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IN THIS ISSUE

Power Plant Budgets...a Delicate Balancing Act
Pages 1-3
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The budgeting process for the owners and co-owners of a power plant can be a stressful balancing act of historical trends and future predictions. Understanding the major plant equipment and how that equipment is expected to run, examining historical O&M costs, and anticipating capital and environmental costs will help to create a more accurate budget for the upcoming year.

Conservation Voltage Reduction (CVR) - an Exit off the Smart Grid Roadmap *Pages 3-5*
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Conservation Voltage Reduction is one of many applications of smart grid technology. CVR is the lowering of the system voltage within allowable limits to reduce power demand and energy consumption. This reduction could produce savings on purchased power costs for the utility and lower customers' bills.

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Power Plant Budgets...a Delicate Balancing Act

The typical consumer is constantly balancing two things in their mind while shopping...Do I want this and how much is it?

If a person is a shopaholic, they may do a bad job of reasonably balancing the two, but inner guilt will remind even the biggest shoe addict that cost is often the bottom line. Unfortunately, unlike the end-consumer at the mall, when an individual or company is manufacturing a product, they most likely won't know what the true cost of the product is until it is made – **especially if the product being created is energy.** For the owners and co-owners of a power plant, the product has already been purchased but no one knows exactly how much the produced energy will cost, at least not just yet. There lies the importance and difficulty of budgeting, or predicting the cost of production.

Setting up an annual budget for power plants can be a delicate balancing act, but instead of an average shopper who has to balance a budget with desire, the non-operating plant co-owner must balance multiple sources of information. This can include Information from the plant managers, historical performance, historical operating costs, and the predicted equipment performance.

Timing, Clarity and Fluidity

Balancing timelines is an important tool when trying to develop accurate power plant budgets; one must balance the historical cost trends versus new information from the power plants. If the budgeting process is started too early, the budget is more likely to rely on information that has expired or become invalid. However, if the process remains waiting on the most up-to-date information, the budget may never get set up in time for it to be useful to a client or plant co-owner. Knowing which items on the budget are most fluid and likely to change can help alleviate this conflict. Also, having positive communication with power plant managers and employees can help ensure the necessary notification if budget information has changed. Open communication with the plant staff will also help identify which budget items are more stable, and which items might change in terms of cost and/or schedule.

Fixed vs. Variable O&M Costs

When budgeting for the power plant's operations and maintenance (O&M) costs, there are costs associated with fixed O&M, and costs associated with variable O&M. Fixed O&M includes items such as:

- **Staffing, administrative, and payroll costs**
- **Operator bonuses**
- **Costs associated with preventative and routine maintenance, health, safety, and routine environmental compliance**

Fixed O&M costs are easier to budget for because they are often subject to

continued from Page 1

the terms of an O&M agreement. On the other hand, variable O&M costs are harder to budget for because they are dependent on how the plant is expected to operate in the upcoming year. For example, fuel costs at the plant are determined by, among other things, **1) the fuel purchase price, 2) the operational heat rate (efficiency) of the plant** (which itself varies with dispatch and availability)**, 3) plant availability,** and **4) plant dispatch.** Other examples of variable operating costs include:

- **Emission credits and charges**
- **Consumable materials and supplies**
- **Auxiliary power (off-line station service)**
- **Water, chemicals, catalysts, ammonia, and gases**

It is also important to remember that everything can be subject to inflation, escalation, and localized market trends. For example, the cost to hire quality power plant operators in Texas may be different than the cost in California.

Predicting Unit Availability

The better one can predict the power plant's performance and schedule for the upcoming year, the better one can predict the costs. Variable operating expenses, such as fuel, are obviously directly influenced by whether the plant is running or not. Maintenance costs will not be distributed evenly throughout the year; instead the highest maintenance and capital costs of the year will almost always take place during scheduled outages, so it is important to set up the budget to expect the highest costs associated with maintenance to take place during or around major scheduled maintenance outages.

Budgeting for maintenance costs is a function of the expected labor workloads and necessary materials at the plant that year. Balancing both the historical performance and the plant projected performance is important because often maintenance work is unplanned, let alone budgeted for. One historical performance indicator to take into consideration is the plant's unplanned forced outage rate, because the variable operating costs associated with starting and stopping (cycling) the plant can vary significantly. If a plant trips or has to shut down often, a higher heat rate will result from cycling the plant. This will increase fuel costs, chemical costs, and also could have long term cost impacts due to stress on the materials. If the plant often undergoes the physical wear and tear of cycling operations, materials can be affected by creep and fatigue damage, which can increase future capital costs due to the parts having shorter and less-effective lifespans. If a base load plant has a higher forced outage rate and greater cycling, it is more likely the plant may experience degradation of the air heater seals and boiler tube failures, which in turn can mean a lot of unplanned and unbudgeted costs.

The plant's forced outage rate also influences whether or not the plant will have higher costs associated with auxiliary or replacement power. If a plant has had a high equivalent forced outage rate (EFOR) in recent history it doesn't necessarily mean that it will always continue to have one. Instead, a detailed evaluation of the plant's performance is required in order to determine whether the EFOR is a systemic problem that is expected to continue or if any recently completed maintenance work is expected to resolve the past issues. As an operator, your nature may be to plan for the best, and as an owner your preferred choice may be to plan for the worst, but a better alternative would be to plan for the most likely outcome. Understanding the plant equipment, how it has run, and how it is expected to run, can help to create a more accurate budget.

Capital Expenditures

How the plant is operating will also affect the capital expenditures at the plant. As mentioned earlier, the power plant's capital budgets are often long-term budgets. The high expenditures planned for on capital budgets are based on the major maintenance schedules required for the equipment at the plant. Equipment vendors are usually most knowledgeable about when the required maintenance outages are needed, because they are most familiar with the equipment. Accordingly, the plants often have long-term contracts set up with the major equipment vendors, so that the plant can follow or get advice concerning when the major maintenance overhauls, and therefore major capital costs, are best scheduled. For example, a GE equipment vendor will often work with the plant staff in determining when the next turbine overhaul will be needed, and what work will be needed. The plant can provide the GE vendor with their best guess about how the plant will be operated in terms of starts and hours, and the equipment vendor knows how well the equipment will respond.

Plant upgrades can contribute to high capital budgets, but could off-set some O&M costs over time. For example, control upgrades at a plant can allow for less operators to run the plant just as safely and effectively. Or the plant may have to upgrade controls in order to comply with their power supply contracts, so that they can be available and selling power to the grid in a short period of time.

The plant's relationship with the equipment vendors may also affect the budget for capital spares. If, for example, GE has reassured the plant that their North American operations have every part in stock, the plant may strategically decide that it is not worth the cost to buy the spares before an actual incident arises.

Environmental Regulations

One of the recent major drivers of the plant capital budgets has been environmental regulations. These regulations are constantly changing, but are a huge factor in plant budgets because they generally require large-scale projects with high construction and equipment costs. This is another area of budgeting where open and regular communication with plant managers can be the best tool for keeping up with **1) what environmental regulations are relevant to the plant, 2) the plant's strategy for compliance,** and **3) the cost of compliance.** Communication is also important because of the inherent nature of the large-scale environmental projects. Most of the projects are constructed over several years, allowing more time for strategies, costs, or even the original environmental regulations to change. Capital plans are often set up as

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Smart grid technology advancements continue to open opportunities for utilities to make improvements to the distribution system that once were not cost effective. These new technologies can help utilities create a more efficient distribution system and aid in reducing power supply costs. **As smart grid technologies continue to expand, so will the exits for utilities to take off the smart grid road map.** One exit off the smart grid road map and application of smart grid is **Conservation Voltage Reduction (CVR)**. Utilities can make use of available smart grid technologies on their system in order to implement CVR.

As power supply cost for utilities continue to increase, so do power costs for consumers. Utilities are looking for ways to leverage existing and new technology to mitigate these increases. Employing a CVR scheme is one option to reduce increasing power costs. CVR has become the recent topic of discussion as utilities are beginning to test out CVR on a limited basis and continue to research CVR's potential. However, the concept of CVR is not new. CVR first came about in force during the oil embargo that occurred in the 1970's. During that time the nation saw large increases in energy prices. Thankfully, we are not seeing that level of increase today; however, we do know that energy rates are going to continue to increase. With CVR, utilities could potentially reduce their current power supply cost and slow the future rate increases.

CVR is a method of reducing power demand and energy consumption by lowering system voltage within allowable limits. The key in this definition is lowering voltage within **ALLOWABLE** limits. The following chart shows the standard voltage limits presented by **ANSI C84.1-2011**. In order to maintain allowable voltage levels on a distribution system, the voltage levels should be continuously monitored at critical points throughout the system. Advances in smart grid technologies have significantly improved a utility's ability to monitor voltage levels, as well as other data, in real time throughout their system making CVR much easier and effective to implement. Many utilities are currently utilizing Advanced Metering Infrastructure (AMI) systems, which provide utilities with the ability to monitor voltage at such critical points.

ANSI Standard C84 Service Voltage Ranges

Service Voltage Ranges	Voltage Range (volts)
Range A	114 - 126
Range B	110 - 127

ANSI C84.1 Standard Voltage Ranges

CVR can help the utility reduce power supply cost through two types of applications; **(1)** overall system energy efficiency and **(2)** peak demand reduction. For peak demand reduction, the system is operated in the CVR mode for short periods of time to either reduce the system peak or to avoid a coincident peak. CVR mode is when the system voltage level is purposely lowered below the normal voltage level setting for a desired period of time to reduce system demand. Placing a system into CVR mode can be done most effectively by the use of one or multiple smart grid technologies. These technologies include SCADA, AMI, and intelligent regulator controls. These technologies will give the utility the ability to monitor and remotely operate intelligent devices throughout the distribution system. Using these technologies effectively can help trim system peaks which will increase the system load factor and decrease overall demand cost.

Using CVR for energy efficiency is not as common as using CVR for peak demand reduction. These two different methods of employing CVR have very different goals as well as rules for implementation. When using CVR for energy efficiency, the system is operating in CVR mode on a continuous basis. This means the system voltage will be reduced continuously. This continuous (24/7) reduction in voltage will result in less kWh purchases from the power supplier. A continuous reduction of system voltage could also have numerous adverse effects on the distribution system, especially during system peak when end of line voltage levels are at their lowest. This is one reason why the continual use of CVR is not very common, especially on long distribution feeders. For the utility, this reduction in kWh purchases from the power supplier will also result in a reduction of kWh sales to customers. Therefore utilizing CVR for energy efficiency generates a reduction in revenue. The utility should closely monitor this relationship to make sure the cost savings is greater than the loss of revenue. This is another reason that CVR for energy efficiency is not as common.

System voltage monitoring is key in CVR implementation. The current system voltage profile at critical points throughout the

continued from Page 2

five-year (or longer) plans, leaving plenty of time for the cash flow to become outdated or change.

It is impossible to predict exactly what problems or successes a power plant may have in the upcoming year, but better communication with the power plant staff and a thorough understanding of past and on-going engineering activities on the power plant equipment will allow a more accurate budget to be developed and delivered to utility decision-makers in time for them to plan around anticipated co-owned plant performance and cost. Making the balancing act a little more steady. ■

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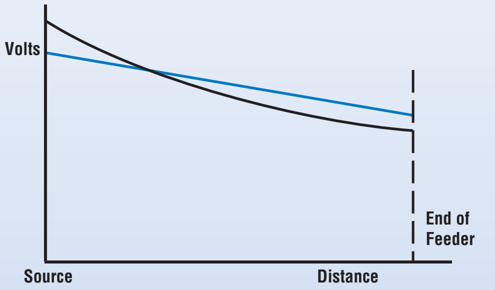
Smart Grid Roadmap

system must be known prior to implementing CVR. System voltage monitoring is achieved with the use of an AMI and SCADA systems, and these systems can be used to continuously gather data and determine the current system voltage profile. This system voltage profile will help determine whether it is feasible to employ CVR on a particular feeder and maintain minimum voltage levels throughout the system. This will also help determine what, if any, system improvements will need to be made prior to implementation, and the amount of voltage reduction that can be achieved. Once this information is known, the utility should determine the amount of savings that can be achieved through CVR and weigh that against the costs of implementation.

Along with an AMI system, a detailed system engineering model is a critical tool in CVR implementation. The system model can be used to simulate voltage levels throughout the utility system after the source voltage has been reduced to the desired level. This can be used to determine necessary system improvements, as well as optimal locations for equipment such as voltage regulators and capacitors. The AMI system can be used to monitor critical points on the distribution system, and can validate these simulations. Typically, the longer feeders on most distribution systems exhibit end of line voltages near the minimum of ANSI Range A voltages and thus continuous monitoring and model simulation will be crucial in implementing CVR. These longer feeders may not be as good of a candidate for CVR when compared to shorter feeders with less accumulated voltage drop at the end of the line.



Voltage profile on a typical feeder with uniformly distributed load

CVR works by lowering the system voltage and flattening the voltage profile. To allow for a lower system voltage and to flatten the voltage profile, voltage drop along the circuit must be reduced. Reducing voltage drop can be done by multiple different methods. The easiest and most economical methods are typically load balancing, load transfer, reducing load and reducing the length of the circuit through optimizing open points. Using historical and instantaneous data from a utility's SCADA system can help in that process. More expensive options will include single-phase to three-phase line upgrades, installing new substations, reconductoring line to larger wire sizes, and line voltage conversion. The most common methods used are the installation of downline regulators and capacitors. Many utility systems currently use regulators, and these may have to be relocated for optimum performance when operating in CVR mode. Existing capacitors may also have to be relocated in order to optimize performance when operating in CVR mode. The location of these should be evaluated within the engineering system model to determine the more effective placement. As stated previously, the costs of these system improvements necessary to implement CVR should be weighed against the potential benefits when determining whether or not CVR makes sense for a particular utility.

Installing capacitors can be an inexpensive way to reduce voltage drop for CVR implementation. The optimal capacitor placement for CVR will differ from the optimal placement at normal voltage levels, because the optimal placement for CVR balances power factor correction while reducing voltage drop. The utility engineering system model, along with data obtained from a utility's SCADA system or power supplier metering can aid in determining the proper size and effective placement of capacitors.

Voltage regulators are another common tool that can be used to help flatten the system voltage profile. As with capacitors the existing downline regulator locations may not be optimal for operation in CVR mode. Therefore the utility should re-examine its voltage regulator locations when implementing CVR. Regulators should be placed either by using the system engineering model or by examining the system voltage profile obtained from AMI and/or SCADA. Line Drop Compensation (LDC) is a regulator control feature that can be used to aid in CVR. This feature is not widely used due to the difficulty of determining the LDC settings, but should be strongly considered when employing a CVR scheme for energy efficiency.

There continues to be considerable research on the overall effects of CVR. The effects of CVR on different load types have been and continue to be studied. Since a lot of the past research has been analytical, load models had to be developed for this research. Today, two load models have been developed: **Loads with thermal cycles** and **loads without thermal cycles**. An example of a load without a thermal cycle is the incandescent light bulb. Light bulbs consume energy as a function of voltage. If the voltage is increased, the energy it uses will increase and therefore if the voltage is reduced so will the energy used. A water heater is an example of a load with a thermal cycle. When the voltage is reduced the water heater will draw less instantaneous power, but it will run longer. Therefore the peak demand has been reduced but the total energy use has not changed.

Loads without thermal cycles have been broken down even farther and researched. The ZIP model divides these loads into constant impedance **(Z)**, constant current **(I)**, and constant power **(P)**. Research has shown that constant impedance loads, like an incandescent light bulb, are the most favorable for CVR. As the input voltage decreases on these, so does the power consumed. Research has also shown that the least favorable loads for CVR are constant power loads like motors and pumps. As voltage decreases to these loads, the current will increase. This increase in current will also cause an increase in voltage drop. These loads will have a negative impact on CVR since the goal is to reduce voltage drop.

The effects of CVR will not remain static forever, and will

CVR – an Exit off the Smart Grid Roadmap

...continued from Page 4

continue to change as the loads on a utility's system changes. Constant impedance loads such as the incandescent light bulb are being replaced daily with compact fluorescent lights (CFL). CVR is more beneficial and provides a greater reduction in power for an incandescent bulb versus a CFL bulb. The same is true for the older CRT televisions when compared to the new Plasma and LCD televisions, which actually consume more power as the voltage is reduced.

The impact and benefits of CVR for a particular utility's system will vary by load distribution and type, and therefore benefits seen on different substations and even feeders will vary. To help determine the benefits and feasibility of CVR, two factors can be determined. The factor for real power **(kW)** is CVRp, and the factor for reactive power **(kVAR)** is CVRq. These factors can be used to determine the effectiveness of CVR on the distribution system and are used throughout all CVR studies. The equation for the CVR factor is:

$$\text{CVR factor} = \frac{(\%\ \text{Change in Power})}{(\%\ \text{Change in Voltage})}$$

The higher the CVR factor is for a utility, the more effective CVR is at providing higher cost savings by reducing power supply costs. However, the factor can be negative which means that the power will increase as voltage decreases, resulting in an increase in power supply costs. Most studies have shown that for a 1% reduction in voltage, there will be a 0.75% to 1% reduction in demand. Utilities can do pilot projects on select substations or feeders to determine these CVR factors. Once the factors are determined they can then be used to determine the potential power supply costs savings for a full system CVR implementation.

Current utility system projects and case studies have shown that CVR is most effective on shorter, heavily loaded, and higher voltage lines. This is not to say that CVR does not work on longer distribution lines. However, these longer lines will require more system improvenents prior to CVR implementation, thus lowering the return on investment.

The theory behind CVR seems simple; however, the implementation is not. There are many things a utility will need to consider in order to achieve optimal performance and benefits from CVR. Once CVR is implemented, the utility should be prepared to adapt the system to the changing loads of the future.

The impacts of CVR implementation on a utility distribution system are far reaching. Implementation of CVR can reduce the power supply cost to the utility and in turn the end-consumer. However, a study by North East Energy Efficiency Alliance found that 80% to 90% of kWh savings came from the customer side of the meter. In addition, peak reduction on a utility distribution system could create excess capacity and delay system improvements. For the power supplier, it could also mean delaying the construction of a new power plant. **Therefore, CVR is still a great technique for utilizing smart grid technology to lower power cost today and in the future.** ■

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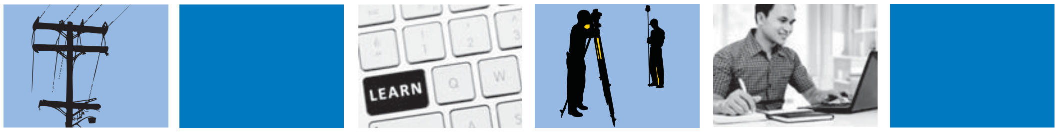

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