Study of Thermal Optimization in Power Plant

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Abstract– **In this paper about the optimization methods like exergy analyses, Pinch analysis, Combined Pinch and Exergy analysis and Life Cycle Cost Optimization Process have been discussed. The Combined Pinch and Exergy Analysis (CPEA) first consider the representation of the hot and cold Composite Curves of the Rankine cycle and define the energy and exergy requirements. The basic assumption of the minimum approach temperature difference required for the Pinch Analysis is represented as a distinct exergy loss that increases the fuel requirement for power generation. The exergy composite curves put the focus on the opportunities for fuel conservation in the cycle.**

***Keywords*–** Optimization Methods, Exergy Analysis, Pinch Analysis and Life Cycle Optimization

I. INTRODUCTION

The name thermodynamics comes from the Greek words therme (heat) and dynamis (power), which is most expressive of the conversion from heat into power. Nowadays same name is broadly interpreted to include all aspects of energy and energy transformations, including power generation, refrigeration, and relationships among the properties of matter. The First Law deals with the amounts of energy of various forms transferred between the system and its surroundings and with the changes in the energy stored in the system. It treats work and heat interactions as equivalent forms of energy in transit and offers no indication about the possibility of a spontaneous process proceeding in a certain direction. The first law places no restriction on the direction of a process, but satisfying the first law does not ensure that the process can actually occur. This inadequacy of the first law to identify whether a process can take place is remedied by introducing another general principle; the second law of thermodynamics.

The exergy method of analysis is based on the Second law of thermodynamics and the concept of irreversible production of entropy. The fundamentals of the exergy method were laid down by Carnot in 1824 and Clausius in 1865. The energy-related engineering systems are designed and their performance is evaluated primarily by using the energy balance deduced from the First law of thermodynamics. Engineers and scientists have been traditionally applying the First law of thermodynamics to calculate the enthalpy balances for more than a century to quantify the loss of efficiency in a process due to the loss of energy. The exergy concept has gained considerable interest in the thermodynamic analysis of thermal processes and plant systems since it has been seen that the First law analysis has been insufficient from an energy performance stand point.

However it can specify where the process can be improved and therefore, it will signify what areas should be given consideration. The simple energy balance will not sometimes suffice to find out the system defect. In such circumstances the exergy analysis is well thought-out to be significant to locate the systems imperfections. Recently, we had new technologies for high temperature air combustion and ultra-high temperature combined cycle. In this case, it is necessary to study the exergy analysis on combustion and thermodynamic processes, because ordinary energy analysis does not have any evaluation supported at its temperature level. If we introduce the exergy analysis against energy analysis, which is supported by this temperature level, it is clear that the high temperature energy has a greater evaluation compared with low temperature one. In this particular field of engineering, it is difficult to use the ambient temperature energy of air and water, which are widely available. When we discuss power generation, high temperature energy of 1500°C and above in combined cycle has higher conversion efficiency than that of 500-600°Cin steam cycle. In a thermodynamic cycle, it is necessary to consider the combustion, heat transfer and energy conversion processes, which include many kinds of effective and invalid items. So, when considering the abovementioned processes, the exergy analysis must be introduced to analyze power generation and heat pump cycles as against energy analysis. Recently a large number of studies based on exergy analysis have been carried out by many researchers all over the world in various system applications.

II. EXERGY ANALYSES

The exergy balance in a system in contact with n heat sources which has a net generated work equal to$\dot{W}$, and has multiple inlets and outlets is represented as follows [1]:

$$\dot{E}_{x,w} = \sum_{\iota=1}^{n^{\cdot}} \left(1 - \frac{T_0}{T_\iota}\right) \dot{Q}_\iota + \sum_{int} m\dot{e}_x -$$

$$\sum_{out} m e_x^{\cdot} - T_0\, S_{gen}^{\cdot} \qquad (1)$$

Flow exergy is generally divided into thermo-mechanical and chemical exergies which can be shown by the following equation:

$$\dot{E}_x = \dot{E}_x^{tm} + \dot{E}_x^{ch} \qquad (2)$$

Thermo-mechanical exergy includes kinetic, potential and physical exergies which can be represented as follows:

$$\dot{E}_x^{tm} = \dot{E}_x^{ph} + \dot{E}_x^{ke} + \dot{E}_x^{po} \quad (3)$$

Physical exergy of the flow is calculated from the following relation (Cengel, 1994):

$$e_{x,ph} = (h - h_0) - T_0(s - s_0) \quad (4)$$

The standard chemical molar exergy of the fuel constituent parts ($\bar{e}^{ch}_{x,\,i}$) can be found in thermodynamic tables (Kotas, 1985). The molar chemical exergy of gas mixture is found from the following relation (Moran, 2000):

$$\bar{e}^{ch}_{x,f} = \sum_i y_i \, \bar{e}^{ch}_{x,i} \quad (5)$$

Where y_i is the molar ratio of the fuel constituent part. The molar chemical exergy of the combustion gases is obtained from the following relation (Moran, 2000):

$$\bar{e}^{ch}_{x,combustion} = RT_0 \sum_i X_i \, Ln\left[\frac{y_i}{y_i^e}\right] \quad (6)$$

Where y_i^e is the molar ratio of the environment elements and X_i represents the unknown coefficients calculated in the combustion process.

III. PINCH ANALYSIS

Pinch analysis is a methodology for minimizing energy consumption of chemical processes by calculating thermodynamically feasible *energy targets* (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as *process integration*, *heat integration*, *energy integration* or *pinch technology*. The process data is represented as a set of energy flows, or streams, as a function of heat load (kW) against temperature (deg C). These data are combined for all the streams in the plant to give *composite curves*, one for all *hot streams* (releasing heat) and one for all *cold streams* (requiring heat). The point of closest approach between the hot and cold composite curves is the *pinch point* (or just *pinch*) with a hot stream pinch temperature and a cold stream pinch temperature. This is where the design is most constrained.

Hence, by finding this point and starting the design there, the energy targets can be achieved using heat exchangers to recover heat between hot and cold streams in two separate systems, one for temperatures above pinch temperatures and one for temperatures below pinch temperatures. In practice, during the pinch analysis of an existing design, often cross-pinch exchanges of heat are found between a hot stream with its temperature above the pinch and a cold stream below the pinch. Removal of those exchangers by alternative matching makes the process reach its energy target. For further study this subject sees [2-5].

IV. COMBINED PINCH AND EXERGY ANALYSIS (CPEA)

By allowing the comparison of the quality of the different forms of energy, exergy is a rigorous way of analyzing energy conversion systems such as SPPs. In the context of process integration analysis, the exergy concept is combined with pinch analysis for reducing the fuel requirement and optimizing the Rankine cycle in SPPs. The Exergy Composite Curve (ECC) and Exergy Grand Composite Curve (EGCC) concepts have been introduced by Feng and Zhu (1997) for this purpose. For each linear segment in the CC, the heat Exergy delivered (e) by a stream delivering a heat load (Q) from the inlet temperature (Tin) to the outlet temperature (Tout) is computed by Eq. 12 [7]: Where, Tlm is the logarithmic mean of temperatures computed by Eq. 13.

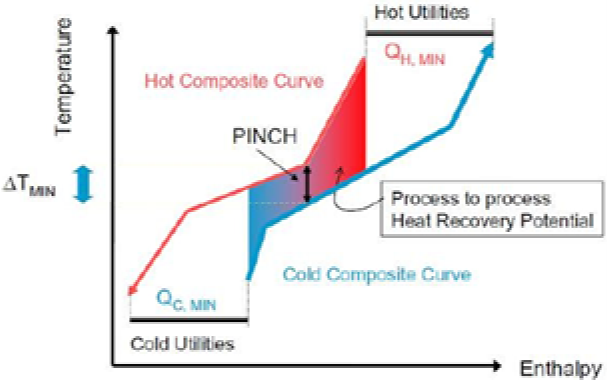

Fig. 1: MRE targeting with and hot CC

$$e = Q(1 - \frac{T_0}{T_{lm}}) \quad (7)$$

$$T_{lm} = \frac{T_{in}-T_{out}}{Ln(\frac{T_{in}}{T_{out}})} \quad (8)$$

When considering the hot CC, the heat delivered is represented by the T-H diagram; the exergy delivered is computed by replacing the temperature axis by the Carnot factor, as expressed in Eq. 14.

$$\eta_c = 1 - \frac{T_0}{T} \quad (9)$$

It then corresponds to the area between the CC and the enthalpy axis [7]. The same procedure is followed for the cold streams, to define the Exergy required by the cold streams [8]. Fig. 3 shows how the CC (T-H diagram) for a heat transfer System can be converted into the ECC and the EGCC. The shaded areas in Fig. 3 indicate the Exergy loss associated with the heat transfer process. The graphical representation of process units involving energy in terms of heat and power has been made possible with the introduction of a variable referred to as energy level defined as follows [7]:

$$\Omega = \frac{Exergy}{Energy} \qquad (10)$$

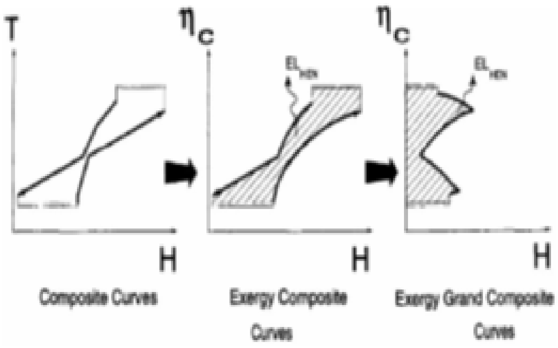

Fig. 2: Exergy transformation from CC to ECC and EG

Thus, for the work, □is equal to 1 but for the heat can be calculated as follows [7]

$$\Omega = 1 - \frac{T_0}{T} \qquad (11)$$

In the case of steady-state flow system, the _ is expressed as follows [7]:

$$\Omega = \frac{\Delta E}{\Delta H} \qquad (12)$$

In addition, all economic limitations and power generation process constraints can be considered in retrofit study of SPPs using CPEA [7]. To achieve this aim, ECC and EGCC as two basic tools of this combined analysis should be calculated. Data required for those plots can be extracted by simulation of the SPP using Cycle Tempo 5 (2006), which is powerful power plant simulation software [6].

V. NEW POWER PLANT OPTIMIZATION OPTION

Deregulation and privatization are requiring power companies to operate their generation assets more efficiently and cost-effectively, while at the same time, information-based economies are creating an increasing demand for energy. Because of this rapidly changing, often unpredictable environment, power generation facilities are looking for ways to do what once seemed impossible – comply with tighter air quality regulations while operating profitable, reliable, more productive plants. Among the most complex environmental challenges facing coal-fired power generators is the reduction of nitrogen oxide (NOx) emissions. NOx is a by-product of combustion – the hotter the flame temperature used in the combustion process, the more NOx the process produces. NOx emissions are also prevalent in industrial areas and regions of heavy automobile activity or traffic congestion. When combined with volatile organic compounds in hot stagnant weather, NOx emissions can lead to smog, or ground-level ozone pollution, which can cause respiratory problems in humans, particularly children and older people. When seeking NOx emissions cuts to avoid continual smog problems, regulators often look to coal-fired power plants for reductions. Traditionally, reducing NOx levels in a power plant, or from any industrial boiler application, is expensive. Equipment like low NOx burners, flue gas recirculation and selective catalytic reduction (SCR) can be costly. Fuel switching, blending or remediation can increase operating costs, and take the fuel handling equipment far off the design parameters. Additionally, NOx reduction equipment installation can extend scheduled outages beyond typical time frames. These often-lengthy outages and can result in lost revenue for a deregulated or privatized generator. In some plants, even expensive new equipment may not achieve compliance without extensive tuning and testing to meet NOx regulations, and other plants that are able to achieve compliance teeter close to the edge, certain to stumble into violations during peak energy-use seasons.

These peaks seasons can also correspond to Ozone compliance seasons further complicating the operation of the generation asset. Reducing the flame temperature in the boiler can also reduce NOx formed during combustion (prompt or thermal NOx), but this method is often costly as well. In most cases, reduced flame temperature means sacrificing boiler efficiency. Lower flame temperatures often result in higher loss on ignition (LOI) or higher levels of carbon in ash, causing plants to generate less electricity from the same amount of flame temperatures often result in higher loss on ignition (LOI) or higher levels of carbon in ash, causing plants to generate less electricity from the same amount of fuel. According to the Electric Power Research Institute (EPRI), even expensive low NOx burners can have unacceptable increases in unburned carbon. In today's competitive power marketplace, high LOI means increased fuel costs and can reduce the opportunity to market fly ash for other uses [9].

A. A Technological and Cost Effective Option

A number of years ago, engineers and scientists began working with neural networks, a type of artificial computer intelligence based on the process of how the human brain "learns." By applying the principals of learning to the complex, automated processes that produce electricity, a neural network system can "learn" or model the process. These models can be inverted to come up with strategies that can be used to refine controls, improving a process until it runs at the most efficient and cost-effective rate possible for the equipment. Operating experience over a wide range can expose the neural network to patterns that appear when NOx is the lowest. These patterns then can be categorized into a model of plant operations that reflect a desirable goal.

These models can then be analyzed for the components that contribute to the desirable goals, sometimes referred to as sensitivity analysis. This newly gained knowledge then can be applied to build or design a prediction model that can estimate the NOx levels. The modeled data then can be used to predict settings that would result in operating at the lowest NOx levels. Neural network technology, which becomes even more reliable when coupled with other advanced computer modeling techniques, such as statistical process control(SPC), data validation, sensor replacement data, and proven linear modeling techniques. This technology can help power plants achieve the critical balance between NOx reduction and boiler efficiency, further decreasing emission levels and increasing the life of combustion equipment – including expensive NOx reduction equipment added to the combustion system. Optimization software tools that employ this advanced computer technology feed plant set points, biases and other operating parameters directly into a power plant's main control computer or distributed control system (DCS). In the case of NOx emissions, software tools optimize the combustion process using conventional fuel-to-air relationships, secondary air registers, and over-fire air ports to affect the fuel-to-air ratio at each burner location. An optimizer working in closed-loop fashion stabilizes emission levels and provides constant process adjustments to provide more consistent and lower NOx levels. Optimizers can check and adjust numerous parameters affecting NOx production every few seconds, enabling the operator to oversee and troubleshoot all other operating processes in a generation facility [9].

B. What Optimization Can Really Do – Or Not Do

The 35 percent with the use of optimization software products. While optimization alone may not be enough to bring some plants into compliance, these software tools provide a low-cost way to achieve a reliable reduction based on which future compliance needs can be evaluated.

Optimization software, used in conjunction with other NOx reduction methods, can also create breathing room for plants anticipating the need for further pollution abatement. Through the emissions consistency gained through optimization use, plants may even see a longer life span for more expensive NOx reduction equipment. Some claims have been made for even higher rates of reduction – as high as 60 percent – but power plants should take a closer look at too-good-to-be- true claims. Many available software packages run "steady-state" optimization, or optimize parameters for NOx reduction only when the plant is operating at a steady rate of generation – not during a plant's naturally dynamic processes, such as startup, shutdown, load swings and dispatched operation. Deregulation and privatization will create increased revenue opportunities for traditionally base-loaded facilities that choose to follow dispatch regulation. With steady-state systems, NOx reductions are sporadic at best, and cannot claim to be consistent, continuous, stable or effective for compliance. For reliable reductions, power generators should require packages that are as dynamic as the facility itself. Generators should also consider prior applications of a manufacturer's optimization product at similar locations.

An optimization tool applied to an older coal-fired plant, perhaps one that has been mothballed for some time or one that has seen few modifications over the years, may appear to reduce NOx significantly. A closer look will show the software to be part of an overall NOx reduction plan that probably includes new process equipment, other pollution abatement tools like low NOx burners, or even an entire plant equipment retrofit As every plant operator knows, each power plant is different. Generation in different plants is affected by a different set of variables – both internal and external. Optimization software that can be tailored to meet the needs of each specific plant has a better chance of providing true NOx reduction and return on investment. Plant engineers and operators should be skeptical of optimization systems that arrive like off-the-shelf software, shrink-wrapped with installation instructions, assuming each steam generator operates under the same set of factors. There are times when the plant has been "de-tuned" to reduce maintenance work, or to reduce alarms from running near operational limits. The performance monitoring aspects of the plant come under scrutiny to insure a fair "before and after" evaluation of the results of an optimization package. The best optimization packages include manufacturer support for installation, service and maintenance related to generation issues and changes in the plant [9].

V. LIFE CYCLE COST OPTIMIZATION PROCESS

Availability and efficiency improvements at power plants can be achieved at the unit level by selectively improving component reliability, maintainability, or efficiency. However, implementation of a specific availability or efficiency improvement or series of improvements may not prove to be cost effective because the gain expected from implementing the improvement is less than the cost of the improvement or because of the imposition of outside constraints such as scheduled outage time and funding limits. The objective of the life cycle cost optimization process is to select those component improvements that will provide an increase in availability or efficiency and also reflect the greatest net benefit within imposed resource constraints (funding, schedule, manpower).The improvement life cycle cost optimization process employs a four-step iterative approach as illustrated in Fig. 1. The first step is to collect the information and data related to the improvements under evaluation. The second step is to apply an economic screening criteria and method to determine which improvement options are potentially cost beneficial. The third step considers various constraints such as funding limitations, outage schedules, and manpower limitations to further evaluate the candidate improvements. The final step of the approach is to evaluate surviving candidate improvements through a dynamic program algorithm to arrive at a sequence of improvements that provide the greatest net benefit within established constraints.

A. Data Collection

In order to implement the life cycle cost optimization process it is necessary to establish a relationship between the cost of implementing an improvement and the expected benefit of that improvement. That relationship is established by determining the cost of the improvement, estimating the expected increase in component availability resulting from that improvement, calculating the effect of the component availability change on overall unit equivalent availability or capacity factor and converting the change in unit equivalent availability into a benefit based on an increase in net generation revenue. To accomplish that, the following information is required: A listing of the reliability, availability, maintainability (RAM), and efficiency improvement options under consideration the cost required to implement each improvement option. The time required to implement each change for RAM improvements, the actual or estimated change in event frequency and/or downtime resulting from each improvement option for efficiency improvements, the expected percent increase in net revenue from either decreasing the fuel cost or in increasing net generation capability. An LCC simulation model and associated baseline data for the plant (or plants) to be evaluated:

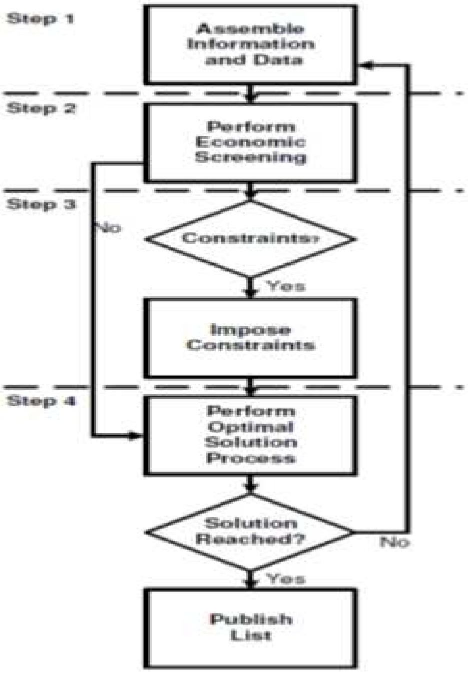

Fig. 3: Validity optimization Process

- The cost relationships between unit availability and costs such as replacement power, fuel, and operations and maintenance expenditures
- Identification of funding, schedule or other resource constraints
- Economic factors such as escalation, discount, and interest rates
- Unit production demand parameters (e.g., base load, cycling, peaking)

The LCC simulation model is used to assess changes in unit availability that may occur due to changes in component RAM characteristics so that the relationship between availability and production costs can be studied quickly and accurately. The need for information relating to constraints is required because the cost optimization methodology must be responsive to the possibility of limited capital, outage time, or the labor and engineering resources available for implementing improvements. This is especially true for improvement projects that must compete for funding.

B. Asset Management for Power Plants

As a consequence of the deregulation in the power industry, utility business units have been transformed from cost centers into profit centers. Whereas they previously had a budget and carried out projects, they are now charged with contributing to growth in corporate earnings. Whereas the justification of their budget was mainly based on engineering criteria related to Operation and Maintenance (O&M), they have become increasingly more focused on return-on-investment.

The primary task of asset management is to reduce negative surprises by identifying performance problems, improving predictive maintenance, extending asset lifecycles, and most of all, developing solid business plans for investments.

Today the utility business faces the challenge of aligning the management of their assets with corporate objectives. This requires engineering and economic tools as well as value-based decision-support. The strategic plan of a company defines the high-level goals and based on this, the business units setup their operational plans to achieve their targets. The asset manager sits between these functions and must therefore have comprehensive tools for decision-making about assets.

The key component in asset management is lifecycle costing, which implies cost minimization starting with the initial investment, continuing through O&M, and ending with recycling or phase-out. This approach requires asset plans to be linked to financial plans. In order to achieve this, the asset manager shall be able to carry out the following tasks:

- Monitoring the condition and performance of each asset.
- Having the key data of all assets available in real-time across the enterprise.
- Calculating asset lifecycle costs and the impact of asset failure.
- Linking trading decisions to O&M decisions.

This is only possible through informed decision-making. The asset manager shall not only receive data about specific assets, but shall also be able to translate that data into knowledge.

VI. CONCLUSION

The Pinch analysis and Exergy analysis concepts were used to design a power plant installation. Availability and efficiency improvements at power plants can be achieved at the unit level by selectively improving component reliability, maintainability, or efficiency. However, implementation of a specific availability or efficiency improvement or series of improvements may not prove to be cost effective because the gain expected from implementing the improvement is less than the cost of the improvement or because of the imposition of outside constraints such as scheduled outage time and funding limits. Among the most complex environmental challenges facing coal-fired power generators is the reduction of nitrogen oxide (NOx) emissions. NOx is a by-product of combustion – the hotter the flame temperature used in the combustion process, the more NOx the process produces. NOx emissions are also prevalent in industrial areas and regions of heavy automobile activity or traffic congestion. The result shows using this optimization method would be useful for reduce pollution and increase efficiency in industrial process.

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