Distributed Polygeneration Using Solar Energy: A Future Sustainable Energy System for India

Avishek Ray and Sudipta De

Abstract Energy is the key element of modern development. Fossil fuels are presently the major source of energy consumed worldwide. However, this is not sustainable. Fast depletion of limited resources and climate change problem due to emission from these fuels are of major concern. Increasing overall efficiency of energy conversion and use is one option. Moreover, exploring new systems with better utilization of renewable resources may be a possible future sustainable option. Decentralized polygeneration to meet energy and other utility demand with rational use of local resources is emerging as a suitable option. To match the varying demand with intermittent renewable resources, storage could be a good solution. However, suitable low-cost and reliable storage is not yet fully developed. Hybridization of different intermittent renewable resources is a possible option. Countries with enough solar insolation like India may develop suitable hybrid polygeneration with solar inputs. Depending on local need, both solar thermal and photovoltaic utilities may be included in this polygeneration. Efficient system integration with possible optimization of different available local resources based on local needs is the key to successful polygeneration design. In this chapter, a comprehensive review of state-of-the-art solar-based polygeneration will be presented. Multi-objective optimization of hybridization of different available resources to meet local needs will be included in this chapter.

Keywords Polygeneration · Intermittent · Solar · Hybridization

1 Introduction

Energy is the critical input for the advancement of human civilization. There are wide variations in the energy consumption of the developing and the developed countries and also between the rich people and the poor people of the same country.

A. Ray · S. De (✉)
Department of Mechanical Engineering, Jadavpur University, Kolkata 700032, India
e-mail: de_sudipta@rediffmail.com

H. Tyagi et al. (eds.), *Applications of Solar Energy*, Energy, Environment, and Sustainability, https://doi.org/10.1007/978-981-10-7206-2_2

The per capita energy consumption is an indicator of the human development index (HDI) [1]. So with the advancement of science and technology, the total energy consumption in the world is increasing. It is predicted that there will be a 56% rise in the global energy consumption by 2040 [2]. Even in developing countries like India, with the increase in gross domestic product (GDP) the total energy consumption has almost doubled since 2010 [3]. Till now, the major sources of energy are fossil fuels like coal, oil. These fossil fuel reserves are fast depleting. The average annual growth rate of coal and oil consumption is 0.2% and 1.8%, respectively [4]. Moreover, they emit greenhouse gas (GHG) during combustion. In 2014, almost 42% of the global electricity was generated by the coal-fired thermal power plants [5]. At the same time, the coal-fired thermal power plants are responsible for 28% global GHG emission which is a significant contributor to global warming. Even in best practices, the electricity generation from coal emits 0.33 kg of CO_2/kWh [6]. So to meet the increasing load, the share of electricity from renewable sources must be increased as a sustainable option. The two strategies identified to reduce the carbon emission from the energy sector are either increasing the energy efficiency or increasing the share of renewable in the energy sector. Solar-based polygeneration system addresses both of these two issues. Solar energy has a good potential almost in all parts of India. In India, 15% of the total installed capacity is renewable. India ranks fourth in the world in terms of the solar energy installation [7]. The solar energy has the major problem of intermittency in nature. So solar energy is hybridized with some other forms of renewable energy like wind, biomass to mitigate this issue. Polygeneration can be looked after as a superior method of sustainable resource utilization than hybridization. In polygeneration, other utilities may also be generated along with electricity as per the availability of resources to maximally accommodate the variation of the load curve, say, when the electrical load is low but the available resource is high, then some other utilities like potable water, biofuels are generated. The efficient system integration increases the overall efficiency of the system. This reduces the levelized cost of electricity and has environmental benefits. Thus, the distributed polygeneration is a good option for developing sustainable energy systems [8]. It has been seen that in the solar-based polygeneration systems, the energy and the exergy efficiencies have increased marginally, but polygeneration shows a sustainable way of production of multiple commodities from the same system [9]. Ozlu et al. [10] have shown that in a solar-based polygeneration system producing electricity, heat, freshwater, and hydrogen the exergy and the energy efficiencies are found to be 36% and 44%, respectively. The polygeneration system has reduced the annual carbon emission by 476 tons than the conventional systems generating the same utility outputs. Khalid et al. [11] designed a multi-generation system producing electricity, space heating, cooling, and hot water. The energy and the exergy efficiencies of the system are to be 91 and 34% which are higher than the energy and the exergy efficiencies of the conventional systems.

In this chapter, the potential use of solar-based polygeneration as a distributed energy system is discussed. The possible method of design of reliable power supply with intermittent solar resources is discussed here. These systems need suitable control strategies to operate efficiently and with maximum reliability.

2 Advantages and Disadvantages of Solar Energy

The solar energy has many advantages [12]. Nowadays, the electricity consumption of the whole world is increasing. So, more power has to be generated by the conventional fossil fuel-based power plants. The fossil fuel-based power plants are polluting. The global emission factor for the coal-based thermal power plants is 532 g CO_2/kWh [13]. The solar energy is non-pollutant in nature. But solar energy has some disadvantages. It is intermittently available. So there is always a mismatch between the demand and supply. The maximum load occurs during the evening when solar energy is not available. Thus, there is a need of storage systems. Hybridization is another option to solve this problem. The problems of electrochemical storage are discussed later.

From the economic point of view, also the solar energy has many advantages and disadvantages. The maintenance cost of solar energy-driven devices and systems are very low. But the initial cost of installation of the solar energy systems is very high. Hence, for the developing countries like India, formulation of proper policy is needed to promote the growth of solar energy in India. The solar energy policy will simultaneously help to meet the global emission standards along with the reduction in the dependence on fossil fuels for energy.

2.1 Essence of Formulating Solar Energy Policy

The Intergovernmental Panel on Climate Change (IPCC) opined that the GHG emission must be reduced by 50% from that of 1990 standard by 2050 in order to keep global warming below 2 °C So the global policy makers met several times to discuss this issue [14, 15]. The different climatic policies in this regard are given in Table 1. Almost all the policies were introduced by United Nations Framework Convention on Climate Change (UNFCC).

Thus, in all these summits, it was unanimously decided by all policy makers to reduce the GHG emission. The two possible ways to reduce the GHG emission identified in the energy sector are either increasing energy efficiency or increasing the share of renewable in the power mix.

The solar polygeneration addresses both of these issues simultaneously. But from the above discussions, it is observed that solar energy has both advantages and disadvantages. Moreover, the disadvantages are not related to technology only, but there are also socio-economic problems. Hence, to accelerate the growth of solar energy, many countries of the world have adopted solar policies as shown in Table 2 [4].

Table 1 Some important climate change mitigation policies

Serial no	Protocol name	Place	Year	Main feature
1	Kyoto protocol	Kyoto, Japan	1997	The Kyoto Protocol was introduced by United Nations Framework Conventions on Climate Change to restrict emission. Emission targets were set to the participating nations
2	Cancun agreements	Mexico	2010	It was decided that the developed nations will annually mobilize 100 billion USD to developing nations as climate protection fund
3	Durban platform for enhanced action	South Africa	2011	Opinion of legal framework formulation was considered to all members of the United Nations. In this agreement, an attempt was made bring the emission targets under a legal framework
4	Paris agreement	Paris, France	2016	The climate change is considered as an urgent threat. The specific areas of fund and technology transfer of the developing nations are identified. The protocols of the technology transfer was vested on the individual nations

Table 2 Solar policies in different countries of the world

Name of country	Salient features
USA	• Incentives for solar energy projects under Public Utilities Regulatory Policy Act • Tax benefit was announced for both investment and selling • There was the provision for net metering
Canada	• Feed in tariff was applicable to the parties installing the solar energy devices • Government subsidy
European countries (Germany, Spain, France)	• Feed in tariff • Government subsidy • Incentives are given to both parties, buyer and seller, of electricity from renewable sources • Definite target was set for renewable power generation and carbon emission
China	• Framing of specific renewable energy law. The concept of renewable power purchase obligation was introduced • Purchasing of photovoltaic power was made mandatory to power companies • Increase in research fund for the development of these technologies • Government fund allocation was for the decentralized projects • PV industry chain was established

2.1.1 Initiatives by the Indian Government for Promotion of the Solar Energy

In India, Electricity Act 2003 was passed in the parliament which laid emphasis on rapid electrification of the unelectrified villages [16]. The supply of power from the large coal-based power plants is not feasible always due to economic reasons as well as adverse terrain conditions. Moreover, the number of consumers in many places is very low. So it is not profitable to use grid power to electrify these villages. In such places, the solar power is more relevant. After this, the Government of India has also launched many programmes like Rajiv Gandhi Grameen Vidyutikaran Yojana and Deendayal Upadhyay Yojana to expedite the rural electrification in India.

After this, the Jawaharlal Nehru National Solar Power Mission was launched which has the target of installing 20,000 MW by 2022 and achieved the grid parity by the same year [17]. Thus, in India, solar power development is mainly driven by international norms to reduce carbon footprint and rapid rural electrification. After the national policy, the various states of India have also adopted solar energy policies based on the resource availability and other socio-economic factors.

3 Availability of Solar Resources in Different Parts of India

Solar radiation is available in situ at the place of its utilization, i.e. it need not to be transported from distance places like coal, oil to the place of utilization. In India, the solar energy is used in many sectors such as water heating, cooking, cooling, desalination, drying, and steam generation. The route of utilization mainly depends on the need of the local people. To select the suitable technology, the resource estimation is very vital. In India, the statewise availability of solar resources is carried out by Ministry of New and Renewable Energy as shown in Fig. 1 [18].

The cooking is done by solar cookers. Solar dryers are common in rural areas. The desalination is mainly useful in the coastal areas. This is done by the solar still working on the principle of thermal distillation of water and its subsequent condensation at low temperature. The solar still generates potable water from the saline water. Solar cooling is done by the vapour absorption cooling system. Solar water heating is done by evacuated or the flat plate collectors using the thermosyphon system. The availability of the solar resource determines the particular type of technology for the use of solar energy.

Thus, it is shown in Fig. 1 that the maximum solar power potential lies in the western and the northern states of India. Polygeneration is an effective outcome of efficient system integration. In solar-based polygeneration, one or more other outputs are there with electricity. Other utility outputs may be decided according to local needs.

Fig. 1 Solar power potential in different states of India in MW

4 Routes of Solar Energy Utilization

The solar energy can be used in various routes as shown in Fig. 2. The solar thermal conversion implies the capturing of the solar heat and using it in many processes. Solar photovoltaic and thermophotovoltaic are the means for conversion of solar energy directly to electricity. The solar thermal energy is captured by the various types of solar collectors. The solar photovoltaic effect is achieved by the semi-conductor devices which can directly produce electricity when the photons are incident on it. Thermophotovoltaic devices directly convert heat to electricity.

4.1 Different Types of Solar Collectors

There are various types of solar collectors based on the principle of operation. The types of solar collectors are shown in Fig. 3. The various types of collectors have different efficiencies and areas of applications.

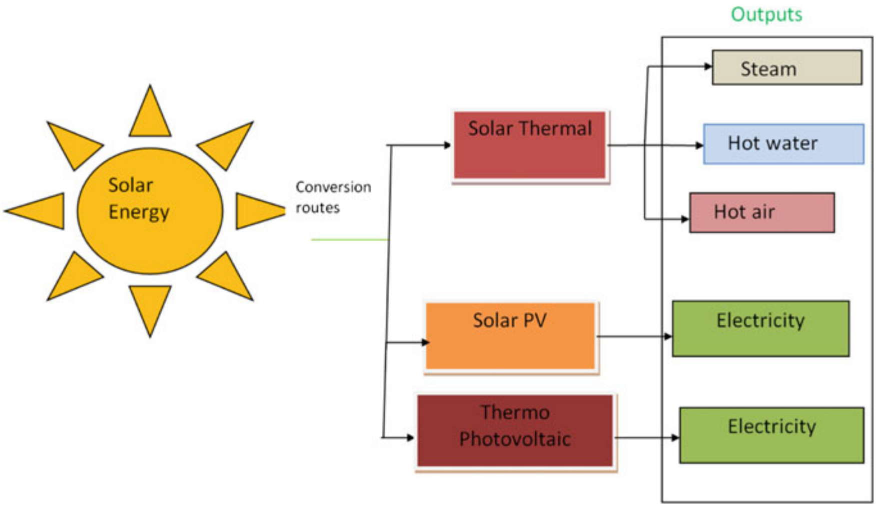

Fig. 2 Routes of solar energy conversion

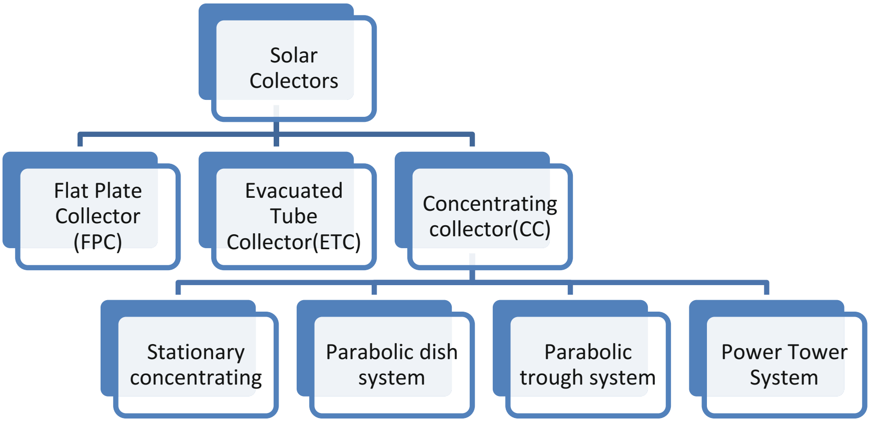

Fig. 3 Various types of solar collectors

The various application areas and efficiency ranges of these collectors are shown in Table 3 [19]. However, the most commonly used collectors are the evacuated tube collector (ETC) and the flat plate collector (FPC). The selection of collectors is made depending on the resource availability and economic issues.

Table 3 Application areas of different types of solar collectors

Type of collector	Temperature range	Application areas
Flat plate collector	80–100 °C	Low-temperature heat is output. Used for water heating, space heating
Evaluated tube collector	120–150 °C	Low-temperature heat is output. Used for water heating, space heating, industrial process heat, solar cooling, and desalination
Parabolic trough	150–300 °C	Industrial process heat
Parabolic dish	Greater than 1500 °C, but it is rarely used	Electricity generation and industrial process heat

4.2 Different Types of Solar Cells

With the advancement in the field of material science, different types of solar cells have come into existence. One has the advantage over the other, but has certain disadvantages also; for example, the organic solar cells need less input energy than the crystalline solar cells, but the efficiency is too low. The various types of solar cells based on the junction characteristics with highest laboratory scale efficiencies are given in Fig. 4 [20]. The numbers in the brackets indicate efficiencies. Till now, the most widely used solar cells are silicon solar cells.

The efficiency of the solar cells depends on the method of fabrication and the material used, say, the efficiency value of the thin film and the crystalline solar cells varies. Moreover, the energy trapped by the device depends on the nature of the semiconductor junction. So in general, the multi-junction solar cells have higher

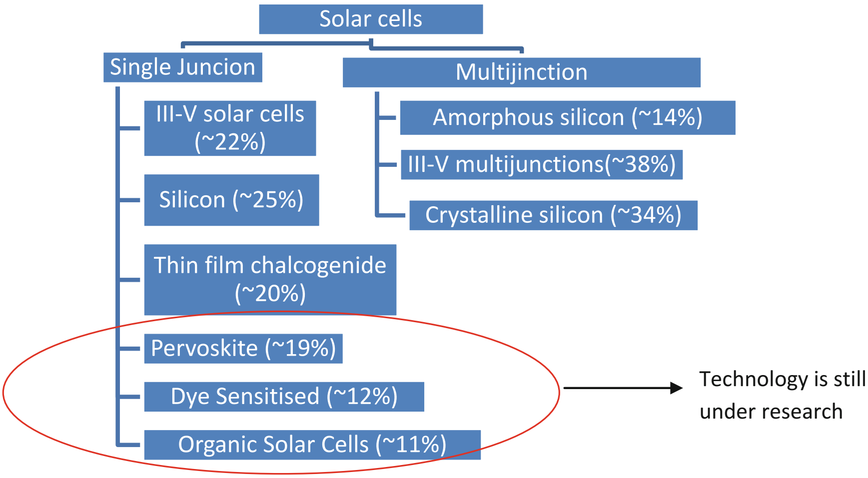

Fig. 4 Different types of solar cells

efficiencies than the single junction solar cells. But their fabrication is costly and hence less used commercially. These are III-V cells, GaAs and the InP cells. The thin film chalcogenide include the CIGS (CuInGaSe2) and CdTe cells [21]. The organic solar cells are made up of organic materials like polyaniline. Thus, with the suitability of application, each type of solar cell is used.

The main application areas of the solar photovoltaic (SPV) are home lighting, water pumping, desalination, and thermophotovoltaic application [21].

5 Intermittency of Renewable and Need for Polygeneration

Though the renewable energy sources are clean, these are intermittent and dilute too. The renewable sources of energy are not available as per the demand of the consumers, i.e. following the load curve. Hence, storage of energy is necessary for efficient operation. When the resource is available but the demand is low, the energy may be stored or utilized for some other purposes. Thus, to patch up the mismatch between resource availability and instantaneous power demand, polygeneration may be viewed as an effective way

5.1 Definition of Polygeneration

Polygeneration is the efficiently integrated process of generating multiple outputs from a single system [22].

In addition to electricity, potable water is also a generally required utility. The economic values of these utilities are added, and the system becomes economically more profitable and socially acceptable. Thus, the polygeneration system is beneficial from the economic, environmental, and the local resource utilization point of view [23]. The solar resources are available only at particular hours of the day. But consumption pattern does not vary in the same way as the insolation varies; i.e., solar radiation is unavailable at night, and the maximum electricity load occurs during evening [24]. To cope with such mismatch of demand and supply storage, hybridization and polygeneration are different options to give a reliable power supply [20]. Polygeneration proves to be environmentally and economically beneficial than the other two options, i.e. hybridization and storage [24, 25]. The basic schematic of a polygeneration system is shown in Fig. 5. Polygeneration can be viewed upon as a means of efficient resource utilization. Here, the possible available resources are utilized to cater the needs of the local people.

Fig. 5 Schematic of a polygeneration system

5.2 Problems of Electrochemical Storage

The need of storage is shown in Fig. 6a, b. The oldest form of electricity storage is done by using batteries [26]. The battery storage systems have the high efficiency but have many environmental impacts. Moreover, most of the batteries are to be replaced after five years. On the other hand, most of the renewable energy systems should have a life of above twenty years to be economically feasible.

During the period when the renewable energy (RE) generated is higher than the instantaneous load, power is fed to the storage device and vice versa. Thus, storage may be one of the options to meet fluctuations of the demand and supply. But it has several limitations regarding capacity, environment, and economic aspects.

5.3 Hybridization of Solar Energy Devices for Polygeneration

Solar energy is to be hybridized with some other renewable sources to get an uninterrupted power supply. The possible hybridization options of solar energy utilization are shown in Fig. 7.

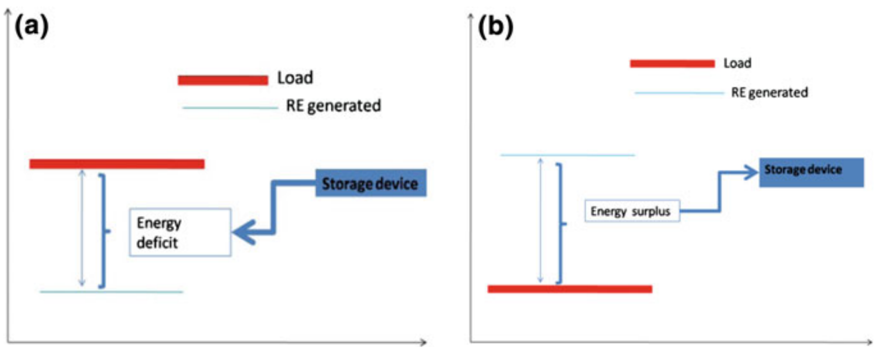

Fig. 6 **a** Energy from storage device (SD). **b** Energy to storage device (SD)

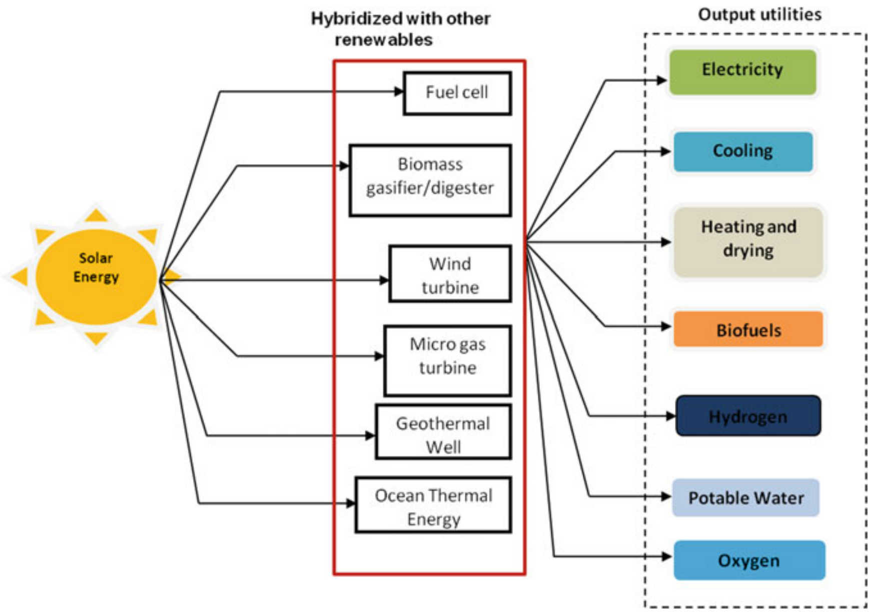

Fig. 7 Possible hybridization options and output utilities

In a polygeneration with solar and biomass inputs, solar–biomass hybrid system may be the option. When the solar radiation is high, then a part of the total syngas generated by the biomass gasifier system may be used to produce ethanol. During night, with no solar radiation, the entire syngas is used to generate electricity. Thus, both the utilities like ethanol and electricity are obtained [24]. Generally, solar energy alone (thermal or photovoltaic) cannot be used for polygeneration. Some literature of solar–hybrid polygeneration is referred to in Table 4.

Biomass is abundantly available in villages of India. So, solar energy is hybridized with biomass. In polygeneration, solar thermal integrates better than solar photovoltaic applications. The generic output utilities of solar-based polygeneration are electricity, potable water, heating, cooling, etc. However, this depends on location and the type of devices used for fabricating the system. The costs of generation of the same utility outputs are less than those generated by the stand-alone units. This is the purpose of developing integrated polygenerations.

5.4 Operation and Control of Polygeneration System

The basic schematic diagram of operation and control is shown in Fig. 8. The optimization of polygeneration is a multi-criteria problem. In most of the cases, the optimization is important for both the demand-side and the supply-side

Table 4 Solar hybrid polygeneration system

Author name (Year)	Routes		Type of hybridization	Input	Output
	Photovoltaic	Thermal			
Kribbus and Mittleman (2007) [27]	√	√	Heat engine	Solar energy	Electricity and heat
Calise (2011) [28]		√	Solid oxide fuel cell	Solar energy	Electricity, cooling, heating
Calise et al. (2012) [29]	√	√	Fuel cell	Solar energy	Electricity, cooling, heating
Calise et al. (2012) [30]		√	Reciprocating engine fed by vegetable oil	Solar energy and vegetable oils	Electricity, heating, and cooling
Rivalro et al. (2012) [31]		√	Wind turbine, wind turbine-based microgrid	Solar energy and wind	Electricity, heating and cooling
Ozturk and Dincer (2013) [32]		√		Solar energy	Electricity, heating, cooling, hydrogen, and oxygen
Al-Ali and Dincer (2014) [33]		√	Geothermal well	Solar and geothermal energy	Electrical power, cooling, space heating, hot water, and heat for industrial use
Aichmayer (2014) [34]		√	Microgas turbine	Solar-assisted microgas turbine	Electricity, hot water, and cooling
Suleman et al. (2014) [35]		√	Geothermal well	Solar and geothermal energy	Electricity, drying, and cooling
Buonomano et al. (2016) [36]	√	√	The entire cogeneration system is coupled with a gas turbine cogeneration	Solar energy, natural gas	Electricity, cooling, domestic hot water
Bai et al. (2015) [37]		√	Biomass gasifier	Solar energy and biomass	Electricity and methanol
Sahoo et al. (2015) [38]		√	Biomass gasifier	Solar energy and biomass	Electricity, cooling, heating and water
Khalid (2015) [39]		√	Biomass gasifier	Solar and biomass	Electricity, cooling, hot water, heated air

(continued)

Table 4 (continued)

Author name (Year)	Routes		Type of hybridization	Input	Output
	Photovoltaic	Thermal			
Ahmadi et al. (2015) [40]	√	√	Ocean thermal energy	Solar and ocean thermal energy	Electricity, freshwater, cooling, and hydrogen
Khan and Martin (2015) [41]	√		Biogas from a digester	Solar energy and biogas	Electricity, biogas, drinking water
Calise et al. (2017) [42]		√	Geothermal energy	Solar and geothermal energy	Electricity, desalinated water, heating, cooling
Islam and Dincer (2017) [43]		√	Geothermal energy	Solar and geothermal energy	Electricity, heating, and cooling
Mata-Torres et al. (2017) [44]		√	None	Solar energy	Electricity and desalinated water
Sahoo et al. (2017) [23]		√	Biomass gasifier	Solar energy and biomass	Electricity, cooling, and potable water
Dincer et al. (2017) [11]		√	Biomass gasifier	Solar energy and biomass	Electricity, cooling, hot water, and space heating

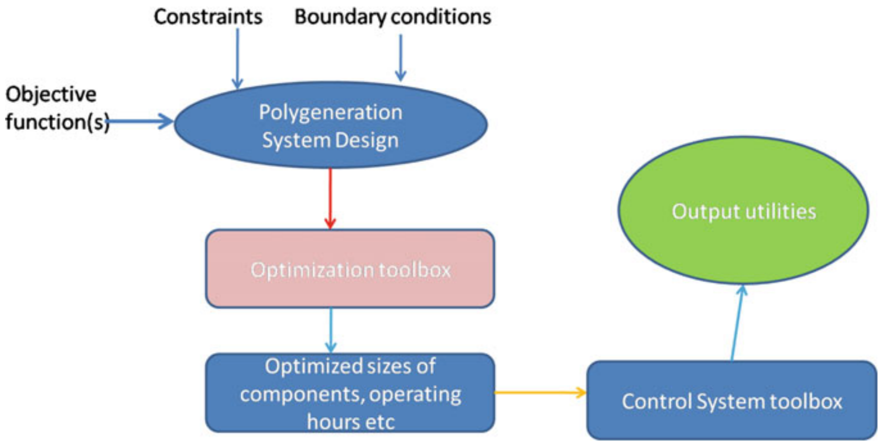

Fig. 8 Scheme of optimization and control of polygeneration

management of the polygeneration systems. Various optimization algorithms such as genetic algorithm, mixed-integer linear programming and nonlinear programming, genetic algorithm are used for the design of the polygeneration systems [45, 46]. Another approach for the optimization is using the expectancy and the probabilistic models taking into consideration. This is very important when the prospective planning of an energy supply of a particular area is needed along with the system design.

Control of solar-based polygeneration system is very important from the demand-side management (DSM) point of view. In most of the cases, the solar energy is hybridized with some other forms of energy to get the reliable power supply. In this context for most of the cases, the model predictive control and the optimal control strategies are used [47, 48]. This control system is achieved by the applications of programmable logic controller (PLC) [49].

6 Conclusions

With the increasing energy demand and threat of climate change due to existing fossil fuel-based energy systems, development of efficient renewable energy systems is a present imperative need. With abundant availability of solar radiation, solar energy systems are considered to be effective for Indian energy need in a sustainable way. However, non-availability at night and unpredictability of availability of solar power over the year, demands for “hybridization” of solar energy systems and such systems emerge to provide reliable continuous power supply. Polygeneration including solar power hybridized with renewable resources like biomass and several other utility outputs like potable water, ethanol, heating, cooling can be a future sustainable option, specifically for Indian application. Polygeneration is a process to build a new energy system through efficient process integration. The process integration increases the efficiency of the system. The better process integration will result in the better output of the polygeneration system. A review of available technologies along with state-of-the-art development as available in the literature is reported in this chapter.

References

1. Gae A (2008) Access to energy and human development. http://hdr.undp.org/en/content/access-energy-and-human-development. Accessed 20 May 2017
2. US energy information administration. https://www.eia.gov/todayinenergy/detail.php?id=12251. Accessed 20 May 2017
3. India energy outlook. https://www.iea.org/publications/freepublications/publication/IndiaEnergyOutlook_WEO2015.pdf. Accessed 11 May 2017

4. Solangi KH, Islam MR, Saidur R, Rahim NA, Fayaz H (2011) A review on global solar energy policy. Renew Sustain Energy Rev 15:2149–63. https://doi.org/10.1016/j.rser.2011.01.007
5. Electricity production from coal sources. http://data.worldbank.org/indicator/EG.ELC.COAL.ZS. Accessed 20 May 2017
6. Carbon dioxide uncontrolled emission factors. https://www.eia.gov/electricity/annual/html/epa_a_03.html. Accessed 20 May 2017
7. http://pib.nic.in/newsite/PrintRelease.aspx?relid=155612. Accessed 21 May 2017
8. Alanne K, Saari A (2006) Distributed energy generation and sustainable development. Renew Sustain Energy Rev 10:539–58
9. Hoggerward J, Dincer I, Naterer GF (2017) Solar energy based integrated system for power generation, refrigeration and desalination. Appl Therm Eng 121:1059–1069
10. Ozlu S, Dincer I (2016) Performance assessment of a new solar energy based multigeneration system. Energy 112:164–178
11. Khalid F, Dincer I, Rosen M (2017) Thermo-economic analysis of a solar-biomass-integrated multigeneration system for a community. Appl Therm Eng. https://doi.org/101016/j.applthermaleng.2017.03.040
12. Tsoutsos T, Frantzeskaki N, Gekas V (2005) Environmental impacts from the solar energy technologies. Energy Policy 33:289–96
13. Rydh CJ, Svärd B (2003) Impact on global metal flows arising from the use of portable rechargeable batteries. Sci Total Environ 302:167–84
14. European environment agency. http://eu/data-and-maps/daviz/dominant-remediation-technolog. Accessed 28 April 2017
15. Paris agreement. http://www.ec.europa.eu/clima/policies/international/negotiations/paris/index. Accessed 01 May 2017
16. Electricity act. http://www.cercind.gov.in/Act-with-amendment.pdf. Accessed 18 May 2017
17. MNRE. http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/. Accessed 18 May 2017
18. MNRE. http://www.data.gov.in/catalog/state-wise-renewable-energy-potential. Accessed 10 May 2017
19. Rabl A (1985) Survey of solar equipments and applications. Active solar collectors and their applications, p 3–11
20. Green M, Emery K, Hishikawa Y, Warta W, Dunlop E, Levi D (2017) Solar cell efficiency tables(version 49). Prog photovolt Res Appl 25:3–13
21. Pandey AK, Tyagi VV, Selvaraj JA, Rahim NA, Tyagi SK (2016) Recent advances in solar photovoltaic systems for emerging trends and advanced applications. Renew Sustain Energy Rev 53:859–84. https://doi.org/10.1016/j.rser.2015.09.043
22. Serra LM, Lozano MA, Ramos J, Ensinas AV., Nebra SA (2009) Polygeneration and efficient use of natural resources. Energy 34:575–86. https://doi.org/10.1016/j.energy.2008.08.013
23. Sahoo U, Kumar R, Pant PC, Chaudhary R (2017) Development of an innovative polygeneration process in hybrid solar-biomass system for combined power, cooling and desalination. Appl Therm Eng 120:560–7. https://doi.org/10.1016/j.applthermaleng.2017.04.034
24. Ray A, Jana K, De S (2017) Polygeneration for an off-grid Indian village: optimization by economic and reliability analysis. Appl Therm Eng 116:182–96. https://doi.org/10.1016/j.applthermaleng.2016.11.020
25. Jana K, De S (2017) Environmental impact of biomass based polygeneration—A case study through life cycle assessment. Bioresour Technol 227:256–65. https://doi.org/10.1016/j.biortech.2016.12.067
26. Aneke M, Wang M (2016) Energy storage technologies and real life applications—a state of art review. Appl Energy 179:350–77
27. Kribbus A, Mittleman G (2008) Potential of polygeneration with solar thermal and photovoltaic systems. Int J Sol Energy Eng 130:1101-1-01101–5
28. Calise F (2011) Design of polygeneration system with solar collectors and solid oxide fuel cell: dynamic simulation and economic assessment. Int J Hydrogen Energy 36:6128–50

29. Calise F, Polombo A, Vanoli L (2012) Design and dynamic simulation of a novel polygeneration system fed by vegetable oil and solar energy. Energy Convers Manag 60:32–7
30. Calise F, D'Accadia MD, Vanoli L (2012) Design and dynamic simulation of a novel solar trigeneration system based on hybrid photovoltaic/thermal collectors (PVT). Energy Convers Manag 60:214–25. https://doi.org/10.1016/j.enconman.2012.01.025
31. Rivalro M, Greco A, Massardo A (2013) Thermo-economic optimization of the impact of renewable generators on polygeneration smart grids including hot thermal storage. Energy Convers Manag 65:75–83
32. Ozturk M, Dincer I (2013) Thermodynamic analysis of a solar-based multi-generation system with hydrogen production. Appl Therm Eng 51:1235–44. https://doi.org/10.1016/j.applthermaleng.2012.11.042
33. Al-Ali M, Dincer I (2014) Energetic and exergetic studies of a solar multigenerational geothermal system. Appl Therm Eng 71:16–23
34. Aichmayer J, Spelling J, Lambert B (2013) Small scale hybrid solar plants for polygeneration in rural areas. Energy Procedia 57:1536–45
35. Suleman F, Dincer I (2014) Development of an integrated renewable energy system for multigeneration. Energy 78:196–204
36. Rady M, Amin A, Ahmed M (2015) Conceptual design of a small scale multi-generation concentrated solar plant for a medical centre in Egypt. Energy Procedia 83:289–98
37. Bai Z, Liu Q, Lei J, Jin H (2015) A polygeneration system for methanol production and power generation with solar-biomass thermal gasification. Energy Convers Manag 102:190–201
38. Sahoo U, Kumar R, Pant P, Chaudhury R (2015) Scope and sustainability of hybrid solar-biomass plant with cooling, desalination in polygeneration process in India. Renew Sustain Energy Rev 51:304–16
39. Khalid F, Dincer I, Rosen M (2015) Energy and exergy analyses of a solar biomass integrated cycle for multigeneration. Sol Energy 112:209–99
40. Ahmadi P, Dincer I, Rosen M (2015) Performance assessment of novel solar and ocean thermal energy conversion based multi generation system for coastal areas. J Sol Energy Eng 137:11013-1-011013–12
41. Khan E, Martin A (2015) Optimization of hybrid renewable energy polygneration system with membrane distillation for rural households in Bangladesh. Energy 93:1116–27
42. Calise F, Macaluso A, Piacentino A, Vanoli L (2017) A novel hybrid polygeneration system supplying energy and desalinated water by renewable sources in pantelleria island. Energy. https://doi.org/10.1016/j.energy.2017.03.165
43. Islam S, Dincer I (2017) Development, analysis and performance assessment of a combined solar and geothermal energy based integrated system for multigeneration. Sol Energy 328–43
44. Mata-Torres C, Rodrigo A, Escobar R, Cardemil J, Simsek Y, Matute J (2017) Solar polygeneration for electricity production and desalination. Renew Energy 101:387–98
45. Rubiyo-Mata C, Marcuello-Uche J, Martinez-Gracia A, Bayod-Rujula A (2011) Design optimization of polygeneration plant fuelled by natural gas and renewable energy sources. Appl Energy 88:449–57
46. Bracco S, Delfino F, Pamparo F, Robba M, Rossi M (2015) A dynamic optimization-based architecture for polygeneration microgrids. Energy Convers Manag 96:511–20
47. Menon R, Paolone M, Marechal F (2013) Study of optimal design of polygeneration in optimal control strategies. Energy 55:134–41
48. Menon R, Paolone M, Marechal F (2016) Intra-day electro-thermal model predictive control for polygeneration microgrid. Energy 104:308–19
49. Delfino F, Rossi M, Miniciardi R, Robba M (2015) An optimization based architecture for local systems managed by PLC devices. IEEE Int Symp Syst Eng

http://www.springer.com/978-981-10-7205-5

Applications of Solar Energy

Tyagi, H.; Agarwal, A.K.; Chakraborty, P.R.; Powar, S.
(Eds.)

2018, XVII, 364 p. 189 illus., 133 illus. in color.,
Hardcover
ISBN: 978-981-10-7205-5