CONF-960306--9

BNL-62067

TECHNICAL CONSIDERATIONS IN REPOWERING A NUCLEAR PLANT FOR FOSSIL FUELED OPERATION

Francis J. Patti
Reactor Division
Brookhaven National Laboratory
Upton, N. Y.

ABSTRACT

Repowering involves replacement of the reactor by a fossil fuel source of steam. This source can be a conventional fossil fueled boiler or the heat recovery steam generator (HRSG) on a gas turbine exhaust. The existing steam turbine plant is used to the extent possible.

Alternative fuels for repowering a nuclear plant are coal, natural gas and oil. In today's world oil is not usually an alternative. Selection of coal or natural gas is largely a matter of availability of the fuel near the location of the plant.

Both the fossil boiler and the HRSG produce steam at higher pressures and temperatures than the throttle conditions for a saturated steam nuclear turbine. It is necessary to match the steam conditions from the new source to the existing turbine as closely as possible. Technical approaches to achieve a match range from using a topping turbine at the front end of the cycle to attemperation of the throttle steam with feedwater.

The electrical output from the repowered plant is usually greater than that of the original nuclear fueled design. This requires consideration of the ability to use the excess electricity.

Interfacing of the new facility with the existing turbine plant requires consideration of facility layout and design. Site factors must also be considered, especially for a coal fired boiler, since rail and coal handling facilities must be added to a site for which these were not considered. Additional site factors that require consideration are ash handling and disposal.

FUEL AVAILABILITY

The potential fossil fuel choices for repowering a nuclear powerplant are oil, natural gas and coal. In today's world oil is not a viable choice, primarily because of cost and availability as a fuel for large powerplants. Further, some countries prefer to use it as an export which can provide foreign exchange. Therefore, the choice is largely between coal and natural gas. Since a repowered plant is already on a site, the availability of the fuel relative to the site must be evaluated. In the case of coal:

- Do the existing mines have sufficient capacity for the life of the plant?
- Will development of an additional mine be required? - At what cost?
- Is an appropriate means of transport - rail or barge - available? If not, what is the cost of transport development?

Natural gas has wide availability, but this must be evaluated in terms of the plant location. It will generally be delivered by pipeline. However, the pipeline must be evaluated in terms of its ability to meet the needs of the repowered plant in addition to those of the current consumers. This may require consideration of a new pipeline dedicated to the repowering.

TURBINE CYCLE

The turbine cycle is the starting point for developing the approach to repowering. Steam for the turbine cycle is derived from fossil fuel, from either the HRSG of a set of gas turbines or from a fossil fueled boiler. This presents several significant challenges to the designer. The first is to match the steam conditions of the new steam source to the throttle conditions of the existing turbine. In doing this, it must be kept in mind that steam turbines for a nuclear plant are designed for saturated steam throttle conditions in the vicinity of 540 F and 950 psig. Fossil fueled steam sources for electrical power generation usually operate at significantly higher pressures and temperatures that are in the superheat region. This improves the heat rate (efficiency) of the power cycle, which is important for the more expensive fossil fuel. The second challenge, is to utilize as much of the existing turbine plant equipment as possible. While doing this, the designer must strive to obtain the best turbine cycle heat rate possible, consistent with the additional investment to repower.

The variations cover a wide range of possibilities. They can range from various simple approaches to complex ones which alter the nuclear plant feedwater cycle or replace the high pressure turbine of the nuclear plant with a new steam turbine that provides a better match between the higher pressure and temperature of the new steam source and the low pressure sections of the nuclear turbine. While intricate approaches improve the turbine cycle heat rate, they add to the capital cost of repowering. For the purpose of illustration of technical considerations, this paper is limited to less complicated approaches.

Gas Turbine Combined Cycle (GTCC)

In this approach multiple gas turbines are used in combination with HRSGs that utilize waste heat from the gas turbines to generate steam. The steam drives the existing nuclear cycle steam turbine-generator. The gas turbines also drive electrical generators. Consequently if the full output of the original steam turbine is developed, the electrical output of the repowered plant will be greater than that of the original plant.

A range of variations on the basic approach are possible. Some possibilities are:

- Supplementary firing of the HRSGs. This reduces the number of gas turbines required to produce the steam flow to match the flow of the nuclear cycle turbine.
- Topping steam turbine. This turbine is located between the HRSGs and the existing nuclear cycle turbine. It provides better utilization of the energy in the steam from the HRSG.
- Low pressure auxiliary turbine. This turbine utilizes low pressure steam available from the HRSG. Alternatively, this turbine can be shut down during the winter and low pressure steam can be used for district heating.

Various gas turbine options are combined in a single schematic diagram in Figure 1. Four possible options, based on this schematic are identified by the alternatives tabulated in Table 1.

The cases considered in this table do not include use of low pressure steam for district heating or process purposes. If this were done, the output of the low pressure turbines would be reduced by an amount corresponding to the steam that is diverted. In the extreme case none of the steam would be used in the topping turbine. The first two cases do not have a topping turbine. Hence, the gross power generated is somewhat lower than the cases with a topping turbine. In these cases, the heat rate is higher (poorer) than in the cases with a topping turbine. This is to be expected since a cycle with a topping turbine utilizes more of the energy in the steam. The cases with supplemental firing do not require as many gas turbines, because some of the steam for the nuclear cycle turbine is produced by the fuel fired in the HRSG. Thus, they have the lowest gross power output of the cases considered. On the other hand, the cases with supplemental firing have the poorest heat rate, because the fuel is fired in the steam generator and its energy does not contribute to the gas turbine cycle.

In order to match the steam flow of the nuclear cycle turbine, a large number of gas turbines are typically required, even with relatively large (222 MWe), gas turbines. For this reason, Table 1 shows that the electrical output of the repowered unit is from 2.9 to 4.6 times the output of the original nuclear unit. This requires that there be a demand for the increased output. Otherwise, fossil power conversion is not a viable option.

Gas turbines, such as those considered in this application are standard components in electrical generating systems. The modular features of these units, together with integration of auxiliaries and controls, simplifies installation and permits a relatively short construction schedule. If needed to meet power demand, the gas turbines can be brought on line prior to connecting the steam lines to the nuclear cycle turbine.

Fossil Fueled Boiler

Fossil fueled boilers could either be gas fired or coal fired. For gas firing the constraints on supply previously discussed are applicable. However, fossil fueled boilers are most frequently thought of in terms of coal firing. They will be considered in this context in this paper.

Design of a saturated steam fossil fueled boiler is not current conventional boiler practice for boilers of the size that can provide the required steam flow for a large nuclear turbine. From the standpoint of steam produced by the boiler, there are two viable options in terms of current boiler practice. The first is a subcritical boiler producing 1000 F steam at 2400 psi. The other alternate is a supercritical boiler producing steam at about 3500 psi. The latter alternative has a significantly better heat rate than the first and is considered further. In the size range under consideration, the steam can be produced by two boilers and possibly one. Steam leaving the supercritical boiler is at a significantly higher pressure and temperature than the conditions acceptable at the throttle of the nuclear turbine. Therefore, a high pressure topping turbine is located between the boiler and the nuclear cycle turbine. This turbine drives its own generator which provides electrical output in addition to that obtained from the nuclear turbine- generator.

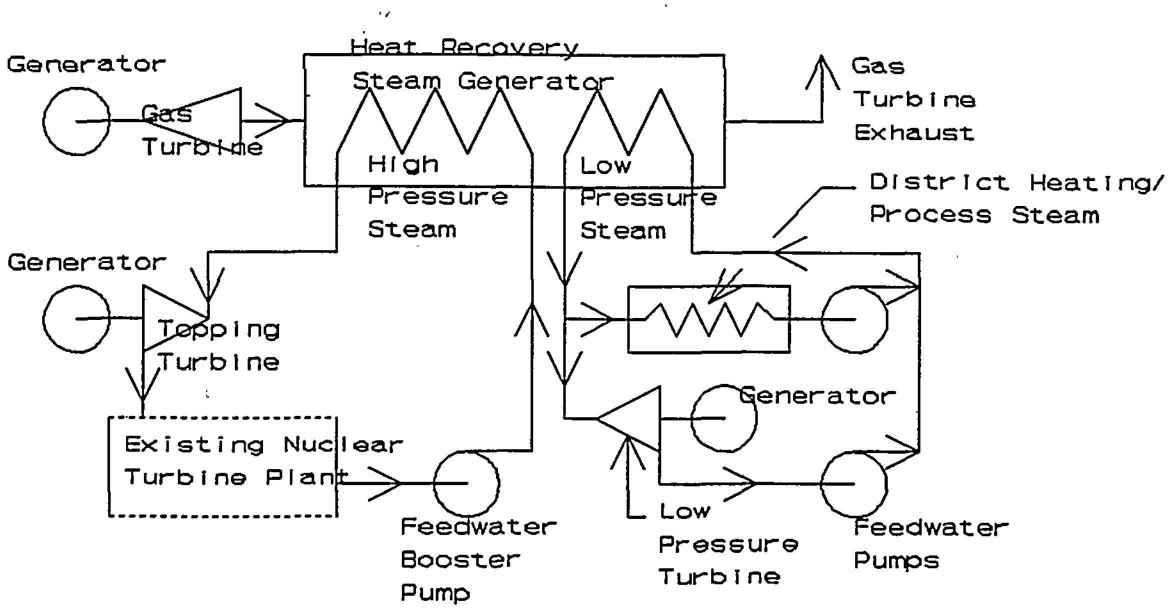

Figure 1 Flow diagram for gas turbine combined cycle

Table 1

GAS TURBINE COMBINED CYCLE
MAXIMUM POWER OPERATION
Low Pressure Steam is Used in Low Pressure Turbine

Alternate	Number GT/HRSG[1]	Nuclear Turbine, MW	GT Gross Output, MW	Low Pressure Turbine, MW	Topping Turbine, MW	Gross Power, MW	Gross Heat Rate, BTU/kWh
1	13	1025	2886	230	0	4141	7551
2	8(SF)[2]	1005	1776	140	0	2921	8856
3	14	1010	3108	210	280	4608	7307
4	9(SF)[2]	1035	1998	125	280	3438	8464

[1] Gas turbines drive generators rated at 222 MWe
[2] SF = Supplemental firing

As in the case of the gas turbines, there are numerous turbine cycle variations. Two of the simpler cases are shown in Figures 2 and 3 for illustrative purposes. These

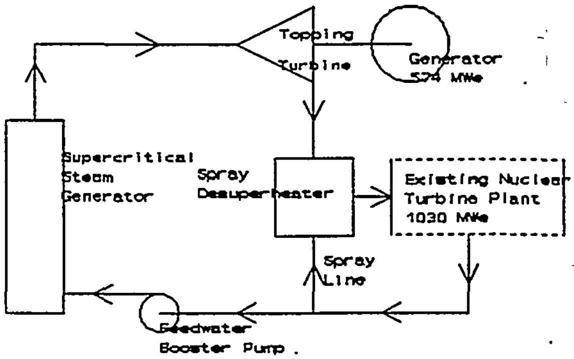

Figure 2 Flow diagram for supercritical boiler with spray desuperheater

reflect the possibility that even after passing through the topping turbine, the steam conditions may still exceed those which are compatible with the nuclear cycle turbine. One approach to resolving this matter is to desuperheat the discharge from the topping turbine in a spray desuperheater with a portion of the feedwater being returned to the boiler as shown in Figure 2. An alternative is to utilize a regenerative desuperheater to bring the topping turbine exhaust to saturation conditions. With this approach, shown in Figure 3, the topping turbine exhaust steam is used to heat feedwater returning to the supercritical steam generator. In a sense, this approach alters the feedwater cycle without physically modifying the feedwater train in the turbine plant.

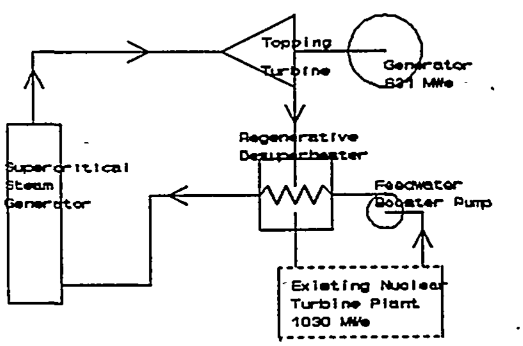

Figure 3 Flow diagram for supercritical boiler with regenerative desuperheater

Comparing these figures shows that the cycle of figure 3 generates about 57 MWe more than the cycle of figure 2, a significant amount. The net plant heat rate for the spray desuperheater case of figure 2 is 9890 Btu/kWh while that for the desuperheating feedwater heater of figure 3 is 9742 Btu/kWh. These heat rates correspond to overall plant efficiencies of 34.5 and 35.0%, respectively. While this difference may seem small, it corresponds to a difference in steam flow of 1.35 million pounds per hour. The lower steam flow rate corresponds to the more efficient cycle of figure 3. This difference in heat rate reflects a substantial fuel cost savings, when considering that several million tons of coal are required each year.

In both of these cases the total plant electrical output is about 150% of that of the nuclear unit operating as originally designed. This is substantially less than in the gas turbine option. But it still represents an increment of generation that must be addressed.

Because the steam generator of a nuclear plant operates at about 1000 psia and the supercritical boiler operates at about 3500 psia, the feedwater pressure must be raised by approximately 2500 psia if a supercritical boiler is used for repowering. This requires a feedwater booster pump in the turbine cycle. Pumps in this size range are generally turbine driven, with steam for the turbine being extracted from the main steam cycle.

Repowering with coal introduces a number of significant considerations beyond the turbine cycle. Among them are pollution control, coal handling and ash disposal.

EXCESS ELECTRICAL OUTPUT

As noted above, full utilization of the nuclear steam turbine results in significantly greater electrical output than would be produced if the unit were operating strictly in the nuclear mode. In the case of the GTCC, the total output of the facility can be approximately three times that of the nuclear unit alone. In the case of the fossil fired boiler, the total facility output is approximately one and one-half times that of the nuclear unit alone. For both cases, it is necessary to find a suitable market for the excess output. This is a more significant problem for the GTCC alternative. If the plant to be repowered is the first unit on a multiunit site, it may be possible to justify the output for even the GTCC alternate and delay or abandon building the additional units. For a country or an area in which electrical power is in short supply, the excess electrical output may be effectively utilized. In either case, it is necessary to expand the switchyard to put the extra generation out over the transmission system. Consideration may also have to be given to modifying the transmission system external to the plant to deliver the additional power.

If the power generated cannot be effectively utilized, another use must be found for the excess steam or the generation must be cut back. Excess steam may be used for process heating, if the power plant is close to an industry, such as a chemical process plant, which can utilize the steam. Alternatively excess steam may be used for district heating if there is a need.

The final situation occurs if the excess electrical power or steam cannot be used. Then, it may be necessary to abandon consideration of gas turbine repowering. If coal is also available at this location, it is a possible alternate. Even the coal fired steam boiler cycle will produce excess electrical power. However, it is not as much and provides an easier opportunity to remedy the situation. As an example, replacing the high pressure turbine of the nuclear cycle turbine with a turbine that provides a better match between the boiler steam conditions and the nuclear cycle turbine could reduce the excess electrical output, while at the same time improving the heat rate. If none of these alternatives provides the means to match the electrical output to the system needs, then the steam flow to the nuclear cycle turbine must be reduced and the nuclear cycle turbine must be derated.

SITE CONSIDERATIONS

Repowering a nuclear unit to use fossil fuel is much more than simply examining turbine cycles and electrical output. Both the GTCC and the fossil fuel boiler alternatives have site impacts that must be considered.

Steam Source

Whether the steam source consists of several gas turbines or a fossil fueled boiler, they require space on site. Further, consideration must be given to routing of steam lines to the nuclear cycle turbine. This requires particular care, since existing facilities, including the reactor building, may impede optimum routing. Consideration must be given to the space requirements for any topping turbine that is used, since generally space will not be available in the same building as the nuclear cycle turbine. Finally, attention must be given to the design of buildings to enclose the gas turbines, topping turbines and boilers, unless climatic conditions permit an outdoor installation.

Pollution Control

For gas turbines pollution control does not require special consideration with respect to the site. The major pollutant is NO_x. In modern gas turbines this is controlled by burner and combustion chamber design.

For coal fired plants, pollutants emitted from the stack that must be considered are particulates, SO_2 and NO_x. All of these pollutants have space requirements associated with the site. The particulates require either electrostatic precipitators or baghouses to collect flyash. Once collected flyash must be disposed. Sometimes flyash, can be incorporated as an ingredient in concrete and the disposal problem is alleviated. Sulfur dioxide is removed from the flue gas by a chemical process called scrubbing. Scrubbers have significant space requirements between the boiler and the stack. Lime storage is required on site for the scrubbing process. The scrubbing process produces a significant amount of waste calcium sulfate sludge. The sludge usually requires disposal. If space is not available on site, it must be transported off site. Depending on the flue gas desulfurization process, it may be used to make gypsum for wallboard. In addition to burner control urea or ammonia is used to control emissions of NO_x. On-site space is required for reagent storage for this operation. Fortunately, the reaction products are water vapor and nitrogen which do not require disposal.

Although not a pollutant in the conventional sense, bottom ash is produce in coal fired plants. This is normally sluiced to an ash pond on site, where it remains or is transported off-site for disposal. Along with these, coal pile runoff must be collected, neutralized and treated to remove the coal dust.

Coal Handling

A large coal fired power plant burns several million tons of coal per year. This coal must be delivered, stored and handled on site prior to combustion.

Delivery can be by barge, ship or rail. A plant on a waterway that can handle barges or ships that have access to coal is well suited to water delivery of coal. Docking facilities are a necessity, but may already exist at such a site. It is then necessary to build facilities to unload the coal from the barge or ship and convey it to the coal pile.

Rail delivery requires another set of considerations. It is likely that a rail line was built into the site to deliver material for the nuclear plant construction. However, an appropriate rail line must also exist between the mine and the plant. If not, one must be built. In addition, a sufficient number of rail cars must be available to shuttle between the mine and the plant to meet the demand for coal. Additional on-site trackage is required to store rail cars not in use. Thaw sheds are required in case the coal arriving in the winter cannot be unloaded, because it is frozen. These hold one or more cars and consume several tens of megawatts when in use.

Car unloading facilities are required. These may be rotary car dumpers, which turn the rail car upside down for unloading. Alternatively, a trestle may be provided for bottom dump cars. The rotary car dumper handles standard coal cars, which have been modified by use of a rotary coupling, and can unload a car approximately every four minutes. Bottom dump cars can unload a car every thirty seconds. They are of special design and construction. The bottom gates of the car are remotely actuated and all open simultaneously. Because of the special features, they are more expensive than the cars handled by a rotary dumper.

In either case, the dumped coal falls onto a high speed conveyor which transports it to a coal pile. The coal is ultimately transported to the boiler building on another conveyor. Conveyors are normally enclosed to provide dust control. Since coal dust in air is potentially explosive, the conveyors require grounding and flame arresters.

Coal storage requires significant land area on the plant site. Generally, there are two types of coal storage. One is long term storage intended to provide fuel to keep the plant in operation during interruptions in the normal coal supply due to strikes or natural phenomena. The amount of coal in long term storage could be as much as three months usage where the supply is unreliable. With a reliable supply, the amount stored could be significantly less. Coal for operation is not usually taken from the long term storage. On the other hand, a smaller coal pile is used to provide a buffer between deliveries and normal usage.

Ash Handling and Disposal

Large quantities of ash are generated by a coal fired plant. Frequently, the ash is disposed of in an ash pond. In such cases, the bottom ash is sluiced to the ash pond. This pond requires several acres on the existing nuclear site. If this acreage is not available, the ash must be disposed of elsewhere. This requires facilities to load rail cars or trucks to transport the ash to the disposal site.

Fly ash quantities are smaller. Depending on fly ash chemistry and local conditions, it may have commercial value as an additive in making concrete.

Water Treatment

The quantity of treated water required for the coal fired plant exceed the needs for a nuclear plant. Therefore, it is necessary to expand both the makeup water treatment system and the demineralized water system to produce the new requirements.

Controls

Control modifications in a repowering project take two forms - control of the turbine cycle and modification of the control room.

The least change in control approach is for the GTCC when the high pressure steam from the HRSG flows directly to the nuclear plant turbine. In this case, the control valves at the turbine throttle can be used in the way the were used before the repowering. However, when a topping turbine is placed between the steam source, whether it be a HRSG or a fossil boiler, the primary flow control has to be at the inlet to the topping turbine. Since the topping turbine and the nuclear turbine are functioning as cross compound units, the function of the stop and control valves on the nuclear turbine are changed. Now they must function as intercept valves.

It is obvious that controls for the nuclear reactor and its auxiliaries are no longer needed in the control room. Instead controls are required for the gas turbines and HRSGs or the fossil boiler and its auxiliaries. Further, if a topping turbine is used, the throttle controls for the nuclear turbine must be changed and controls added for the topping turbine and its auxiliaries. Therefore, a major control room renovation is part of a nuclear repowering project.

ACKNOWLEDGEMENTS

I wish to acknowledge the work of those whose efforts contributed to this paper. From Burns & Roe, John Butz, Dennis Shikar and Frank Silaghy were the principal contributors. Russ Allen and Darrell Boyle from the Raytheon office in Philadelphia provided pertinent guidance and criticism. Bill Brynda, Cliff Scarlett and Ed Fiegler of Brookhaven National Lab provided valuable comments. Jack Allentuck of Brookhaven National Lab provided overall guidance for the work which resulted in this paper.

Work described in this paper was performed under contract DE-AC02-76CH00016.