Operational and Technical Limitations of the Generating Facility of GNPK

Technical Paper prepared by GNPower Kauswagan Ltd. Co. in view of the Current Status of its Facility and Compliance to Relevant Rules

Introduction

One of the most important concerns with respect to the generation, transmission and distribution of electricity is achieving efficiency. The ability to attain and maintain production economically largely depends on the methods of allocating loads, not only to the equipment in the power plant, but also to the generating stations of multiple units and to the entire system interconnected with transmission backbone.

In order to operate the power plant efficiently, the operator is confronted with the problem of selecting which equipment to be put on service while ensuring that the operations of any equipment will obtain the greatest possible efficiency that considers both the operational constraints and compliance to the requirement of the Grid to maintain the stability and resiliency of the system. Furthermore, the operator also faces challenges in avoiding prolonged downtime of the facility.

The old Market Management System (MMS) imposed a hard limit which is known as *Unit Commitment Model* on the Minimum Stable Load (Pmin) of each facility, thereby producing a schedule that is always equal to or higher than the operating limit of such facility. Thus, the Energy Regulatory Commission (ERC) requires the Certificate of Compliance (COC) to have a validated Pmin by conducting a Plant Capability Test. On the other hand, the *Unit De-Commitment Model* which is the New MMS allows any plant operator to manage the facility, particularly its minimum stable generation, in cases when its equipment will be constrained by the System Operator in order to maintain the integrity of the power system on a grid scale.

This technical paper provides the concepts, technical, and operational limitations of most coal-fired power plants.

I. ISSUES

The topics below shows the technical, and operational limitation of the GNPK facility which shall be discussed in detailed in Section II of this paper.

A. Understanding the Thermodynamic Cycle and Process of a Thermal Plant
B. The Deeper Meaning of Minimum Stable Load
C. Efficiency of 300 MW Boiler is not the Same as 150 MW Boiler
D. Flame Loss: Power Plant not Suitable for Supplying Extreme Fluctuating Load
E. The Problem of Resonant Whirl, Torsional Resonance and Frequency Excursion at Varying Low Load
F. Environmental Impact
G. Avoiding Cyclic Loading to Eliminate Thermal Shock
H. Accelerated Degradation of the Facility
I. Heat Rate Curve Versus Incremental Cost

II. DISCUSSION

The relevant issues presented below discusses the operational and technical constraints of GNPK facility and the characteristics of the mechanical and electrical components of the equipment.

A. Understanding the Thermodynamic Cycle and Process of a Thermal Plant

Steam Bypass is a procedure of discharging the generated steam by means of vent valves and/or atmospheric dump valves (sky valves) installed on the steam headers. The dumping of steam to atmosphere is not desirable as it results in loss of valuable condensate and also raises environmental concerns due to noise pollution. The steam bypass system is generally used during the following modes of operation: start-up and shutdown, steam turbine trip, steam turbine no-load or low-load operation. On sudden load drop of the generating unit the steam by-pass operation is executed to maintain a load without delay on ramping up again on the next interval should the load increase. In addition, a faster response of the Steam Turbine Generator (STG) is possible since the bypass system provides the capability of close temperature matching between the steam inlet temperature and the steam turbine metal temperature. This is achieved by continuous steam dumping to the condenser until the optimum temperature, pressure, and flow requirements are achieved for starting and loading the steam turbine. The combustion turbine remains loaded while the steam generated is gradually diverted to the condenser through the bypass system.

In case of a steam trip, the bypass system is placed in full service immediately. However, in a controlled shutdown, the STG load is gradually reduced and excess steam generation is diverted to the bypass system. The steam turbine can then be tripped at a reduced load and subsequently isolated. If the steam turbine is isolated while the load is comparatively high, the steam turbine metal temperatures remain high. This enables the steam turbine to be ready for a hot start, which is preferable because it minimizes start-up time and start-up stresses in the turbine metal. During the dumping and bypassing of the steam, GNPK loses valuable condensate and generates noise as well as vibration. During the transition of sudden load drop, the plant operators are obligated to perform steam diversion to maintain the balance of the frequency at a cost not recoverable and not entitled for additional compensation in WESM.

B. The Deeper Meaning of Minimum Stable Load (Pmin)

The economy of operation of a turbine is affected by the temperature of the steam supplied to the throttle. A decrease in temperature due the implementation of steam by-pass because of sudden aberration of load towards less than the minimum stable has a detrimental effect to the performance of the turbine mechanism. Consequently, although two boilers maybe operating in parallel with equal efficiencies, if their respective steam temperatures are not the same, the steam at a lower temperature has less efficiency. The minimum steaming rate at which a boiler will be operated such as those stoker-fired boilers, the more important factors which usually determine the minimum steaming rate are the ability to maintain satisfactory fuel-bed conditions, the efficiency, and the responsiveness to sudden demands which may be made upon the Boiler while operating at a low load.

For a boiler burning pulverized coal with low size, the minimum rate of operation depends upon the minimum burner capacity required for *"flame stability"* and whether or not the burners can be cut out and resulted to *"flame loss"*. As such GNPK facility operates on N + 1 contingency mode on the required burners and mills for stable operation even at minimum steaming where N is the number of burners and mills.

Since the maximum generation requirement in Mindanao has never been established for thermal plants, proper banking sequence and for the calculation of incremental rate curves were also not established properly. During the daily operation of the facility, GNPK implements *"banking"* practice. The purpose of this is to eliminate the necessity of operating boilers below their minimum steaming rate daily and thus increasing the boiler-room efficiency of running unit/s. The "*banking*" practice merits careful analysis of the behavior of the generator, turbine and the boiler. Banking involves the operation of a boiler with no steam output. The resulting loss will depend on the manner of *banking*. If a boiler is operated with the thought in mind that it may suddenly be called upon to generate steam, then sufficient fuel is burned to maintain the boiler pressure at or slightly under line pressure. Under these conditions, the boiler is said to be operating at a live bank.

These, however, must be coordinated with GNPK's Trading Team and exercise the "Reserve Shutdown" mode, the state in which a Unit is available but not in service or not electrically connected to the grid. This also includes Generating Plants/Units that are Available but not scheduled in the WESM. This mode of operation can be successfully implemented by opening the generator breaker. **Closing the breaker would necessitate a higher level of generation to maintain the normal power flow,** the excitation system alive, and avoid reversal of power; i.e. generation voltage must be higher than the grid. Intermittency of firing of burners required to maintain the boiler at a live or steam banking will produce a loss by consuming fuel necessary to maintain the boiler at the required condition.

The plant operator know that the boiler cannot handle sudden demands for steam, it may be operated at a pressure considerably less than the line pressure. Hence, when the boiler is thereafter brought up to line pressure and to steaming condition, additional heat will be required to bring the settings back to normal operating temperature. The very low load of the running unit will result to extreme stressing of the mechanical components of the machine and thus, loading below minimum steaming was not recommended by Siemens.

Table 1 shown below is the historical dispatch of the active unit, by performing a *Unit De-commitment Optimization Model* in a controlled environment, and allowing the remaining unit to have the same incremental cost, it will result in a load distribution shown in Table 2 and Table 3 below.

Table 1 – Original Optimization Run (result from NMMS)

Dispatch Level	Unit 1	Unit 2	Unit 3	Unit 4
</= 78	53.80%	63.50%	57.89%	48.29%
>78 - </= 115	14.37%	15.66%	19.15%	16.62%
>115 - </= 152	31.82%	20.84%	22.96%	35.09%

Table 2 – When all the Units are Running (Unit Commitment Model)

Dispatch Level	Unit 1	Unit 2	Unit 3	Unit 4
</= 78	73.49%	86.54%	85.06%	73.36%
>78 - </= 115	26.36%	13.35%	14.83%	26.49%
>115 - </= 152	0.15%	0.11%	0.11%	0.15%

Table 3 – When all the Units are Running (Unit De-Commitment Model)

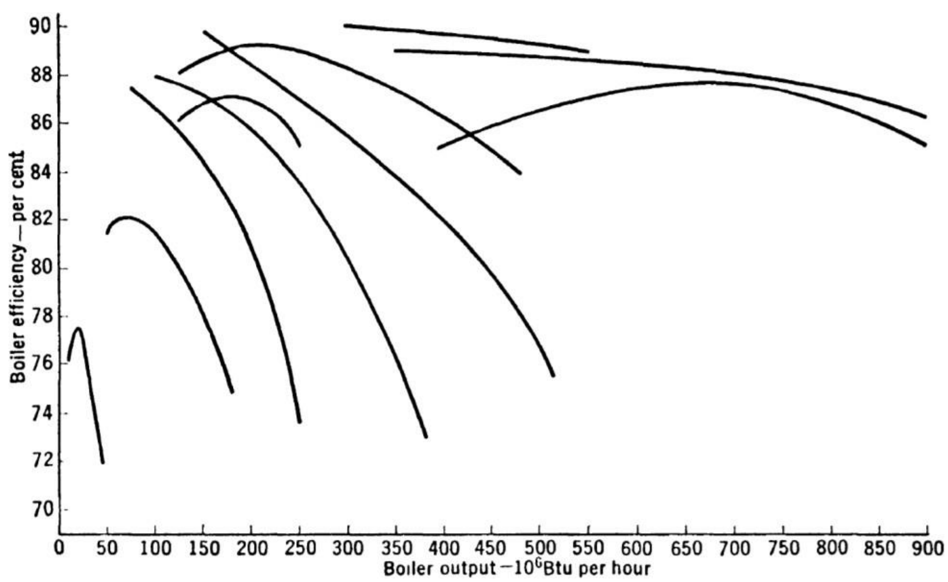
Dispatch Level	Unit 1	Unit 2	Unit 3	Unit 4
</= 40	13.39%	13.88%	13.92%	12.84%
>40 - </= 75	58.60%	70.80%	68.86%	58.51%
>75 - </= 115	27.86%	15.21%	17.10%	28.51%
>115 - </= 152	0.15%	0.11%	0.11%	0.15%

Analysis revealed that when all the units are running at *a Unit Commitment Model* all the generating units of GNPK are running at Pmin level at 80% of the time while on *Unit De-Commitment Model* all the generating units of GNPK are running below Pmin level at 77% of the time. It is thus evident that *a Unit Commitment Model* will force more volume under the constrained limit and this leads to an increasing amount of low and negative prices in the WESM, which results from non-responding conventional power plants, especially coal-fired power plants, during low residual loads causing an irreducible minimum of conventional feed-in. The MMS is only designed as an optimization for short start-up times, it does not capture the operational stability and fuel constraints of a particular thermal plant. As the power output of the generation units is influenced by boiler stability, running the plant below and at Pmin level for longer period of time will result to component failure, creating unwanted vibrations, and degrade the performance of the machine over time which will lead to forced outages.

C. Efficiency of 300 MW Boiler is <u>Not the Same</u> as 150 MW Boiler

The problem of the boiler loading is natural result of the advancement in the art of boiler design. In the early days of the industry, it was common practice to install a large number of relatively small boilers of uniform design and performance characteristics. For a high demand system, loading of these machines does not ordinarily exist since the boiler will have a maximum efficiency. Larger and more efficient boilers installed in Luzon such as those 300, 350 and 440 MW coal plants will load the boiler efficiently at a base utilization. It was logical to assume that more efficient boilers should generate a greater proportion of the load when there is a demand. With a smaller rating on the other hand, operating the unit with extreme variation, numerous fluctuations and excursion due to low system demand requirement becomes a challenge to both the plant and System Operator. Of course, it is easier from the point of view of the Market Operator to produce an optimal schedule in a *Unit De-Commitment environment*, the solution is actually a *"Local Sub-Optimal Solution"*. The *"Boiler Efficiency Curve"* as shown in Figure 1 below shows the characteristics of the boiler and is generally expressed as a function of boiler output which can be indicated by the nominal rating of the boiler, quantity of steam delivered by the Boiler, and heat absorbed by the boiler. The Boiler Efficiency Curve represents the most important data, and its accurate determination is essential and vital in analyzing the level of comfortable dispatch specially for smaller units.

Figure 1 – Boiler Efficiency Curve



The boiler output is calculated as product between the steam delivered to the boiler and the difference between the enthalpy of the steam delivered by the boiler and the enthalpy of the feedwater supplied to the boiler and thus higher capacity thermal plant has a different performance on those smaller units. The "*Boiler Efficiency Curve"* should be used for load division purpose, one which represents the performance of the Boiler under actual operating condition. This is not easily obtainable even when adequate test facilities are available. GNPK has adopted the *"Boiler Loss Method"* in modelling the performance curve, however, the sensor and instrumentation required for the complete model are not yet put in place, thus, approximations on the empirical formula are still adopted. The lessons learned and the established parameters by the PEMC-ECO in Luzon should therefore not be used to evaluate and assess the performance of similar technology but should use parameters suitable for smaller rating such as the 138MW (net) of GNPK, and other comparable units.

D. Flame Loss: Power Plant not Suitable for Supplying Extreme Fluctuating Load

Flame stability can be an issue at low loads, increasing the risk of a boiler trip if the flame detection fails. If the flame stability is a problem during dynamic load changes, the problem may be solved by modifying the primary and secondary air control loops and this feature are not in place in GNPK. If flame instability is observed in stationary operation, a solution may be to reduce the number of mills in operation to one, accepting the increased risk of a unit trip, thus increasing the number of mills in operation in redundant mode will avoid significant unit tripping.

Maintaining a good flame in a boiler is the key to a good boiler performance. Unstable flame is always a threat for boiler furnace explosion, which can lead to a large outage of the boiler and economic loss. When a flame failure occurs in a boiler, the plant operator and the engineering team will have to act immediately and bring the boiler back on line with all safety taken in to consideration. It is always seen that the greatest number of explosions in boilers takes place during start-up and shutdown. It is during this period that the probability for unburned to accumulate in flue gas path of the boiler is very high. Hence, it has become a practice of all boiler designers to interlock purging the boiler with boiler start-up.

Flame failure in a boiler can be due to many reasons and one of the most common is sudden reduction in the mill feeders to a minimum due to very low load. Flame stability is not an issue in fluidized bed boilers and the characteristic of the pulverized coal should not be compared to fluidized bed technology. In order to maintain the stability of the flame during the low to very low load, the plant operator may use an expensive solution, that is, assisting the primary fuel with bunker fuel oil. The cost, however, cannot be recovered to GNPK off takers nor entitled for additional compensation by the WESM. A thermal power plant is not well-suited for supplying a fluctuating load because it is a large-scale power generation facility that is designed to operate at a consistent and steady output level. The power output of a thermal power plant is difficult to adjust quickly in response to changes in demand, as the process of generating electricity from heat requires a significant amount of time and energy. Additionally, GNPK units are not equipped with the necessary controls and systems to respond quickly to changes in load, so they are not well-suited for supplying a fluctuating load amount of variation they can handle. A coal-based plant has a higher time constant and thus responds slowly and has a lower ramp rate, generally a thermal plant can vary 30 to 40 MW within a single block (i.e 15 min). Changing the steam pressure and quantity takes time.

E. The Problem of Resonant Whirl, Torsional Resonance and Frequency Excursion at Varying Low Load

Resonant whirl is the condition whereby a rotor is resonating at a frequency equal to its own running speed. Rotors can resonate to frequencies other than those equal to their operating speeds (they would be resonant, not in resonant whirl) relatively long, smaller diameter, higher speed armature is subject to resonant whirl. Such armatures usually have operating speeds of approximately 3600 rpm or higher at 60 Hz. In such situations, the rotor produces the same exaggerated flexing or "curling" mode shape as for non-rotating part resonances. But instead of flexing back and forth and reversing its stresses, the rotor simply rotates with this continuously "bent" shape. There is no flexing back and forth and, therefore, no reversible stresses. For example, if a rotor is running resonant to its own 1st critical speed, its mode shape will be the same as for any other part resonating at its 1st resonance frequency. To visualize this, mentally bend a wire into that shape, then rotate it.

One way that torsional resonance can occur is if the turbine generator is allowed to operate with unbalanced load on the generator terminals while it has a torsional mode with a frequency close to twice the grid frequency. The unbalanced load can result in a steady oscillating negative sequence current torque at twice the grid frequency that can cause significant damage to the turbine-generator if it has an excitable torsional mode with a frequency too close to that of the exciting torque.

F. Environmental Impact

Flue gas temperatures at low loads are also expected to be low. Temperatures less than 110 deg C will result to automatic bypass of baghouse. This bypass is a protection for the filter bags and the whole system from corrosion attack due to condensation of acid in the flue gas. Bypass of the baghouse means emitting total suspended particulates and particulate matter into the environment.

Operating the four units at low loads, contributes to a higher consumption of resources like the coal, demineralized water, and chemicals for wastewater treatment since the boilers should operate at their minimum requirements. In effect, the air emissions and water discharges are not kept at the lowest possible quantity.

G. Avoiding Cyclic Loading to Eliminate Thermal Shock

Of all the modes of boiler failure, thermal shock seems to be the one that can happen at any time. It is thus important to understand exactly how thermal shock destroys a boiler because there are several situations that are called thermal shock that aren't consistent with the normal perception. Thermal shock can destroy a boiler in a single incident or it can take several shocks to produce evident damage. There is a specific combination that must exist for thermal shock damage. First, the metal of the boiler (or refractory) must be exposed to a change in temperature that's enough to produce a range of stress in the material. Sudden erratic changes in the load from minimum steaming, below minimum stable load, and increasing again on the next trading interval is catastrophic to the boiler performance. The second important element of thermal shock is thickness of the material. When the metal is thin enough, the difference in temperature across it is not adequate to produce enough stress to produce cracking. The thicker parts of a boiler, tube sheets, shells, and drums are more susceptible to thermal shock than the tubes. The third element is frequency. One violent shock may not be good for a boiler but hundreds of little ones repeatedly occurring will eventually result in failure because tiny micro fissures (very little cracks) that form in thinner metals or where the temperature differences are not dramatic will, if constantly bombarded with thermal shock conditions, eventually grow into large cracks that finally result in boiler failure. Any boiler that trips while running at high fire and immediately goes into a purge is subjected to thermal shock because the metal of the boiler's heating surface is immediately subjected to contact with cold purge air right after it was exposed to the hottest flue gas of normal operation. Add to that the trip occurring near the maximum operating temperature (and related pressure) and there's potential for failure.

H. Accelerated Degradation of the Facility

Operationally speaking, firing a boiler to keep one on standby is inefficient and bad for the boiler. Boilers do shut down unexpectedly and loss of pressure or temperature will happen and running another boiler on standby and anticipate the failure of the running boiler. A very good analogy of this scenario is like bending a wire, you can't break a wire by bending it once but bending it repeatedly can cause stress on the nick portion. As far as Boiler is concerned doing more damage to your standby boiler by running the pressure up regularly than you would if you poured the fire to it to get it up to pressure from a dead cold start the one or two times in its life that was necessary. The damage to the boiler and fuel consumption for keeping it hot normally outweigh any advantage of keeping it hot by regularly warming it up. On the other hand, the maintenance of pressure or temperature may be so critical that loss of a boiler is unacceptable. There is simply no way to justify the concept of keeping a boiler on hot standby by firing it regularly. The only means of maintaining a hot standby is when the facility has a convection heaters and blowdown transfer. By installing a heating coil in the bottom drum of a boiler or installing a heat exchanger, circulator and piping connecting the blow off and feedwater to heat the boiler water using steam from operating units you can keep a boiler hot enough that it can be brought on line as fast as one that's fired to keep it warm. Blowdown transfer uses the continuous blowdown from operating boilers to keep an idle boiler hot. Depending on the amount of blowdown it's possible to keep more than one boiler in hot standby without firing them. GNPK doesn't have this type of facility because of its size. Either of these methods doesn't apply heat to the refractory so some minor refractory damage may incur if a standby has to be brought on line immediately but the pressure parts will be uniformly heated and the boiler will come on line quickly without danger of stress cracking. Notwithstanding heating up a boiler to maintain a standby is a waste of fuel, it increases environmental pollution and it damaging to the equipment. Plants with multiple heating boilers and just because the pressure gauge shows the same pressure as operating boilers doesn't mean the boiler is hot. Steam from the operating boilers will flow to an idle boiler. A power boiler with a leaking non-return valve can hold a head of steam. The problem is that pressure and temperature is only above the water line; everything below can be dead cold, and in one case was actually freezing. For the same reasons that water circulates in a boiler when it's firing it will stagnate when it isn't. Some Boilers that show pressure where it reaches down and touch the bottom drum or a portion of the shell and find it cold, a boiler in that situation is not a hot standby, it's a bunch of thermally distorted steel. Any rapid changes in the water level can result in stress cracking of the drum or shell and tube sheets. Systems that simply drain the condensate off at the surface of these boilers maintains an artificial state that is dangerous. Those boilers should either be allowed to flood, so they're all cold, with the condensate removed in a section of piping above the boiler, or isolated and put in lay-up properly. It's not too expensive to replace a piece of piping compared to replacing a boiler. This activity exacerbates the technical anomaly of the equipment which resulted to accelerated degradation of the equipment and early maturity of the facility. The Mindanao grid need a reliable source of electricity in order to sustain the economic progress and GNPK are one of those generation resources that can provide this objective, it just need stable operation.

I. Heat Rate Curve Versus Incremental Cost

The incremental rate of a generating unit at any given output is mathematically equal to the partial derivative of the cost with respect to the incremental output or numerically the slope of Input-Output Curve. It measures the rate of change of the input with respect to the output. Heat rate in the context of power plants can be thought of as the input needed to produce one unit of output. It generally indicates the amount of fuel required to generate one unit of electricity. An example of Heat Rate is presented below;

Figure 2 – Heat Rate as a Function of Thermodynamic Parameters

$$\text{Plant Gross Heat Rate} = \frac{+\;\begin{matrix}2099457F \times 3410.4H - 2099457F \times 1327.7H \\ 1716739F \times (3597.6H - 3000.6H) + 2923F \times (3597.6H - 730.0H)\end{matrix}}{728{,}078\text{ kW} \times 85.85\%} = 8{,}648.72 \text{ kJ/kWh} \quad \eta=41.62\%$$

$$\text{Plant Net Heat Rate} = \frac{+\;\begin{matrix}2099457F \times 3410.4H - 2099457F \times 1327.7H \\ 1716739F \times (3597.6H - 3000.6H) + 2923F \times (3597.6H - 730.0H)\end{matrix}}{665{,}178\text{ kW} \times 85.85\%} = 9{,}466.57 \text{ kJ/kWh} \quad \eta=38.03\%$$

P : Pressure (bara)
T : Temperature (°C)
F : Flow (kg/h)
H : Enthalpy (kJ/kg)

These Heat Rate curve is associated with the I/O Cost Curve by the sample empirical formula below;

$$C(P) = \alpha P^4 + \Phi P^3 + \theta P^2 + \omega P^1 + k$$

The semi cubical (4^{th} degree for smoothing) parabola model expresses the resulting cost of a certain generating unit given the Thermodynamic equivalence of the Fuel (Pressure, Temperature, Flow, Enthalpy, among others) injected to the boiler. If it were necessary to increase the total output by 1 million BTU per hour, then the additional or incremental fuel must be injected producing an increase in the Thermodynamic quantities and thus increase in energy. The power output of a coal power plant is difficult to adjust quickly in response to changes in demand, as the process of changing the load considers the slew heat rate and requires a significant amount of time, thus reduction of load on the next trading interval already compromise the already converted steam injected prior to the targeted interval thus forcing the *"Steam Bypass Procedure".*

SUMMARY AND CONCLUSION:

In view of the detailed discussion of the technical and operational limits of GNPK, GNPK respectfully prays for the Rules Change Committee to consider these limitations in the WESM Rules and Manuals to protect its consumers by considering the viability of the facilities of the power suppliers.