Energy Management Solutions for Louisiana Industry - Predictive Tools and Concepts for Optimization and Emission Reduction

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Background

An industrial plant consists of an input of energy, raw materials and labor and an output of products, waste energy and waste materials. If raw material and labor costs are relatively fixed, a reduction in the plant's energy costs and waste materials are the two best means of improving profitability. This project specifically evaluates cogeneration opportunities as a means of substantially reducing energy costs and waste materials in Louisiana's energy intensive chemical plants, oil refineries and paper industries. As detailed, any cogeneration opportunity must consider existing utility costs, projected fuel costs and the impact of merchant power plants. This project will help bring stability and growth to Louisiana's existing manufacturing base. In addition, the tools developed can be used by any new industry in Louisiana to help determine its optimal energy infrastructure. This IT project will rely on existing expertise in Chemical Engineering, Mechanical Engineering, Chemistry, ISDS, Computer Science, Electrical Engineering, and the Center for Energy Studies, as well as key hires from outside the University.

Chemical plants in Louisiana manufacture 25% of all the chemicals produced in the United States including more than 1,600 products. Louisiana refining capacity exceeds 900 million barrels of refined product/year which is about 28% of the refining capacity in the United States. These industries generate more than $46 billion in sales which represents 42% of the total income generated by the state. Louisiana ranks second nationally in industrial energy consumption with 2.4 quads (quadrillion BTU's) and first in the EPA Toxic Release Inventory with 451 million pounds.

Generally in cogeneration or combined heat and power (CHP) generation, a natural gas driven turbine is used to produce electricity and waste heat is recovered and used in the industrial plant. In Louisiana, CHP has seen a steady increase in the number of applications since the 1980s, with CHP now in 22 non-utility sites producing about 3.5 Gigawatts (GW). The Public Service Commission estimates that Louisiana industry has a total CHP capacity of about 40 Gigawatts.

CHP expansion in Louisiana is being driven by several factors. Louisiana used 1.2 quads more energy last year than it produced. Most people in Louisiana do not appreciate that we import between 17% and 20% of our current electrical demand. This shortfall in energy makes Louisiana industry very susceptible to curtailment throughout the peak summer and winter months. This energy shortfall will influence new industry locating in Louisiana.

Numerous studies by academics and research institutes alike have repeatedly shown that U.S. electric utilities have not improved their productivity since the 1950s. Moreover, the dominant generation technology is based on the steam turbine, which has seen few efficiency improvements since the 1970s. There was no reason to improve operations. These regulated monopolies have had little incentive to take advantage of technological advances that can double today's average efficiency for power, or triple that efficiency when waste heat is recovered. As a result, traditional power companies burn at least twice as much fuel (and produce twice as much pollution) as necessary. Traditional power companies in Louisiana, and the region upon which these utilities purchase and import their power, are grossly inefficient relative to new CHP generation. Over 90 percent of all power generation in Louisiana and its surrounding regions operate at heat rates over 10,000 BTUs of energy per kWh. Some units, operating 5 months out of the year to serve retail peak load, are operating at a grossly inefficient heat rate of 28,500 BTU of energy per kWh. Most CHP applications at large industrial facilities, operate at between 5,000 to 6,000 BTUs of energy per kWh.

The average operating efficiency of a U.S. power generation plant is 33%. The average operating efficiency of a CHP plant is near 85%. With increasing equipment efficiencies CHP will continue to drive down generation costs, further lowering energy costs to plant owners and customers. Another major consideration is emissions. Emissions regulations are tightening throughout the country. Until recently, power plants could be permitted with virtually no limits on NO_x emissions. Now, it is difficult to permit a plant with NO_x emissions higher than 10 ppm in many areas of the country. Within a few years it is expected that the NO_x standard will drop to between 3 and 5 ppm. In addition, five other items are measured in most clean air legislation: ozone, particulate matter, carbon monoxide, sulfur dioxide and lead. NOx is considered a pre-curser to ozone and is often singled out as the primary target for reductions.

CHP goes a long way in reducing NOx and other pollutants from power plants. The average utility power plant emits approximately 4.9 lbs of NOx for every megawatt hour (MWH) while a five MW gas turbine produces 0.167 lbs of NOx per MWH. Regarding CO2 emissions, the average utility plant produces about 1.06 tons of CO2 per MWH, while a five MW gas turbine emits about 0.30 tons of CO2 per MWH.

CHP presents the opportunity to generate power both efficiently and with low environmental impact. The potential exists to trade CHP generated power for power generated from older less efficient utility plants.
Texas is about to adopt stringent emissions rules for its non-attainment areas. In the Houston-Galveston area, these rules will force dramatic changes on many parts of society. Because of its non-compliance status, area industry and utilities will be forced to reduce NOx emissions by 90% through such actions as advanced controls, advanced cleanup technologies and NOx cap and trade programs. California and Texas are often considered the leaders in such regulations and other states, including Louisiana, are likely to adopt similar rules.

Basically we want to provide definitive answers to the following industrial concerns:

- Is our plant energy efficient
- Should I continue to purchase electricity or move to cogeneration
- Could a group of plants in my area join together under one cogeneration project
- What impact will changing utility and energy prices have on profitability
- What impact will changing emission rules have on operations and profitability
- Can emissions be reduced by moving to cogeneration
- If I implement advanced emission reduction techniques what will be the impact and cost
- Can load shifting and on-line optimization be effective from a cost and emissions standpoint
- If I start a new business in Louisiana what are my energy options and which is best
- If I start a new business in Louisiana what is the power quality and reliability

On the State level we want to provide answers to these concerns:

- Can industry in Louisiana continue to grow if the state is a net importer of electricity
- Should Louisiana support merchant power plants
- What is the impact of tightening emission standards on power generation
- What level of reliability, quality and power cost is required to attract new industry

Specification of IT Tasks and Deliverables

This project will develop IT software specifically targeted for: 1) the optimal design of new cogeneration facilities, 2) cost-effective operational improvements in exiting or new cogeneration facilities and 3) analysis of state wide energy policies. The software will be designed to answer the industrial and state concerns listed above.

The proposed research will develop layered simulation tools with macro- or network-based outer models and physics-based inner models. Given the complexity of power generation, and the many components that must be modeled, the proposed computational effort is extremely challenging and will require the resources of a parallel computing cluster. The physics-based models specifically attempt to resolve the unsteady, small scale flow, heat/mass transfer and combustion processes. These models require finite element or finite difference calculations schemes using millions of nodes or elements. Physics based simulations for the various components (compressor, combustor, heat recovery steam generator, etc.) therefore require the resources of a super- or parallel computer. The results from the physics-based simulations, appropriately parameterized, are fed to the macro-simulations.

Basically, we believe the energy problem in Louisiana must be treated as “onion diagram” with sequential layers. At the center are operational plants; each plant must determine if its current energy use is at an acceptable level or if cost effective improvements are possible. The next layer is for the plant to consider cogeneration as a viable energy option. If cogeneration already exist, or if a new cogeneration facility is implemented, the next layer evaluates if the cogeneration system is operating in a optimal fashion. It is important to realize industrial plants are dynamic and cogeneration systems must respond to changes within the plant. The next layer moves more state wide and addresses questions such as the impact of merchant power plants and tightening emission standards on Louisiana’s energy base. Throughout these layers varying levels of modeling sophistication will be needed. In the sections below we touch on new cogeneration design and operational improvements. State wide energy considerations are briefly touched on.

1) Cogeneration Design Software

Here software will identify economically optimum combinations of enhanced heat recovery in the industrial plant and CHP. Emissions is a key consideration in this procedure, and the predictive software will be able to analyze available feed stocks, and the various gas turbine components, and provide estimates of emissions. The software will include advanced concepts of emission reductions such as selective catalytic reduction (SCR), post-processing of emissions, etc. We will also incorporate improved burner concepts such as dry-low-NOx, RQL (Rich-Burn, Quick-Quench, Lean Burn) into the predictive scheme. The cogeneration software is based on a network analysis, and leads to a nonlinear thermal optimization problem. In the proposed work, detailed simulations will also be performed at a component level to provide accurate and necessary information for a specific component configuration at the network level. These detailed component simulations are necessary to provide fidelity to the models used in the network analysis. Thus the proposed work involves two major components: an overall network analysis that attempts to provide the optimum configuration of the cogeneration system, and a detailed component analysis using commercial CFD tools that will provide the necessary input to the overall network analysis code.

Key components of the software include:

Total Site Analysis. Here an analysis of the existing heat exchanger network and utilities system in the processing plant is performed. Minimum plant wide steam, hot water, cooling water and refrigeration requirements are determined and these values compared to existing usage (Shenoy, 1995). Improvements and changes in the existing heat exchanger network should be evaluated in conjunction with the planned CHP system. Targeted plant values for steam at various pressure levels, hot water, cooling water, refrigeration and electricity can then be set (Smith and Delaby, 1991; Dhole and Linnhoff, 1993; Klemes et al., 1997; Axelsson et al., 1999).

Gas Turbine System Configuration. There are many options for the configuration of the gas turbine system. An optimal configuration at an allowable emission level is crucial. Initially calculations are performed on a fixed gas turbine configuration with a conventional waste heat boiler often termed a heat recovery steam generator (HRSG) . This fixed configuration results in a nonlinear thermal optimization problem (Valero et al., 1994; Bejan, Tsatsaronis and Moran, 1996). A utilities superstructure can be used to allow evaluation of configuration options (Papoulias and Grossmann, 1983).

Component analysis (compressor, combustor, turbine, heat recovery system, etc.) will be performed using commercial CFD software (FLUENT, STARCD, etc.) for specific configurations to provide model input needed for the network analysis and optimization.

A major emphasis will be on including the ability to predict emissions. We will explore different strategies for emission predictions. These will include:

! Empirical predictions of NOx as a function of equivalence ratio and burner geometry. These empirical predictions will be obtained through CFD predictions using commercial CFD software (e.g., FLUENT, STARCD, etc.). These commercial software incorporate the well accepted NOx chemistry models.

- The CFD predictions for gas turbine combustion and emissions will be performed for a variety of combustors manufactured by different gas turbine companies (General Electric, Siemens-Westinghouse, Solar Turbines, Allstom Power, Honeywell etc.). These primarily include Lean Premixed Combustion systems.
- Advanced low-NOx combustor concepts such as RQL, catalytic combustion, and trapped-vortex combustion will be explored since future gas turbine systems are likely to be equipped with such combustors. As an example, the GE-PGT-10B will be equipped with the Xonon combustor that contains a catalytic combustion unit marketed by Catalytica Inc. This combustor is planned for integration into the GE-PGT-10B within the next two years and will produce less than 5ppm, NOx, lower than any existing unit today. The catalytic combustion process will be incorporated empirically into the predictive software using published measurements. It should be noted that LSU is exploring the purchase of a cogeneration system with a NOx emission requirement of less than 15ppm. Specific instrumentation for NOx and CO emissions will be provided for this system. The proposed optimization software will be evaluated for the LSU cogeneration system.

Manufacturers data combined with performance calculations are used to predict real turbine behavior under varying load and operating conditions. LSU is in a unique position because of the above mentioned low NOx cogeneration system planned for campus installation in the summer of 2002. As part of this project will be able to incorporate the newest remediation technology into the design software.

HRSG Design. Our software is based on premise that there must be a sink for the recovered heat in the processing plant or cogeneration may ultimately not be economical. Therefore the design of the HRSG must be accomplished in conjunction with the selected turbine. The HRSG is designed to operate with an expected turbine performance of exhaust gas flowrate and exhaust gas temperature. Especially important is determining HRSG performance in off-design cases (Ganapathy, 1991). The optimal location and number and pressure levels of HR units (superheater, evaporator, and economizer) is a complex problem which can be solved as a MINLP (Rodriguez-Toral, 1999). For selected HRSG designs, CFD calculations will be performed in order to verify and improve the performance of the HRSG predicted by the cogeneration design software based on a network analysis.

System Profitability. System profitability is a complex problem and must account for all of the layers of the "onion diagram" introduced above. At first glance the problem may appear to be a simple, purchase electricity or cogenerate using a properly designed turbine and HRSG. But this decision is a combinatorial problem involving: power reliability and quality; plant operations including design, peak-power, off-peak and shoulder production rates; and, the impact of long term energy prices and merchant power.

Not only must technical engineering issues be considered, but economic and institutional issues significantly impact, and confuse, the decision making process. For instance, the Louisiana Public Service Commission will soon allow industrial customers to choose their own electric providers. This creates an additional decision option for industrial facilities: namely, their ability to optimize energy usage across multiple plant sites. This new shift in regulation will allow Louisiana industrial facilities to affiliate wheel power generated at one site, to another location within the state.

In addition to the self-build option, industrial facilities will have to assess the trends in regional power prices, as well as the potential implications that their project will have on those regional trends. One of the current trends that will be difficult to assess is how competing merchant power facilities will impact regional power prices. Currently there are 11.8 GWs of announced merchant capacity in Louisiana. Some 5.5 GWs of this capacity is associated with cogeneration – mostly through combined cycle (CC) facilities. However, whether these facilities will be realized – and whether they will be enough to offset future Louisiana demand growth, and have a meaningful impact on displacing older traditional utility generation facilities, is yet to be seen.

2) Cogeneration Operational Software

Cost-effective operational improvements in existing cogeneration facilities may represent an even greater challenge than the optimal design of new CHP facilities discussed in the previous section. Improved operation may result from fuel switching, the addition of new technology equipment within the CHP or changes in process operating conditions, both in the plant and in the CHP. We believe the best solution, for a given emissions standard, must again start with a Total Site

Analysis of the plant. A reduction in the plants hot and cold utilities is the first step in modifying the CHP cycle for savings (Axelsson et al., 1999).

A big issue in the operation of existing cogeneration facilities is the performance and optimization during off-design operation. A specific example of interest is the effect of fuel variability. This can often degrade performance, and it is important to be able to respond to these changes in fuel variability (through control of fuel and air feed streams) so that required performance measures in terms of heat release and emissions are maintained. Such optimization and control can be simulated by the operational software and can be implemented in practice. A related issue is the use of available fuel at site (like landfill gas, syngas and other low to medium BTU fuels), and the prediction and optimization of the cogeneration system with different fuel feeds. Such capability, made possible with the proposed software, will allow significantly greater flexibility to the cogeneration plant operation without compromising on performance.

The Overall Team

This project will be led by Knopf (Chemical Engineering), Acharya (Mechanical Engineering) and Dismukes (Center for Energy Studies). Faculty in Chemical Engineering have been actively involved in cogeneration modeling (Knopf), on-line optimization (Pike), and advanced control strategies for cogeneration systems (Dooley, Corripio and Henson). Other Chemical Engineering faculty have modeling expertise in combustion emissions and air pollution modeling (Thibodeaux, Reible, Valsaraj and Sterling). Chemistry faculty are involved in predicting combustion products from large scale sources and modeling the impact of these PAH's on the environment. In Mechanical Engineering, Acharya and Nikitopoulos lead a strong effort in detailed turbine component modeling of a swirl-stabilized combustors with a Parker-Hannifan nozzle, trapped vortex-combustors (Mancilla et al., 1999; Mancilla et al., 2001), and flow in turbine blade passages. In CES, Dismukes follows state wide energy use, regional wholesale power and gas markets, and the impact of regulatory changes on the energy sector.
This project will involve compilation and manipulation of large data base structures. Naturally it is expected that faculty from Computer Science and ISDS will be involved. The long term economic decision tools will involve faculty from the business college and power stability questions can be address by Electrical Engineering faculty.

We have formed a project Advisory Committee. These experts include: Louis Braquet (President of Braquet Consulting) a recognized expert in utilities pricing and cogeneration design; Kurt Kieslik (Energy Manager, BASF Geismer Facility); David Cheshire (Louisiana Energy Coordinator, ExxonMobil); and Mike McAnelly (President of Power Systems and Control) the leading company in Louisiana for power integration and distribution control systems. In addition the investigators have strong ties with the manufacturers of the gas turbine power generation systems (General Electric, Westinghouse, Solar, Allstom).

We believe that existing and new industry in Louisiana must have detailed knowledge of plant-level energy consumption and energy conservation techniques, and the interrelation of the purchased power, cogenerated power and power availability throughout the state A concerted effort by LSU faculty, plus new hires, will allow all Louisiana industry to operate in the most efficient energy mode with minimal environmental impact. Louisiana must have a sound and dynamic energy policy to ensure energy will be available for existing and future industries.

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