CHAPTER-7

CONCLUSIONS AND FUTURE SCOPE

In India, the energy consumed for different applications, either domestic or industrial, mostly originates from coal. Therefore, the hybridization of solar energy with existing CFPP has profound and realistic implications. Thus, the thesis demonstrates the technical and economic potentials of hybridizing STE with the widely utilized coal-based power plants. In this research, two case studies are performed on existing sub-critical and supercritical CFPP to achieve the desired objectives. The critical conclusions drawn from this research work are discussed as follows:

7.1 Concluding Remarks of Case-Study-1

This case study examines the hybridization of an existing sub-critical coal-fired power plant (CFPP) with concentrated solar thermal energy on energetic, exergetic, economic, and environmental criteria under three different integration scenarios. In this study, a solar field consisting of PTC arrays is integrated with an existing 330 MW sub-critical CFPP for feedwater preheating. The three different integration scenarios considered in this case study are:

- Option-1: High-pressure FWH No.1 (GJ1) is substituted by the solar field
- Option-2: High-pressure FWH No. 2 (GJ2) is substituted by the solar field
- Option-3: Both high-pressure FWHs (GJ1 & GJ2) are substituted by the solar field

For the base case, the design energy efficiency of the 330 MWe CFPP is 34.17%. In power-boosting mode, the improvement in energy efficiency over the base case is 7.14%, 3.86%, and 11.32% for all three options, respectively. And the improvement in exergy efficiency over the base case is 7.16%, 3.59%, and 11.34% for all three considered options, respectively. The most significant improvement in energy and exergy efficiency over the base case is obtained for Option-3. The results of the energetic analysis show that the highest energy efficiency of 38.04% is attained for Option-3. Similarly, the results of exergetic analysis show that the highest exergy efficiency of 36.22% is achieved for Option-3.

The generator power output of the solar-coal hybrid power plant is increased from the generator's rated power output for all three options by 24/13/38 MW, respectively, in power boosting mode and the solar collector area of about 16.69/10.54/27.23 ha is required for all three options considered in this study, respectively. It is also observed that the value of ExPI is greater than EnPI for all replacement options. Both EnPI and ExPI are maximum for Option-1, and the highest ExPI of 0.46 is obtained for Option-1. The study concluded that using solar energy for feedwater heating based on exergy is more efficient than that based on energy. The solar contribution for Option-3 is the highest (11.56%), followed by Option-1 (7.38%), and the solar contribution is the least for Option-2 (4.85%). The biggest improvement in excess power generated is witnessed for Option-3 (11.34%), followed by Option-1 (7.16%) and Option-2 (3.88%).

The environmental analysis has been performed using a fuel-saving approach, and the outcome of the ecological investigation concluded that Option-1 results in annual coal saving and the corresponding reduction in CO_2 emissions of about 23856 tons and 47072 tons, respectively. For Option-2, the annual coal saving and the corresponding reduction in CO_2 emissions are 13584 tons and 26804 tons, respectively. In Option-3, the annual coal saving and the corresponding reduction in CO_2 emissions are 37104 tons and 73213 tons, respectively. The environmental analysis concluded that the maximum reduction in coal consumption and CO_2 emissions corresponds to Option-3.

The results of the economic analysis showed that the increase in total capital costs (*TCC*) over the base case for Option-1 is 15.72%, for Option-2 is 9.93%, and for Option-3, it is 25.64%. The economic analysis found that LCoE (USD/kWh) for the base Option and three replacement options are 0.0436/0.0452/0.0447/0.0463 and simple payback period (years) are 3.05/3.39/3.26/3.57, respectively. The annual savings in the fuel cost are 0.86/0.49/1.33 million USD for Option-1, Option-2, and Option-3, respectively. It was also observed that the annual saving in fuel cost for Option-3 is the highest.

7.2 Concluding Remarks of Case-Study-2

This case study examines the hybridization of an existing supercritical coal-fired power plant (CFPP) with concentrated solar thermal energy on energetic, economic, and environmental criteria under three different integration options. In this study, a solar field consisting of PTC arrays is integrated with an existing 660 MW supercritical CFPP for feedwater preheating. The three different integration options considered in this case study are:

- Option-1: High-pressure FWH No.1 is substituted by the solar field
- Option-2: Both high-pressure FWHs are substituted by the solar field
- Option-3: All high-pressure FWHs are substituted by the solar field

For the base case, the design energy efficiency of the 660 MWe CFPP is 41.7%. In power-boosting mode, the improvement in energy efficiency over the base case is 6.37%, 13.69%, and 16.83% for all three options, respectively. And the improvement in exergy efficiency over the base case is 6.27%, 13.58%, and 16.72% for all three considered options, respectively. The results of the energetic analysis show that the highest energy efficiency of 48.72% is achieved for Option-3. Similarly, the results of exergetic analysis show that the highest exergy efficiency of 46.90% is achieved for Option-3.

The generator power output of the solar-coal hybrid power plant is increased from the generator's rated power output for all three options by 42/91/112 MW, respectively, in power-boosting mode, and the solar collector area of about 26/61.2/86.7 ha is required for all three options considered in this study, respectively. It is also observed that the value of ExPI is greater than EnPI for all replacement options. Both EnPI and ExPI are maximum for Option-2, and the highest ExPI of 0.4688 is obtained for Option-2. The study concluded that using solar energy for feedwater heating based on exergy is more efficient than that based on energy. The solar contribution for Option-3 is the highest (19.35%), followed by Option-2 (15.46%), and the solar contribution is the least for Option-1 (7.85%). The biggest improvement in excess power generated is witnessed for Option-3 (16.72%), followed by Option-2 (13.58%) and Option-1 (6.27%).

The environmental analysis has been performed using a fuel-saving approach, and the outcome of the ecological investigation concluded that Option-1 results in annual coal saving and the corresponding reduction in CO_2 emissions of about 47496 tons and 68485 tons, respectively. For Option-2, the annual coal saving and the corresponding reduction in CO_2 emissions are 96744 tons and 139500 tons, respectively. In Option-3, the annual coal saving and the corresponding reduction in CO_2 emissions are 116256 tons and 167635 tons, respectively. The environmental analysis concluded that the maximum reduction in coal consumption and CO_2 emissions corresponds to Option-3.

The results of the economic analysis showed that the increase in total capital costs (*TCC*) over the base case for Option-1 is 11.99%, Option-2 is 28.2%, and for Option-3, it is 39.92%. The economic analysis found that LCoE (USD/kWh) for the base Option and three replacement options are 0.045/0.046/0.047/0.048 and simple payback period (years) are 3.03/3.33/3.68/3.88, respectively. The annual savings in the fuel cost are 1.5/3.1/3.8 million

USD for Option-1, Option-2, and Option-3, respectively. It was also observed that the annual saving in fuel cost for Option-3 is the highest.

In case study-1, the associated change in LCoE from base case to Option-3 is 0.27 cents/kWh, and in the case of study-2, it is 0.33 cents/kWh, which means no significant increment in electricity cost would be suffered from the consumer side. This also helps in better penetration of CSP technologies because the less sensitive unit electricity cost change would cause no market mistrust for potential investors by capitalizing on green projects.

7.3 Concluding Remarks of Policy Interventions

India wishes to shift from a fossil fuel burning economy to a relatively low carbon economy through increased use of renewable energy sources because of issues such as climate change and environmental protection. India is facing pressure to control GHG emissions at the international front; therefore, GoI has released JNNSM to install 100 GW of solar energy installations across the country by 2022. In India, the solar energy sector's growth is moderate even when there are several motivational factors like plentiful solar radiation and land availability; due to the absence of a single comprehensive solar policy. To successfully achieve the target, the Indian government has to extend support to the solar industry, especially solar thermal industry, in framing common policy at the central level, implementing the policies at the ground root level, and the single-window clearance system easy and long term financing, and proper infrastructure. Besides the above-said steps for India's solar power sector's growth, GoI needs to invest in improving research and development facilities, manufacturing facilities, and infrastructure. These initiatives will undoubtedly attract national/international investors to invest in the Indian solar power market and provide a favorable environment. With the center targeting 40% renewable sources in the energy mix by 2030, the Indian electricity sector is at the heart of a seismic changeover. These ambitious targets are supported by legislative, regulatory, and policy interventions at the center and state levels. This is also in tune with global trends supporting green industrial policy for an immaculate and sustainable form of economic growth. The recent focus has shifted to a commitment with the market through the establishment of an assisting policy environment, instead of control over the market. However, there is lucidity at the center level on driving renewable energy reform; there is an apparent apprehension at the state level. For the success of any renewable energy policy, the role of DISCOMs is rudimentary, but the recent perception is that the state DISCOMs are working against the national policy. In the present study, all the government initiatives for promoting the growth of renewable energy sources (especially solar energy) have been discussed in detail. The analysis of state-wise solar policies shows that the government has taken many initiatives to achieve the target of 100 GW solar power by 2022. Still, the share of CSP technologies seems negligible in these policies.

To further promote renewable energy (RE), the central government has introduced RPO through CERC for renewable energy in general and solar power in particular. The central government continues to encourage the development of RE sources through several key policies and governing methods. During the FY 2016-17, these measures include notification of RPO targets, waiver of inter-state transmission system (ISTS) charges and losses, reinforcement of the ISTS under the Green Energy Corridor program, and amendments to the captive power producer rules to provide more lucidity and encourage long-term investments in the sector. The lenient enforcement of RPO policy in India is one of the key reasons for non-compliance with RPO targets. To attain India's RE targets, effective implementation of RPO policy is critical. Regretfully, previous years' trend has proved that ensuring RPO compliance is an uphill battle with most DISCOMs unable and often reluctant to meet RPO targets. Obligated entities use the RECs to fulfill their RPO requirements. Tradable RECs help meet the solar RPO when there is inadequate solar capacity in a particular state.

Finally, this study deliberates the policy framework of CST technologies to identify the key policy instruments launched by the GoI to support CSP projects, which is one of the key objectives of this study. In JNNSM Phase-II, MNRE has decided to reduce CSP share to 30% because of poor performance in JNNSM Phase-I. The limited growth of CST technology in India is due to a lack of prioritization because the government is providing a maximum focus on solar PV technologies. Therefore, Solar PV technologies have outshined CSP technologies. According to a channel partner, if all the exemptions that are given to solar PV are extended to solar energy as a whole, then the CST sector will definitely grow at a much faster rate. CSP technology has the enormous potential that can be tapped in a much more inexpensive and feasible manner to meet future energy needs and mitigate climate change. Still, if suitable policy instruments are not put in place to support this technology, this valuable technology may lose its attractiveness in the market. Although the central government offers subsidies, tax benefits, and funding programs, the policies and guidelines put in place have no primary boosting framework for encouraging CST systems' deployment. Policy support needs to provide competitive pressure for innovation and cost reductions. The deployment policies for CSP should be designed to include key advantages of CSP, i.e., dispatchability and plunging cost pressure, to trigger cost reductions and more efficient plant designs. Such policies are auctions or feed-in tariffs. The CSP policy instrument should include research, development, and demonstration-related support for industry partners. It should also include policies to cover the increased risk of implementing new and innovative components and designs. Implementing such a policy framework could revive the CSP industry with a balance of lucrative profits.

7.3.1 Policy recommendations

The study provides recommendations for improving the existing solar energy policies more accurately. While all states may not hug the shift to RE, the central government needs to take a closer look at state-specific practicalities and address prevailing institutional inadequacies before moving ahead with its reform agenda. Thus, the study suggests the following recommendations for promoting solar power:

- The enforcement of the RPO policy should be strict. For non-compliance of RPO targets, severe penalties should be imposed on the obligated entities, while market-based incentives should be given to accountable entities for meeting the RPO targets. RECs should be issued for solar thermal power projects using lucrative offers.

- For promoting the most valuable CSP technology in India, MNRE should frame policies that incentivize the solar-fossil hybridization projects because it paves the pathway to a more economical, environment friendly, and reliable supply of electricity. The authors strongly recommend that hybridization should be given first preference wherever possible. Hybridization is possible where coal/gas/biomass-based power plants already exist with adequate land for commissioning CSP plants. Therefore, such possibilities should be identified so that the full benefit of CSP technology can be harnessed.

- For promoting CSP technology, the government should encourage local manufacturing of CSP components and provide incentives to set up manufacturing facilities. This will considerably reduce the cost of CSP components and transform India into a manufacturing hub for CSP with abundant employment opportunities.

This research study suggests that there should be a performance-based financial assistance mechanism for off-grid and decentralized CST projects in place of capital subsidy being provided by MNRE.

In conclusion, there is a technical and economic potential for hybridization of CSP technologies with existing and new conventional thermal power plants within lower to middle capacity ranges. The government bodies should provide incentives for such projects through low-interest loans, introducing carbon tax credits, and proposing higher prices for augmented annual energy generated from renewable technologies.

7.4 Future Scope

The techno-economic and practical feasibility of integrating solar energy for substituting extraction steam utilized for feedwater preheating in existing CFPP in fuel-saving and power-boosting mode is investigated in the current research work. This thesis work is carried out assuming full load condition and without thermal storage option. The following are the future scope of the work:

- In this work, only one CSP technology (PTC) is used for integrating with existing CFPP. Therefore, the study can be further extended by using other CSP technologies such as linear Fresnel, solar tower, and solar dish for integration and comparison can be made.
- This research focuses only on feedwater preheating in the hybrid system; the other integrating options for incorporating solar energy can be investigated and compared.
- The work can also be further extended by using thermal storage options for different durations and using different HTF with relevant parameters.

- The effect of DNI in transient mode and variation in solar multiple for different locations can be explored in future studies.
- The life cycle and exergoenvironmental analysis of solar-coal hybrid TPP can be an excellent option for further research.
- The proposed solar-coal hybrid system can be investigated experimentally.