Demand-Side Response from Industrial Loads

M. Starke[1], D. Letto[2], N. Alkadi [1], R. George[2], B. Johnson[3], K. Dowling[3], S. Khan[4]

[1]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[2]ENBALA Power Networks, Toronto, ON, M5H 2V6, CANADA
[3]University of Tennessee, Knoxville
[4]University of Texas, Austin

ABSTRACT

Through a research study funded by the Department of Energy, Smart Grid solutions company ENBALA Power Networks along with the Oak Ridge National Laboratory (ORNL) have geospatially quantified the potential flexibility within industrial loads to leverage their inherent process storage to help support the management of the electricity grid. The study found that there is an excess of 12 GW of demand-side load flexibility available in a select list of top industrial facilities in the United States. Future studies will expand the number of industries examined increasing the quantity of flexibility as more in-depth analysis of different industries is conducted and demonstrations are completed.

Keywords: energy management, demand-side loads, process flexibility, electricity, geospatial

1 INTRODUCTION

Demand-side load management (DSM) services can be procured by electricity system operators to maintain reliability of electricity supply through coordination, control, and monitoring of the electric power system. As part of the identified barriers in a recent DOE workshop [1], understanding the potential resource from load across the U.S. is needed to understand market and policy impacts of significant penetration of DSM as an existing resource in deregulated markets. The analysis discussed in this paper is part of this ongoing work.

This study was conducted by determining which processes are the major power consumers and using their individual process flexibility as a function of the facility average demand. The inherent storage that arises from a load's inherent flexibility is extremely valuable because it can be used for multiple grid-supporting ancillary services. Although any one single load may not meet the requirements for one specific demand-side service, all loads are able to participate as part of a large network to assist in the management of the power system.

2 DSM SERVICES

Regional electricity systems do not necessarily procure every type of demand-side load management service nor are the requirements and nomenclature consistent from region to region [1]-[2]. Further work is required to determine the amount of flexibility the loads can provide by DSM type. The identified DSM services are curtailment programs, frequency response, distribution and high voltage transmission relief, primary frequency response, emergency load shedding, renewable integration, and voltage control and support [3].

3 CHARACTERISTICS FOR DSM PARTICIPATION

For a load to have the ability to provide DSM, certain characteristics are necessary – speed of response, automation, load directionality, metering, frequency of request, and geographic location of response. As an example for synchronous reserve, the speed of response (time to respond to the Independent System Operator/Regional Transmission Organization (ISO/RTO) requests from the load) is fairly slow with a required response period of less than 1 minute while with regulation service it is fast (less than 20 seconds). To participate in synchronous reserve, the load can be manually controlled, unidirectional in consumption, and only requires metering at the facility level. However, for regulation service, automated control is needed due to the speed of response required, the loads need the ability to move both up and down, and must be sub-metered. The expectation is that synchronous reserves will only be called upon intermittently, while providing regulation is a continuous service.

4 METHODOLOGY TO IDENTIFY DSM

Three main groups consume electricity: industrial sector, commercial sector, and residential sector. The focus of demand-side load participation is primarily on the industrial sector due to the inherently large loads, existing sensors and metering technologies available, and existing staff of competing plant managers and energy buyers. The commercial sector has a load consumption characteristic that is generally more distributed (smaller loads), but facilities with enough flexibility may have the ability to participate. Residential loads are also being examined, but have not largely been used since the loads are small, distributed, and not automated.

The framework for the load analysis in this study includes evaluation by industry, process step, and device as shown in Figure 1. Industrial classifications, NAICS [4] (North

American Industry Classification System) and SIC [5] (Standard Industrial Classification), were selected to be able to establish a statistical database for energy information and industry characteristics. The NAICS data set was used to identify and select the top 20 industries used for this study.

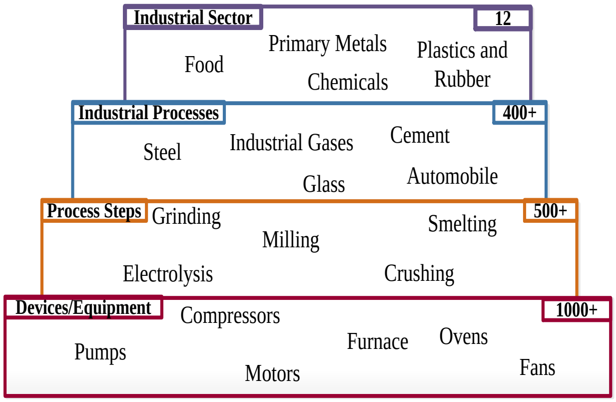

Figure 1. Framework for Analysis.

These loads can also be classified as follows: *Main Process Load (MPL)* are process steps that are dedicated to the direct output of the facility through the handling or transformation of raw materials; *Ancillary Process Load (APL)* are processes involved in supporting the main process loads; and *Environmental Process Load (EPL)* are processes required to provide a safe and comfortable working environment for the facility employees. These each have inherent flexibility. In this case, flexibility is the availability of loads to move a portion of the consumption and is not specific towards any service.

To identify the top 20 industries that can provide useful demand-side load participation, a set of criteria were used to identify what sectors demand-side loads are best suited to participate in providing energy management services. Table 2 defines these criteria and shows the weight assigned to each. A low number (1) indicates the smallest value. A high number (10) indicates the highest value.

Table 2: Filter Criterion Decision Matrix Weight and Ranking

CRITERION	WEIGHT (%)	RANKING
Electricity Consumption (GWh)	40%	1 - 500 GWh 10 - 57400 GWh
Per Establishment Average Power Demand (kW)	35%	1 - 500 kW 10 - 61500 kW
Establishments With Computer Control of Process or Major Energy Using Equipment	15%	1 - <10% 10 - 100%
Establishments With Adjustable Speed Motors	5%	1 - <10% 10 - 100%
Establishments With Participation in Energy Management Activities	5%	1 - <10% 10 - 100%

The data analyzed has been taken from report EC0731I1, "*Detailed Statistics by Industry for the United States*" for the Manufacturing sector in 2007 [6] and the US EIA *Manufacturing Energy Consumption Survey* [11]. Statistics such as quantity of electricity purchased, number of establishments, number of employees and many others are grouped by six-digit North American Industry Classification System (NAICS) code. Based on this report, this decision matrix was used to evaluate the results from the filter criteria. Table 3 is a comprehensive list of the top 20 electricity consuming facilities of the industrial sectors based on ENBALA's filter criteria in no particular order.

Table 3: Top 20 Industries to Participate in Demand-Side Load Management Services

NAICS Code	Industry Name
3221	Pulp, paper, and paperboard mills
3222	Converted paper product manufacturing
3272	Glass and glass product manufacturing
3274	Lime and gypsum product manufacturing
3311	Iron and steel mills
3313	Alumina and aluminum production
3315	Foundries
3364	Aerospace product and parts manufacturing
31131	Sugar manufacturing
32411	Petroleum refineries
32511	Petrochemical manufacturing
32512	Industrial gas manufacturing
32518	Other basic inorganic chemical manufacturing
32519	Other basic organic chemical manufacturing
32521	Resin and synthetic rubber manufacturing
32531	Fertilizer manufacturing
32541	Pharmaceutical and medicine manufacturing
32731	Cement manufacturing
33611	Automobile manufacturing
311221	Wet corn milling

5 QUANTIFYING THE FLEXIBILITY AVAILABLE IN DSM

The total industry flexibility is determined through the assimilated sum of the products of *% process step demand total industry average demand*, *% device demand of process step demand*, and the *device flexibility (%)*. The methodology for obtaining these parameters is provided below.

Processes within a facility generally operate in one of two ways – binary and analog. Binary processes have two states – on and off. The total proportion of load that is available for participation in demand-side load management services from binary processes can be represented by the *% process step of total industry average demand*. If the process step were shut down, it would reduce the facility average demand by the defined percentage. Analog processes and their associated devices have an infinite number of states between 0 (off) and 1 (on). This means that the analog flexibility gives intermediate power states that are represented by *total flexibility of industry average demand*. This flexibility can be applied to demand-side load management services.

Survey information provided by the EC0731I1 report, provides energy usages by industry. For the purposes of this study, *% process step of total industry average demand* was determined from survey data by calculating the percentage of electrical energy usage for total process and non-process use.

Devices are defined as the terminal unit of the process step that consumes the electrical energy. Often, a process step is comprised of a collection of devices. Each device has a set of constraints that contribute to its overall flexibility, and therefore its ability to participate in DSM. Each device within a process step was determined to consume a portion of the identified process electrical demand. For example, for the chilled water production process step, chillers consume a large portion of the total process demand as compared with the chilled water pumps. This is utilized to establish *% device demand of process step total demand.*

The term *% device flexibility* is defined as the typical flexibility of the device for its specific function within the process step. This number is defined from ENBALA's experiential knowledge, past engineering assessments, site investigations, and implementations of demand-side loads.

Total Industry Flexibility = $\sum_{i=1}^{P} \sum_{j=1}^{D_i} p_i \cdot d_{i,j} \cdot f_{i,j}$

where*:*

- p_i represents percent industry demand in process step i out of a total P process steps
- $d_{i,j}$ is the percent demand of device j within process step i total demand, from a total D_i ,devices
- $f_{i,j}$ represents device flexibility for device j in process i, out of a total D_i ,devices

6 QUANTIFYING THE FACILITIES AND SIZES ACROSS THE US GEOSPATIALLY

The Industrial Assessment Center Evaluations (IAC) is a collection of publicly available assessments and recommendations performed by auditors. Currently there are 24 Industrial Assessment Centers in the United States situated at particular universities across the US. These assessment centers are funded by the Department of Energy as a means to spread ideas relating to industrial energy conservation. The information contained within these databases (size, industry, energy usage, average peak demand, hours of operation, production volume, etc.) and details of resulting recommendations are implemented in this analysis. Over 15,000 assessments have been conducted across the U.S. [7]. The information particularly of interest within the IAC Database consisted of reported plant electrical energy consumption by year, plant average peak demand, sales of the plant, and SIC code. It has been shown in [8] that within glass manufacturing a direct relationship exists between sales and electrical energy as shown in Figure 2.

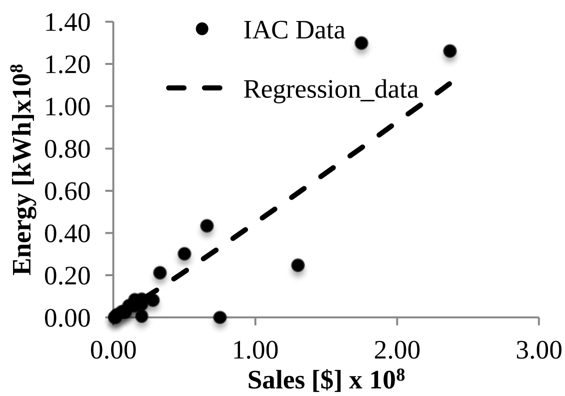

Figure 2. Linear regression applied to glass industry.

The Manufacturer News Inc (MNI) database [9] was polled for the full list of U.S. manufacturing plants focusing particularly on the SIC (Standard Industrial Classification) and NAICS (North American Industry Classification System) codes as well as any sales and address information. This MNI databases contains information regarding specific companies related to the manufacturing industry including: name, sales figures, mailing address, and company contacts. Over 400,000 entries exist in this database which is similar to the official count by the Census Bureau. With the regression results captured from the IAC database, the sales information from each plant is utilized to produce electrical energy estimations by plant across the U.S. This analysis is further detailed in [10].

The mailing address for the plants provides zip codes which can be directly linked to geospatial coordinates. When linked to the energy information regarding each plant, each plant was provided a geospatial coordinate for the purpose of mapping and displaying relevant information to Google Earth and comparing to EIA industrial electrical energy consumption statistics by state. The comparison results of industrial energy consumption and EIA are shown in Figure 3 and demonstrate the relative accuracy of this approach.

The IAC also contains hours of operation and is used to capture the average demand for linking to derived statistics.

7 RESULTS

The top 20 industries were evaluated to determine their absolute flexibility as a function of their average demand. The *% process step demand of total average demand* provides an indication of a response where the process step as a whole was turned ON or OFF – uni-directional response. The *% total flexibility of industry average demand* is calculated for each level defined: *Industry Type, Process Type, and Process Step*. This provides an indication of a response where the process step as a whole was flexed in a bi-directional response. Figure 4 displays the accumulated top 20 industries' available flexibility in loads in relation to the process type. This information has also been geospatially linked to understand impacts regionally. A depiction of the plant locations in Google Earth is shown in Figure 5.

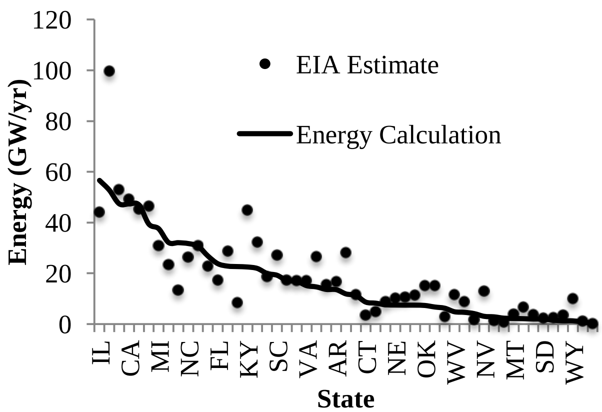

Figure 3. Calculation of industrial electricity consumption by state compared to EIA estimates.

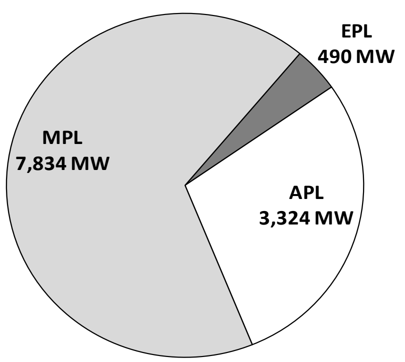

Figure 4. Industrial Load Flexibility by Process Type

8 CONCLUSIONS

The combined effort of ENBALA and ORNL's analysis concluded that the amount of flexibility across the top 20 industries identified is in excess of 12 GW for the United States. This data has been qualified by determining which processes are the major power consumers and then quantified by the individual process flexibility as a function of the facility average demand. This data has been linked geospatially for meaningful representation across different utilities and markets. Load directionality (ramping up or down) is deemed to be the qualifying parameter to determine the available load response and to which energy management service it will apply. These industries have the flexibility available to support the real-time needs of the electric power system through the inherent demand-side storage of loads quantified in this study. Future studies publications will breakout the specific demand-side services available from this flexibility.

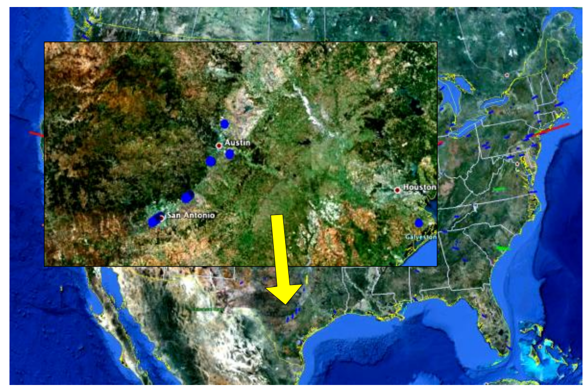

Figure 5. Geospatial representation of flexibility SIC 3241

REFERENCES

[1] Load Participation in Ancillary Services, U.S. Department of Energy, 2011.
[2] O. Ma, N. Alkadi, P. Cappers, P. Denholm, J. Dudley, S. Goli, M. Hummon, S. Kilicotte, J. MacDonald, N. Matson, D. Olsen, C. Rose, M. Sohn, M. Starke, B. Kirby, M. O'Malley, Demand Response for Ancillary Services," Transactions on Real Time Demand Response 2013.
[3] Enbala website: [online]
Available at: http://enbala.com/
[4] Census [online] Available at: http://www.census.gov
[5] NAICS Association [online] Available at:
http://www.naics.com/search.htm
[6] US Census Bureau. 2007 Economic Census, *"Manufacturing: Industry Series: Detailed Statistics by Industry for the United States."* EC0731I1.
[7] Industrial Assessment Center Database. [Online]. Available: http: //iac.rutgers.edu/database/
[8] B. Gopalakrishnan, R. Plummer, N. Alkadi, "Comparison of Glass-Manufacturing Facilities Based on Energy Consumption and Plant Characteristics," The Journal of Energy and Development Vol. 27, Autumn 2001.
[9] National Manufacturers Databases by Industry. [Online]. Available: http://www.mnistore.com/
[10] N. Alkadi, M. Starke, O. Ma, K. Dowling, B. Johnson, S. Khan, S. Nimbalkar, D. Cox," IGATE-E (Industrial Geospatial Analysis Tool for Energy Evaluation)" 35th Industrial Energy.