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Repurposing of Coal Decommisioned/to be Decommisioned Fired Thermal Power Plants

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1.0 Introduction

Globally, countries are phasing out thermal power plants due to their ageing fleet, reduced profitability, and growing environmental concerns, and are taking different approaches to move away from coal. In India, old plants are not only grappling with low-capacity utilization and environmental issues but also have become uneconomical to customers and unprofitable to utilities. It is evident from the fact that the average plant load factor (PLF) of coal fired thermal power plants, an indicator of capacity utilization, has seen a steady decline from 77.5% in 2009 to 58.87% in 2021. Also, since March 2016 to May 2019, 25 years or more old and inefficient coal/lignite based thermal power units of total 8470 MW capacity have been retired on the basis of un-economic operation or due to other reasons. In addition, 810.94 MW capacity gas based/DG set units have also been retired since Sept.'2015 to May' 2019. However, their infrastructure and components could well be reused for other productive purposes. This strategy of conversion of decommissioned/to be decommissioned coal-fired power plants, endowed with valuable assets for providing economic utilization, renewable energy (RE) integration, or grid services, is referred to as coal plant repurposing. The existing site and various components of the incumbent plant can be repurposed to produce energy, store energy, or provide ancillary services[1]. Additionally, repurposing projects address various issues including: (1) land constraints for developing new renewable energy (RE) projects (2) managing environmental and social aspects of new development as well as social resistance to plant closures (3) transmission constraints for new projects (4) addressing grid stability (as previously provided by the coal power plant). It also caters to the imperative aspect of "Just Transition" which is important for sustainable growth to all segments of citizens of our country.

This paper deals with different aspects of coal plant repurposing including its need, repurposing options relying on well-established technologies, namely, solar, battery energy storage system (BESS), SynCON etc., ways of improving the financial position of the utility concerned and thereby allowing stranded assets to derive potential value and providing an effective exit strategy for utilities.

2.0 Need for Repurposing Old and Ageing Thermal Power Plants

In India, old plants are not only grappling with low-capacity utilization and environmental issues but also have become uneconomical to customers and unprofitable to utilities. In 2016, the Central Electricity Authority (CEA) identified approximately 9,000 MW coal-based thermal power plants capacity for retirement/replacement by new super-critical units on the basis of age (more than 25 years old) and uneconomic operation. Increasing environmental concerns and decline in capacity utilization of coal plants over the last decade have rendered the thermal power plants uneconomical as well as unprofitable. Arguably, the strongest driver of decommissioning coal fired plants is that the capacity factor of coal plants that once used to be 80 per cent

[1] "Ancillary services" is used to refer to variety of operations beyond generation and transmission that are required to maintain grid stability and security. This services generally include active power control or frequency control and reactive power control or voltage control.

has dropped below 60 per cent and getting closer to 50 per cent on average.

On the other hand, Government of India has set the following targets:

- India will get its non-fossil energy capacity to 500 gigawatts by 2030
- India will meet 50% of its energy requirements till 2030 with renewable energy
- India will reduce its projected carbon emission by one billion tonnes by 2030
- India will reduce the carbon intensity of its economy by 45% by 2030
- India will achieve net zero by 2070

So, in the present scenario India is at a crossroads in terms of increasingly unremunerative, old, and polluting coal plants on one hand, and ambitious RE targets on the other hand. Repurposing allows for retirement of old, polluting, and unprofitable coal plants, while capturing value by reusing part of the assets such as the substation, generator, turbine, and so forth.

With land and reduced equipment costs, a repurposed coal plant site may potentially bring down high initial investment requirements for a greenfield RE or storage project and lower the cost of RE power generated.

Repurposing may also include continued use of the existing transmission assets obviating the need for additional transmission and interconnection costs for RE and storage projects, thus reducing the overall cost of power.

Beyond direct cost benefits, coal plant decommissioning and repurposing provides environmental, social, and grid stability benefits.

On the social front, repurposing helps to mitigate the negative impact of decommissioning on employees and local communities.

Repurposing allows for retaining part of the workforce for an upcoming RE or storage project at the same site; this would partly ameliorate the socioeconomic impact of potential layoffs. The share of workforce that can realistically be reemployed (and retrained) in a repurposed project would depend of course on the nature of the project, but it is likely to be quite small (e.g., 10% or at best 20%). Like the original coal plant, the repurposed plant would also continue to support local economies and the surrounding communities by providing jobs and enabling economic activities and their well-being in the long run.

The above discussion presents a strong case for the old and ageing thermal power plants to be decommissioned and repurposed with renewable energy integration for power generation, energy storage through BESS and for providing ancillary services by using existing assets and infrastructure.

3.0 Methodology

Coal fired plants can be repurposed in numerous ways, such as solar plant for energy; battery storage for providing frequency control ancillary services, energy storage, and capacity; and synchronous condensers for delivering reactive power and inertia; biomass plants for both energy and capacity.

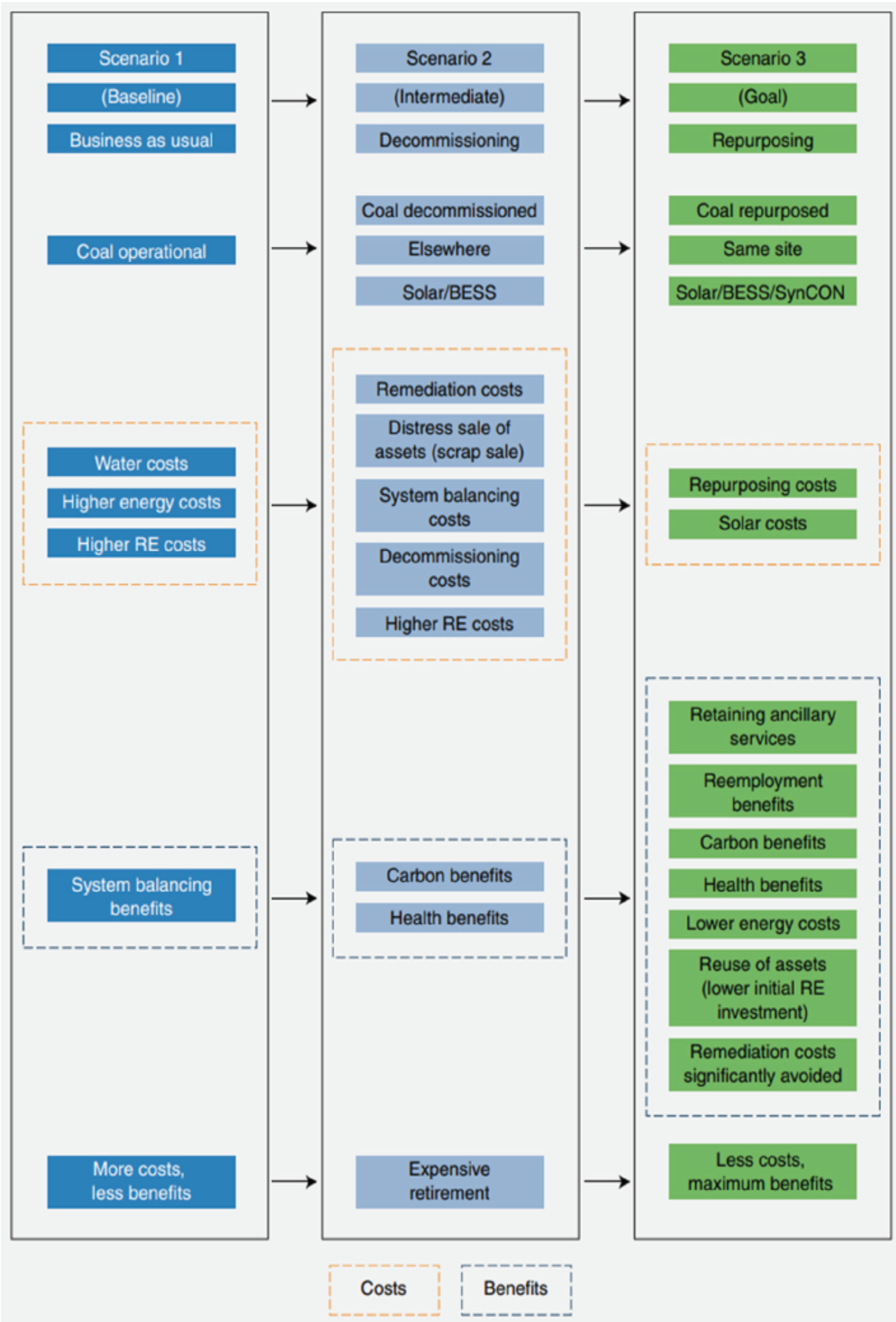
The requirements for additional renewable and ancillary services on the existing site will need to be carefully assessed through a planning study, which in turn will also determine the combination of technologies and their sizing best suited for the site. The precise selection of the combination of technology would depend on a number of factors, including availability of land; alternative energy resource quality (e.g., wind, solar, biomass, etc.); requirement of the wider system for energy, storage, and ancillary services; relative economics of the repurposed project; and social and environmental considerations.

For the analysis, three distinct scenarios may be considered, namely,

- Scenario 1 (Business as usual): Coal plant continues to function
- Scenario 2 (Intermediate): Coal plant is decommissioned and new solar, battery energy storage system (BESS) comes up elsewhere
- Scenario 3 (Repurposed site): Coal plant is repurposed for the appropriate option on-site (i.e., a combination of solar, BESS, and synchronous condenser (SynCON)

Scenario 1 is the baseline scenario, which represents the business-as-usual case and reflects the existing paradigm of the power sector in India, with coal plants staying operational. Scenario 2 considers the possibility of coal plants being decommissioned even while solar and BESS capacity addition continues in a usual manner. Finally, Scenario 3 offers repurposing of existing coal plants into appropriate combinations of solar, BESS, and SynCON at the coal plant site. To fully demonstrate how various costs and benefits unfold, Scenario 2 is considered as an intermediate case, whereas Scenario 3 is considered the goal.

As we move across the three scenarios, we assess the costs and benefits from economic and environmental standpoints. Scenario 3 incorporates the environmental benefits offered by Scenario 2, and overcomes various costs associated with moving from Scenario 1 to Scenario 2, via reusing assets as well as retaining ancillary services and employees. Scenario 3 also helps in avoiding some of the clean-up costs (e.g., ash ponds) that would otherwise be required in Scenario 2. Various costs and benefits associated with repurposing have been categorized as direct or indirect. The direct costs are accrued to the utility/plant and are one time in nature, while indirect costs accrue to the system and



Source: ESMAP Technical Document

would be calculated on a yearly basis. As mentioned earlier, there may be system-level costs and benefits as described in the study, but the empirical analysis primarily focuses on the direct ones which are incurred or accrued to the utility or the plant and can be easily monetized.

One of the key objectives of the paper is to identify and illustrate related costs and benefits based on a representative coal plant.

To summarize, using a representative coal plant, we calculate costs and benefits for the following combinations of movement between scenarios: (1) simple retirement or decommissioning (i.e., from Scenario 1 to Scenario 2); (2) repurposing a decommissioned plant (i.e., from Scenario 2 to Scenario 3); and finally, (3) repurposing an operational plant (i.e., from Scenario 1 to Scenario 3)

4.0 The Costs

Now, while moving from Scenario 1 to Scenario 2, we discuss applicable costs, which have been segregated into direct, indirect, and additional costs. Some of these costs are mitigated, moving from Scenario 2 to Scenario 3, and are, therefore, reconsidered as benefits in the analysis above. Direct costs are related to the decommissioning of a coal plant that has served its economic life and are one time in nature, whereas additional costs (except social costs) are related to the decommissioning of a coal plant before the end of its economic life. For the purposes of our paper, given that we mostly focus on coal plants beyond their economic lives; we focus primarily on direct costs, which are incurred by the plant. A comprehensive list of various costs and sub-costs is below, followed by corresponding explanations.

A. Direct costs, including (as related to)

1. Employee costs, station overheads, and O&M expenses post-retirement
2. Environmental regulation, such as asbestos and hazardous material abatement
3. Demolition of the plant and scrap removal from the coal plant equipment and machinery
4. Coal combustion residuals (i.e., ash/residue ponds) clean-up
5. Coal storage areas clean up

B. Indirect costs, including (as related to)

1. Contingency costs, such as unanticipated environmental costs

C. Additional repurposing costs, including (as related to)

1. Remaining capital expenditure (CAPEX) on the coal plant
2. Remaining operational expenditure (OPEX) margins on the coal plant
3. Social costs, such as temporary income support for employee rehabilitation

5.0 Indirect Costs

Indirect decommissioning costs are considered over the remaining plant life and include two main components. First, post-decommissioning expenditure toward monitoring and mitigation of the negative effects of a coal plant toward soil, habitat, and so forth; and meeting contingencies related to unanticipated damages in the future. Second, system balancing costs, necessitated due to the decommissioning of a coal plant in terms of reactive power, inertia, peaking requirements, and so forth. However, this study limits the analysis to the former as the latter would require a more detailed system-level investigation.

6.0 Additional Costs

Scenario 3 may entail three additional costs, remaining CAPEX/OPEX and social costs. The first two arise mainly due to retirement of coal plants before the end of their economic lives and, therefore, are unlikely to exist for plants being retired after the end of their economic lives. These do not form part of our analysis, as the representative plant under consideration for repurposing has been assumed to have completed its economic life.

If utilities are interested in retiring plants before their economic life, consideration of these additional costs may be useful

7.0 The Benefits

A repurposing project derives its benefits by moving from Scenario 1 (business-as-usual) to Scenario 3 (repurposed site), namely, the coal plant stops working ahead of its planned retirement. Benefits may be thought of comprising two components, namely, (1) benefits that arise from shutting down the plant and Renewable/BESS/SynCON that may be developed elsewhere – the avoided carbon emissions benefits in most cases due to early retirement might account for the majority of the benefits; and (2) additional cost reduction and other benefits of avoided remediation cost, reemployment, and so forth that stems from locating Renewable/BESS/SynCON on the same site. The distinction is somewhat artificial given that the prospect of an early retirement might be reinforced by both the tangible and intangible benefits associated with repurposing the site with Renewable/BESS/SynCON. The direct benefits are in terms of monetary (and guaranteed) one-time benefits connected to coal plant decommissioning and repurposing, whereas the indirect benefits are associated with the period for which the coal plant decommissioning is brought forward. Indirect benefits are further divided across societal and power system benefits, as discussed in detail below. A comprehensive list is as follows.

A. Direct benefits, including (as related to)

1. Salvage value/scrap value of coal plant machinery
2. Land reutilization
3. Equipment (i.e., switchyard, substation) reutilization
4. Remediation benefits (i.e., reduced remediation costs)
5. Transmission and interconnection evacuation reutilization
6. Reactive power benefits with SynCON by retaining system balancing service

B. Indirect benefits: societal benefits, including (as related to)

1. Carbon benefits
2. Health benefits
3. Water benefits
4. Reemployment benefits

8.0 Indirect Benefits

Societal benefits, though indirect, are realizable at the societal level in terms of their environmental value and merit inclusion. For instance, decommissioning coal plants reduces emissions (B.1; i.e., carbon benefits), improves the health of people in the vicinity of the plant (B.2; i.e., health benefits), and saves on water consumption (B.3; i.e., water benefits). Additionally, repurposing helps in retaining part of manpower employed in coal plants (B.4; i.e., reemployment benefits), thus reducing the social costs (C.3). The indirect benefits (B.1 to B.4) do not form part of our analysis, as we focus primarily on the benefits accrued to the plant via repurposing (i.e., the direct benefits). In case other studies are interested in considering these benefits, the description provided in this study shall be useful in monetizing these.

9.0 Criteria for Identifying Thermal Power Plants Suitable for Repurposing

1. Units aged 25 years or more or ones having completed their economic life.
2. Units having higher energy (variable) cost as higher energy cost plants are not prioritized in least-cost dispatch and, therefore, operate at lower capacity utilization levels. Accordingly, coal plants with variable energy costs greater than INR 3.0/kWh, a threshold established in lieu of the current tariffs for the main competition for coal plants, namely, renewable energy sources, may form a suitable choice for repurposing.
3. State-level qualitative factors also merit consideration. These include willingness of stakeholders (i.e., state governments favourable disposition toward RE), locational attributes of the coal plant site in terms of its RE potential, and availability of cheap land.
4. The last criteria suggest targeting coal plants located in rural locations, where land is relatively cheaper.

10.0 Potential Impacts on Electric Power Grid After Decommissioning of Thermal Power Plants

As the transition to renewable energy supply grows and the decommissioning of more traditional fossil-fuel based power stations increases, assessment of its potential impact on electrical power grid should be evaluated at the planning stage for repurposing the decommissioned/to be decommissioned coal fired plants. We have tried to shed some light on the potential impacts which are as follows:

1. Impact of Reduced Inertia on Frequency Stability in the Electric Power Grids

Turbines, generators, and motors in fossil, nuclear and hydro power plants spin at speeds proportional to grid frequency. The rotational energy of these massive devices provides significant inertia that can counteract changes in grid frequency due to disturbances. For example, if one power plant in a region goes offline, grid frequency will decrease. Other spinning generators can respond by speeding up slightly to resist the frequency shift and stabilize the grid.

Because solar energy plants do not have any moving parts (and thus inertia), the power system's inertia declines as solar penetration grows – potentially leading to rapid frequency changes. If left unchecked, such changes can cause electricity service interruptions. Wind generation likewise does not contribute inertia because most modern wind turbines transmit energy through power electronics and are not connected directly to the grid. According to the EPRI study, smaller, islanded grids already face inertia-related challenges. Grid operators in Ireland and Nordic countries regularly adjust power plants' output based on predictions that low inertia will cause service interruptions. These operators are monitoring inertia on a second-to-second basis and re-dispatching power plants to maintain frequency stability.

There may be some potential technological, operational, and market-based solutions for grid operators, such as:

Controlling the inverters of solar and wind power plants and battery energy storage systems to provide frequency support during disruptions

- Requiring an inertia "floor" or minimum that results in the operation of additional spinning generators
- Compensating generators for providing inertia to encourage them to stay online.

Accordingly, these and other solutions need to be evaluated for their effectiveness in maintaining grid stability. A study of minimum inertia requirements, including a cost benefit analysis of introducing an inertia floor may be carried out and a methodology to be developed for the same. In addition, operators need more real-time data on the impacts of reduced inertia along with analytical tools to evaluate those impacts.

2. Short Circuit Power

As the transition to renewable energy supply grows and the decommissioning of more traditional fossil-fuel based power stations increases, the need for short circuit power (SCP) has never been greater. Generated through synchronous condensers, SCP is a key component in stabilising grid power supply for renewable energy sources such as onshore and offshore wind. SCP provides the necessary power to the high voltage system required to ensure continuity and reliability of supply to the grid that would otherwise lead to unnecessary blackouts. Short circuit power also plays a significant role in detecting faults in the grid and is essential for the clearing those faults. Additionally, it provides the necessary power to maintain the voltage level in case of a fault.

Traditionally, SCP has been generated as a by-product of large-scale power plant operation. But with the decommissioning of traditional power stations, the rise of more renewable energy has introduced weaknesses in the grid which need to be compensated for. This is because large fossil-based power stations produce significantly higher levels of short circuit power than the equivalent renewable generation of a similar power output. When operating a higher ratio of renewable generation, operational challenges can be faced with the potential for voltage changes causing disturbances which can trigger generation equipment to trip or, even worse, the whole system to become unstable. A back-up solution is therefore needed to avoid disruption or what could lead to a total collapse of the system.

To generate SCP, synchronous condenser technology is needed. The short circuit power generated from the synchronous condenser, not only helps identify where the fault is but provides the necessary refill, or in real terms, the voltage to keep supply going. And in recent times they have made a bit of a worldwide renaissance for their role in providing grid stability through the creation of short-circuit power and inertia for dynamic loads.

3. Balancing Demand and Supply

To properly balance electricity supply and demand on the power grid, grid operators must have a sense of how much renewable energy is being generated at any given moment, how much renewable energy generation is expected, and how to respond to changing generation. All this information can be difficult for grid operators to know due to the intermittent nature of renewable power and the wide variety in the size and locations of renewable energy resources across the power grid. As the proportion of renewable energy capacity on the grid grows, these issues will become increasingly important to understand.

4. Impact of Reduced Reactive Power for Voltage Regulation of Grid

Rotating synchronous machines can generate leading and lagging reactive power and contribute to the stabilization of the transmission grid voltage. Thus, retiring a conventional power generation unit can create a deficit in reactive power that directly affects the transmission grid voltage stability and reliability

In order to avoid any voltage disturbances and enough transmissions capacity a stable and reliable grid with continuous local regulation of reactive power is required. This critical task is supported by conventional power plants with synchronous generators. For the rated transmission of active power in the line no additional reactive power is required. In case more active power shall be transported, transmission line will require increased reactive power. It is especially critical for the redundant power lines, when one of them shall take over the capacity of the other one.

To solve the problem of stability and reliability in the grid a regulation of the reactive power needs to be planned and implemented accordingly. To realize this either a new synchronous condenser can be built or instead of shutting down decommissioned power plants, it is possible to continue economical operation by utilizing the generator as a synchronous condenser. In such case the generator is reconfigured for stand-alone functionality with inductive as well as capacitive reactive power.

11.0 Stages of Repurposing

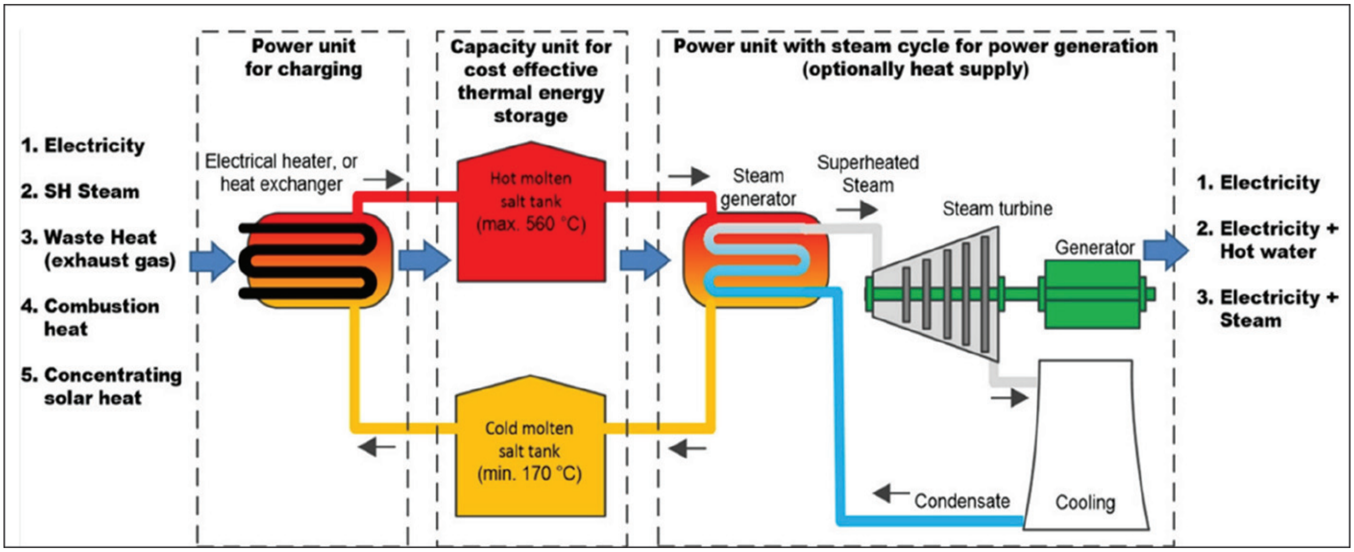
Repurposing of coal fired plants can be categorized into different stages depending upon the amount of renewable energy integrated into the power system, actual amount of renewables in functional condition, rate of phasing out of coal fired power plants, status of inertia remaining or required in the system, reactive power supply and demand, short circuit capacity in the electrical power system.

Initial stage

In the initial phase when still there are decent number of large synchronous generators in the system and a lesser percentage of renewable energy is integrated into the system, there will not be much change in the factors affecting grid stability. So, solar PV plants, wind generators and BESS could be explored as possible ways of repurposing coal fired plants.

Intermediate stage

In the intermediate stage we assume that rate of phasing out coal fired plants is accelerated accompanied by the acceleration of renewable energy integration into the grid. In this stage we contemplate the pick up of ancillary services market as the factors affecting grid stability would gain prominence. Use of Synchronous Condensers (SynCON) provides substantial voltage control services critical for the power system. To realize this either a new synchronous condenser can be built or instead of shutting down decommissioned power plants, it is possible to continue economical operation by utilizing the generator as a synchronous condenser. In such case the generator is reconfigured for stand-alone functionality with inductive as well as capacitive reactive power. Already realized projects in Germany, Denmark, USA and other countries show that such reconstruction can be done in a short time. The net additional benefits of repurposing via SynCON are expected to increase further mainly due to two reasons. First, the ancillary services market is developing around the world, particularly in developing countries, leading to increased demand and higher compensation for these services; and, second, accelerated penetration of variable renewable energy (RE) into the grid requires greater reactive power balancing which can be provided by SynCON, thereby ensuring a major revenue stream for the repurposed plant. As synchronous condenser is a rotating device it also provides short circuit support in addition to the reactive power supply



Carnot Battery (Source: Google)

Repurposing via synchronous condensers along with conventional renewable energy and battery storage could be explored as viable options as the repurposed site can therefore continue to provide part of the energy needs and a significant part of the frequency control and voltage support services that the original coal plant provided.

Advance stage

For the advance stage we assume the existence of renewable energy dominated electrical grid. There could be a severe shortage of inertia, reactive power, short circuit capacity etc. in the electrical power grid system which may severely affect its stability. Such situation would call for repurposing options which could provide the much-needed factors like inertia, reactive power, short circuit capacity etc for the stabilization of grid. These options may include:

1. Carnot Batteries

Carnot batteries are an emerging technology for the inexpensive and site-independent storage of electrical energy. Also referred to as “Pumped Thermal Electricity Storage” (PTES) or “Pumped Heat Electricity Storage” (PHES), a Carnot battery transforms electricity into heat, stores the heat in inexpensive storage media such as water or molten salt and transforms the heat back to electricity when required. Reaching from a few megawatt hours up to the gigawatt hour scale, Carnot batteries have the potential to solve the global storage problem of renewable electricity in a more economic and environmentally friendly way than conventional batteries.

Concentrating solar power (CSP), also known as solar thermal electricity, is a commercial technology that produces heat by concentrating solar irradiation. This high-temperature heat is typically stored and subsequently used to generate electricity via a steam turbine (Rankine cycle). In other words, the thermal energy storage (TES) system corrects the mismatch between the unsteady solar supply and the electricity demand. The different high-temperature TES options include solid media (e.g., regenerator storage), pressurized water (or Ruths storage), molten salt, latent heat, and thermo-chemical. Similar to residential unpressurized hot water storage tanks, high-temperature heat (170–560 °C) can be stored in molten salts by means of a temperature change. Molten salts used for TES applications are in solid state at room temperature and liquid state at the higher operation temperatures. High-temperature properties such as the volumetric storage density, viscosity and transparency are similar to water at room temperature. The major advantages of molten salts are low costs, non-toxicity, non-flammability, high thermal stabilities, and low vapour pressures. The low vapour pressure results in storage designs without pressurized tanks. Molten salts are suitable both as heat storage medium and heat transfer fluid (HTF).

2. Small Modular Reactors (SMRs)

Small modular reactors (SMRs) are advanced nuclear reactors that have a power capacity of up to 400 MW(e) per unit, which is about one-third of the generating capacity of traditional nuclear power reactors. SMRs, which can produce a large amount of low-carbon electricity, are:

- Small – physically a fraction of the size of a conventional nuclear power reactor.
- Modular – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.

Small Modular Reactor (SMR) (Source: Google)

- Reactors – harnessing nuclear fission to generate heat to produce energy.

More than 70 SMR designs are at different stages of development worldwide, with SMR units now operating in China and Russia. Repurposing coal plants with SMRs would enable the continuation of power production for local customers. Their generation capacity, between 200 MWe and 400 MWe, is similar to that of a typical coal fired plant, therefore these SMRs would also be suited to existing grid connections.

Both public and private institutions are actively participating in efforts to bring SMR technology to fruition within this decade. Russia's Akademik Lomonosov, the world's first floating nuclear power plant that began commercial operation in May 2020, is producing energy from two 35 MW(e) SMRs. Other SMRs are under construction or in the licensing stage in Argentina, Canada, China, Russia, South Korea and the United States of America. SMRs offer unique attributes in terms of efficiency, economics and flexibility. While nuclear reactors provide dispatchable sources of energy – they can adjust output accordingly to electricity demand – some renewables, such as wind and solar, are variable energy sources that depend on the weather and time of day. SMRs could be paired with and increase the efficiency of renewable sources in Hybrid Energy System. These characteristics position SMRs to play a key role in the clean energy transition, while also helping address the Sustainable Development Goals (SDGs).

12.0 Conclusions

With the tremendous increase of RE power integration in the electricity grid, coal fired thermal units are being decommissioned or phased down gradually worldwide and to meet the net zero target. However, present available repurposing options are not always economically viable. Suitable models are still being developed with evolving technologies in near future.

References

1. ESMAP Technical Document 016/21 June 2021 (World Bank Group)
2. Usage of existing power plants as synchronous condenser, Alexander Deecke, Rafael Kawecki
3. CEA Website
4. Carnot Batteries, iea.

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