Resources into an Optimized Portfolio© (IDROP) smart grid application. IDROP uses systems-level analytics to combine the distributed resources into a "virtual power plant" to meet the needs of both Duke Energy and its customers.

In this paper, we present an overview of the IDROP application, and look at actual results from the McAlpine Creek pilot. We conclude with a consideration of the possibility of using smart control technologies to improve today's electric system.

## IDROP and the Virtual Power Plant

With a microgrid consisting of a sub-station PV and large battery storage combined with two-way communication with customers via residential energy management systems, the utility gains substantial opportunities to manage energy usage during peak periods.

The simplest example of virtual power plant is presented on the Duke Energy Smart Energy Newsroom (http://smartenergynewsroom.com/), and is demonstrated in a simulation in this video (http://www.youtube.com/watch?v=E1Jrdt1OV8s). In this scenario, when the microgrid is experiencing high electricity demand, the utility can do two things:

1. Send stored battery from the battery into the grid to supply the neighborhood and reduce demand from the grid. If this is not sufficient, then the next step is used.

2. Send communications to the customers equipped with the REM system notifying them that the system is experiencing high demand, and requesting them to reduce their electric usage.

This is attractive in its simplicity, but it does have some significant drawbacks. First, there is no guarantee that the battery will have any electricity available to send to the grid, unless the utility is willing to leave the battery constantly charged during peak hours. While this is an option, it is missing out on a large number of potential energy arbitrage opportunities (i.e., selling power back to the grid at a higher price than it paid for the power) during non-critical peak days, which is fundamental to offset the cost of the battery. Second, there is a great deal of uncertainty associated with requesting customers reduce their energy usage. Many customers may not be home, may not be interacting with their REM system at that point in time, or simply may not respond to the request by the utility. Given the cost of the microgrid, this form of the virtual power plant is not a cost-effective approach to managing critical peak situations.

The IDROP system was designed to provide a cost-effective solution to managing the microgrid in all situations, under normal days as well as critical peak days. IDROP is a real-time distributed resource dispatching engine that follows many of the concepts used in the utilities supply side. The IDROP engine allows a utility to optimize the micro-dispatch of appliances, electric vehicles, photovoltaic generation, wind energy and distributed storage, all at a systems or circuit level. This means utilities can now maximize value and take into account customer-established constraints, cost of service, compliance histories, expected load and market prices, or the specific needs at local sections of circuits.

Instead of reacting to energy constraints, IDROP proactively predicts load, choreographs demands and shapes loads, all in real time. The dispatching can be used to generate value for a utility while respecting its diverse business objectives, including maximizing customer satisfaction, distribution efficiency and supply costs. IDROP aggregates a variety of grid scale system inputs, such as price, margin, carbon dioxide, predicted weather, etc., and marries them to historical household energy consumption for optimal load shaping in the true sense of demand-side management. In fact, the original vision of DSM is now uniquely operational in IDROP.

By coordinating all these system inputs, IDROP creates an architected, level load that benefits the whole system into a true virtual power plant that maximizes value for both customers and the utility. The solutions that are dispatched is based on real-time analysis of the combinations of distributed resources available and may include the dispatch of a few, discrete household end uses at micro levels (often times a levels imperceptible to the customer) designed to alter total system load in a way that benefits the system as a whole.

In addition, IDROP mitigates the uncertainty associated with requesting power reductions from customers that have the HAN units. This can be accomplished in two ways. First, since IDROP incorporates customer-specific modeling of electricity end-use demand, the dispatching algorithm will capture the behavioral responses of each individual customer given historical request for power reductions, including the uncertainty about their response. Thus, behavioral responses will be directly incorporated into the dispatch results. The other option, is that the utility can allow the customer to set their response to such requests to “automatic,” and just allow the utility to use IDROP to take whatever actions are necessary, within parameters that the customer can set, during an critical event period. This will allow the customer complete control without having to manually adjust such thinks as the thermostat setpoint or appliance run-times.

The next section presents the some results of the McAlpine pilot and shows how a virtual power plant based off this real-time micro-dispatching of distributed resources can benefit all customers.

## Program Results

In this section, we will address a the specifics of the McAlpine Creek pilot, particularly the REMS units and the details of the microgrid.

The target population for the REMS customers were those customers on two of the six circuits out of McAlpine Substation. From those customers, the REMS eligible customers were required to use electricity for their HVAC and water heating systems, as those were the targeted end-uses for this pilot. Further, in order to allow two-way communication between IDROP and the HAN, the customer would have to have an existing broadband internet connection. Given the relatively small population and strict eligibility requirements, the net result was that only slightly over 20% of the available customers were eligible for the program, and 10% of those customers would have to agree to participate in the program. To achieve this level of participation, an extensive marketing campaign including direct mailing and telephone calls was required to achieve the goal of 100 participants.

Of the 100 participants, half were supplied with one vendors REMS system, and half were supplied with another vendors. In both cases, the customer was also given a web-based customer portal that allowed the customer to control at least their thermostat setpoint. It was planned that the customer would also have access to real-time information to both their total house energy use from their smart meters (from a different vendor), and also from their HVAC and their water heating systems.

Since the McAlpine Creek pilot was based designed to use cutting-edge technology, there was always the risk that it would become bleeding edge, and indeed that was the case. Integration between the IDROP system and the smart meter vendor in real-time turned out to be problematic, so it was not possible to supply whole house usage data to the customer.

In addition to consumption data, each customer portal allows the customer the ability to opt-in or opt-out of the demand response events during the summer. There were three types of events:

1. High Usage load reduction events (maximum three events per month, lasting no more than three hours, with a 1° to 5° thermostat setback)

2. Extreme Usage load reduction events (maximum two events per month, lasting no more than two hour, with no more than a 5° thermostat setback) and

3. Line Balancing events where customer's total hourly AC and WH should not be impacted, just coordinated across all customers.

The customer received an incentive based upon the number of events they opted into. The web-portal also allowed the customer to override.

The customer only had the ability to opt-in or out of the program, how the customer was dispatched during the program was controlled by IDROP.

IDROP integrated the customer specific collected by the HAN vendors, determined which customers to dispatch to achieve the required load reduction based on the signals from Duke Energy, and sent these to the HAN vendors, who in turn were responsible for the actual dispatching of the individual appliances at the houses**.** **Figure 1** presents the genera structure of the McAlpine pilot microgrid.


**Figure 1: McAlpine Pilot Microgrid**

In terms of the battery storage system, again the state-of-the art aspect of the project created problems. The battery technology that was used in the pilot so new that the battery was not available for installation during the summer cooling season, and thus the microgrid concept could not be tested during the summer of 2009. Therefore, IDROP was unable to dispatch the battery and PV along with the HAN customers, and at the time this paper is being written, no data is available to show how this concept works in practice. Therefore, we have little choice but to present simulation results, and during the conference we will present how a battery can be used to eliminate the volatility associated with a PV system (micro-dispatching customer end-uses is not an option since the participant base was chosen for their cooling systems, not their heating systems).

In this scenario, we have five different customers, each with different load shapes, and associated with these customers are two different cost-of-service (COS) resulting from the locational marginal cost( LMP) on the system (i.e., essentially the marginal cost to generate the power) and the characteristics of the distribution systems to these five customers (**Figures 2, 3** and **4**). The generation of the PV for the day in question is presented in **Figure 5**. Notice how the PV generation is strongly affected by clouds passing overhead, so the typical bell shaped is observed.

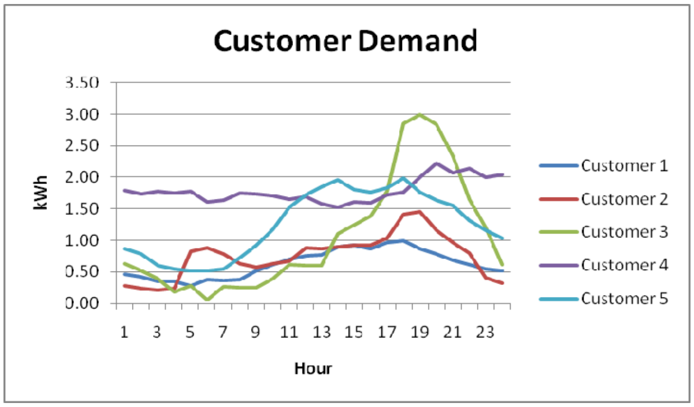


**Figure 2: Customer Demand**

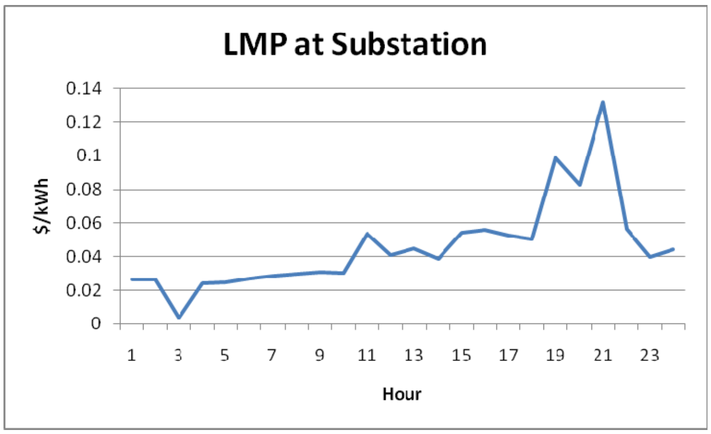


**Figure 3: LMP**

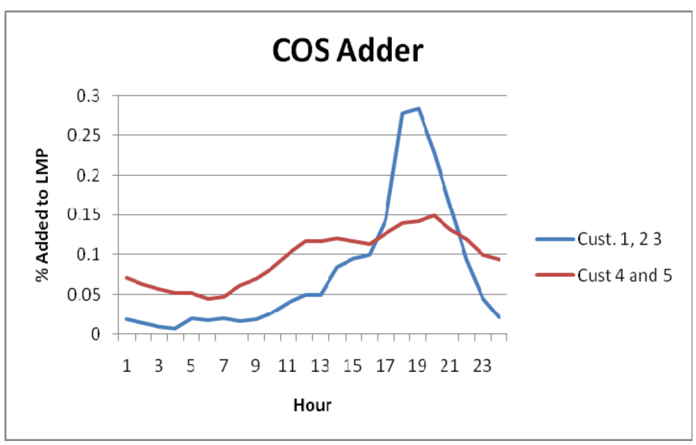


**Figure 4: Cost-of-Service Adders**

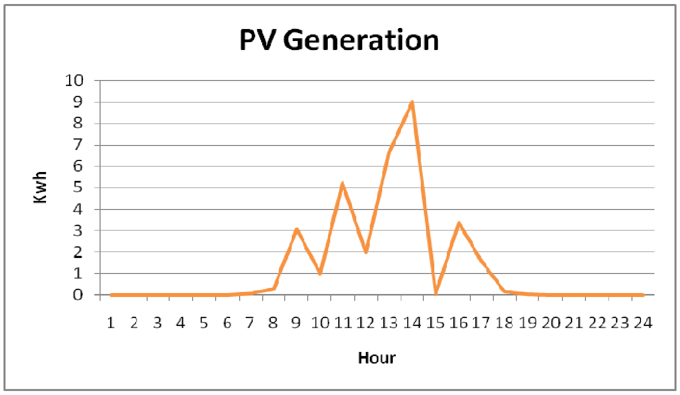


**Figure 5: PV Generation**

The resulting solution from IDROP in terms of how power should be dispatched from the battery (4 kw capacity), and the grid purchases, is presented in **Figures 6** and **7**.

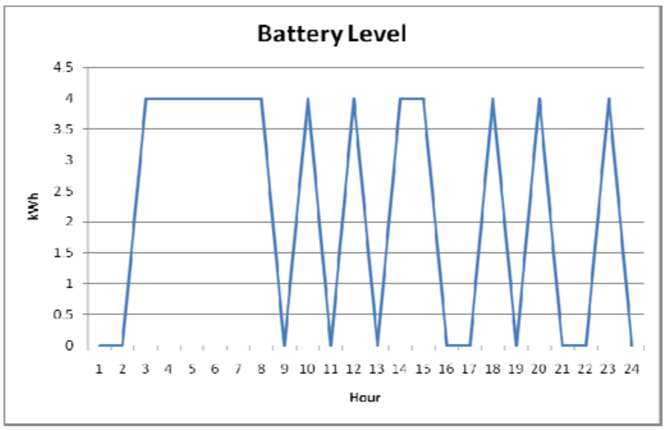


**Figure 6: Battery Dispatching**

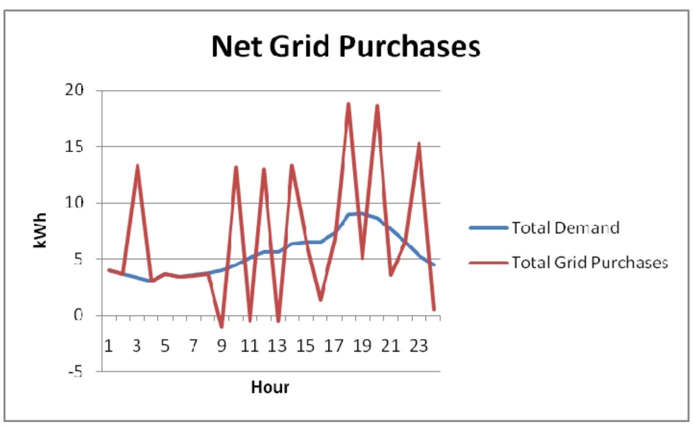


**Figure 7: Grid Purchases (less PV sales)**

In this example, dispatching the battery and customers based on the LMP and COS has profound changes on the net value to the utility. **Figure 7** shows that the battery is charged and discharged repeatedly throughout the day, in response both to the price of electricity (the LMP) but also relative to the generation of electricity by the PV system.

**Figure 7** shows that the utility is indeed purchasing and selling power well in excess of the total demand. The implication of this is that arbitrage opportunities are playing a significant role in this case, and these arbitrage opportunities are relatively short term, spanning hours, rather than the more commonly thought case where the utility charges the system during the nighttime and sells the power to the grid during the day. In any case, the implication is that without any dispatching of the distributed resources, the microgrid would result in a net loss of over a dollar, while managing all these resources as a system results in a net income of over four dollars. The results of course will vary depending upon the actual market conditions including relative prices, demand, and incentive costs, but as this example illustrates, there are clearly opportunities for significant value added using a system like IDROP in a microgrid environment.

## Conclusion

By managing the interplay of solar power, energy storage and home energy management systems, the Duke Energy McAlpine Creek pilot project has been compared to a "virtual power plant." The project includes solar power, large-scale energy storage, all linked together by a smart-grid architecture that keeps power flowing and balanced.

The project includes a 50-kilowatt solar array Duke has installed at its McAlpine substation in south Charlotte. The solar array can feed into the grid or power up a 500-kilowatt zinc bromide battery. One hundred households have received smart meters from the utility and participate in a residential energy management system. Using the IDROP advanced control software, the household air conditioners, heat pumps, and water heaters are optimally powered down or turned off in micro-increments in coordination with the dispatching of the battery to save energy and help the utility curb peak power demands in the most cost-effective, least uncertain, and least intrusive manner.

Utilities in general are seeking ways to curtail electricity at peak time, such as the middle of a hot summer day, when they may need to fire up expensive and polluting auxiliary power plants to meet high demand. Rather than bring on new power capacity during peak times, the McAlpine Creek substation draws stored electricity from the battery and level off demand through the residential energy management system. Consumers can volunteer to have their air conditioner thermostat adjusted or other appliances turned off for a short period to reduce energy usage. The information about power reduction--aggregated across the different homes--is communicated back to Duke via a network so the utility can supply electricity to meet adjusted demand.

As America rebuilds its vital infrastructure and implements a sustainable energy policy, smart energy grids will play a critical and essential role. Managing energy grids and the many resources involved—such as generation, external supply, demand and consumption—requires a sophisticated, real-time analytic application suite and infrastructure. With the IDROP technology, the utility can micro-dispatch appliances, electric vehicles, photovoltaic generation, wind generation, and distributed storage units to maximize its value, given customer-established constraints, cost of service, compliance histories, expected load, and market prices. This real-time smart energy grid management solution being used today at the Duke Energy McAlpine Creek substation is a proven solution that is easily extensible to deliver short- and long-term return on smart-grid investment.