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Review

A Comparative Study on System Profit Maximization of a Renewable Combined Deregulated Power System

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Abstract: Electrical energy plays a key role in the development of the social as well as the economic front. The power sector has historically been owned and operated by state agencies due to its tremendous importance. It has been restructured over time, and the power market is being deregulated. In terms of consumer prices, efficiency, and environmental implications, both regulated and deregulated electricity markets offer advantages and disadvantages. Policy-based techniques are typically used in regulated markets to address the costs of fossil-fuel resources and boost the viability of renewable energy sources. Renewables can be integrated into deregulated markets through a combination of regulatory and market-based measures to extend the system's economic stability which has been deployed in this paper. As the need for energy has expanded dramatically over the last few decades, particularly in developing countries, the amount of greenhouse gas emissions has climbed rapidly, as have fuel prices, which are the key driving forces behind initiatives to use renewable energy sources more effectively. Despite the apparent benefits of renewable energy, it has significant downsides, such as generation of optimization methods applied to renewable consistency, because most renewable energy supplies are climate-dependent, necessitating complicated design, planning, and control optimization methods. There have been numerous optimization strategies applied to the renewable integrated deregulated electricity system. With the increased use of renewable energy, energy storage technology has grown in importance, as these devices can capture electricity generated by renewables during off-peak demand hours and put it back into the grid during peak demand periods. Using stored renewable energy instead of adding generation based on fossil fuel can help to minimize greenhouse gas emissions. There is an interest in better utilizing available power system capacity by implementing FACTS to maximize the social benefit in a deregulated system. As a result, effective FACTS device placement provides novel control capabilities in both steady-state power flow regulation and dynamic stability control. This study reviews several aspects of renewable integrated deregulated power systems and provides a clear picture of the most recent research developments on this subject. The main objectives of the reviews are the maximization of system profit, maximization of social welfare, and minimization of system generation cost and loss by optimal placement of energy storage devices and FACTS controllers.

Keywords: regulated system; deregulated system; energy storage devices; modern power system; profit

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1. Introduction

Nowadays the electricity demand is increasing rapidly due to the modernization and advancement in technologies in all aspects of human life. Humans always want to maintain or increase their life comfort day by day. Conventional energy sources fulfill the maximum electricity demand to date but non-conventional energy sources are also required to minimize the rising burden on raw materials of conventional energy sources [1,2]. As per the US EPA survey, greenhouse gases are one of the most air-infecting agents. Almost 32% of total greenhouse gas was generated from the US power sector in the year 2012, with an increment of 11% from 1990. The surveys of this report only highlighted the case of the US, but after going through many reports it can reveal that the entire world faces the same problem regarding the production of greenhouse gases from the power sector. To minimize the level of air contamination, the arrangement of renewable energy sources for electricity production is a necessity. To cope with this issue, the power sector has given a vital and large area to the renewable power sector [3–5]. Renewable energy is created from natural sources, which are continually reinstated. Non-conventional energy is the main focus of this modern era due to the much lower environmental effect than conventional energy sources and has become the solution to the world's increasing energy needs [6]. A budding number of nations are recognizing the social, economic, and environmental benefits of renewable energy and are moving toward it [7,8]. Society's rising concern for the environment and the gradually rigorous guideline of emissions in the power sector have driven strategies to raise the expanse of renewable energy in the electricity market. Electricity creation from renewable sources generates slight or often zero emission of pollutants compared to fossil fuel generating technology.

One of the most significant worldwide energy developments of the previous century has been the deregulation and restructuring of the power supply industry. Before the 1980s, most countries relied on government monopolies to finance, build, own, and run their electrical distribution networks. More than 30 nations or parts within nations have implemented plans to overhaul their power supply industries since the mid-1990s. Generation, transmission, and distribution are all autonomous authorities in the deregulated electricity market. The key benefits of a deregulated approach include lower costs, lower rates, more options, and better service. Electric service providers all across the world are shifting away from vertically integrated mechanisms and toward an open market structure.

Mass deployment of renewables has introduced several new players and new devices into the energy market [9–12], and coupled with deregulation changed the scope of activity for many of the existing players [13,14]. The following entities can be identified on a wide level: generator companies (GENCOS), transmission companies (TRANSCOS), distribution companies (DISCOS), independent system operator (ISO), market operators, or retailer and customers [15]. Opening up the electrical sector to competition is a key technique for improving power generation efficiency and thereby benefiting customers. Vertically integrated utilities could recover their costs regardless of how efficiently they functioned. However, the emergence of competition has resulted in a significant departure from this method. Producers' exclusive rights to create and supply electricity no longer protect them. Competitive markets drive generators to develop and operate as efficiently and cost-effectively as possible to stay in business and recover their costs [16]. Customers and industry participants benefit from a competitive power market in a variety of ways. The majority of the benefits stem from the declination in electricity prices as industrial participants compete for the purchase of their electricity and services [17]. Other advantages of establishing a competitive electricity market include the following: cheaper electricity, efficient capacity expansion planning, pricing is cost reflective rather than a set tariff, cost minimization, more choice, better service, more employment [18]. Figure 1 depicts the basic structural difference between the regulated and deregulated power industry. The system controller is not present in the regulated power industry, which is present in deregulated power system. Due to the competitiveness among the market players in deregulated power systems, the customer gets high-quality power at lower prices.

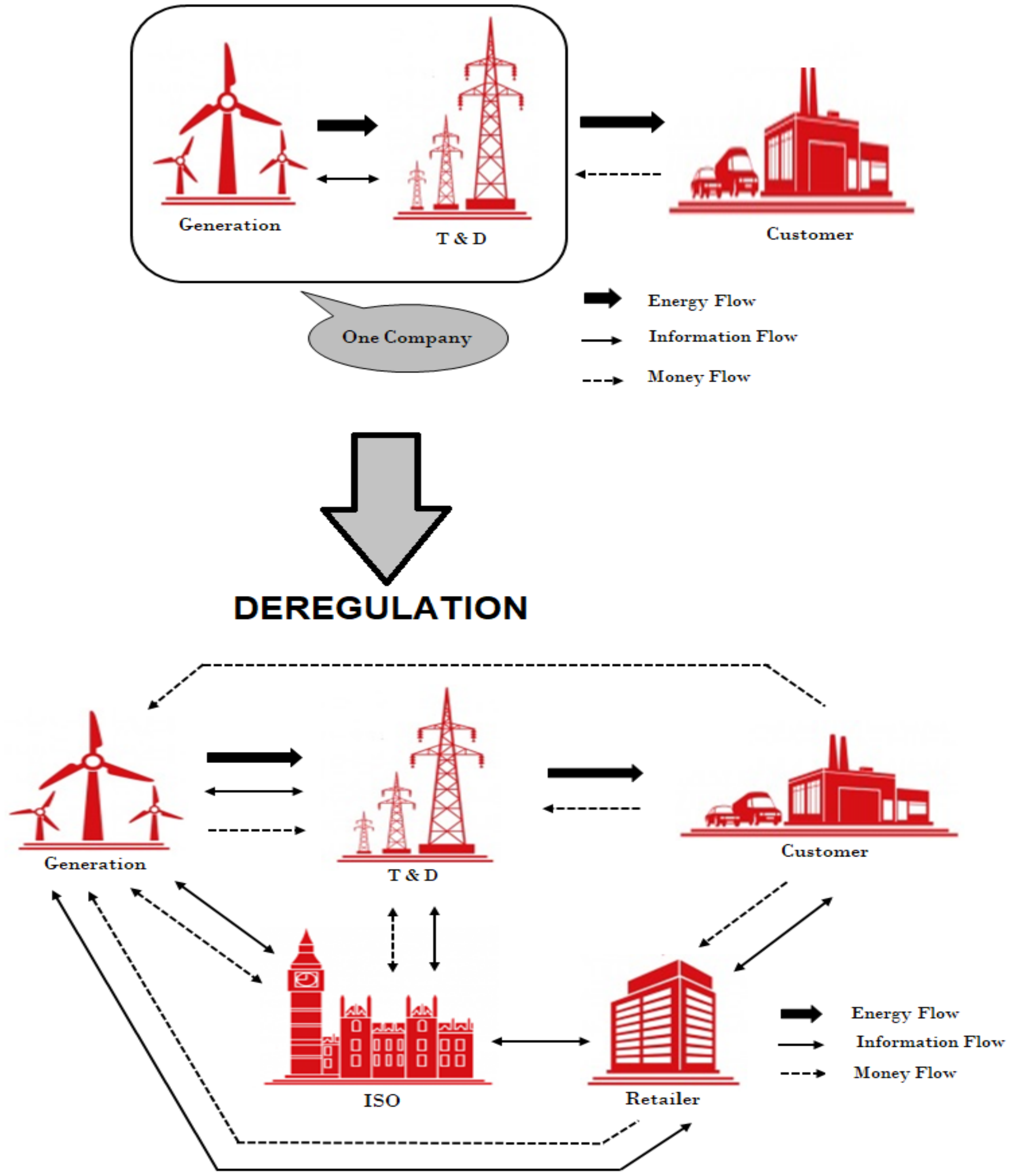

Figure 1. Structure of Regulated and Deregulated Power Industry.

To promote competition, efficiency, and economy in the operations of the electricity industry, the Government of India created regulatory commissions in 1998 under the Electricity Regulatory Commissions Act 1998 (Central Law). The restructuring was first implemented at the Orrisa State Electricity Board, then spread to numerous other states. In collaboration with the State Electricity Regulatory Commission, the Central Electricity Regulatory Commission (CERC) plays a critical role in rationalizing the tariffs of generating companies that are owned or controlled by the Central Government (SERC) [19,20].

It is safe to say that the deregulation of the electric power sector has taken hold and that operations will never be the same again. This brings up a whole new set of concerns and problems that will present a challenge and learning opportunity for power engineers in the years to come.

This paper reviews several aspects of renewable integrated deregulated power systems and provides a clear picture of the most recent research developments on this subject. In a deregulated power system, every market player wants to maximize their economic profit. This can only be possible by using renewable energy sources, energy storage, FACTS device placement, and adopting other modern optimization techniques. This paper reviews all the possible techniques with their benefits and limitations. The organization of this paper is as follows:

Section 1: Introduction to regulated and deregulated systems.
Section 2: Status of Renewable Energy Integration.
Section 3: Status of Flexible AC Transmission Systems (FACTS Devices)
Section 4: Status of Energy Storage Devices
Section 5: Literature Studies of Renewables and FACTS Devices in Deregulated System
Section 6: Conclusions

2. Status of Renewable Energy Integration

The world's energy production has continuously grown over the past half a century, reaching approximately 14,165 Mtoe in 2020. Between 2000 and 2020, energy production increased by 1.4 times with an average increment of 1.7% per year [21]. Figure 2 displays the year-wise total energy production scenario throughout the world for the last 20 years. There is a clear indication of increased energy production in recent years from the previous time. To date, non-renewable sources contribute almost 90% of the total energy mix.

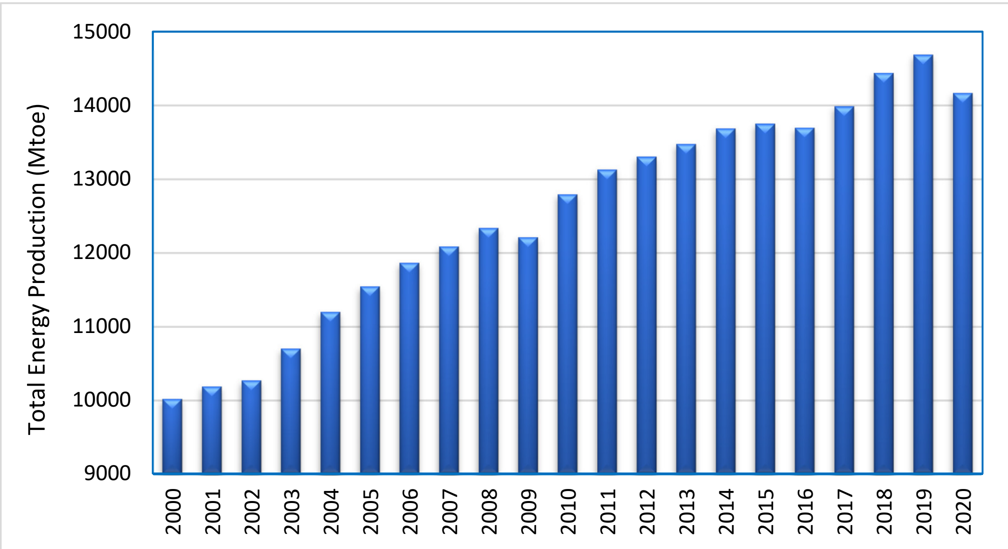

Figure 2. Yearly Total Energy Production in World in Mtoe.

The share of global primary energy is depicted in Figure 3. From the study, it is obtained that coal, natural gas, and oil are the main sources of energy with a contribution rate of 83%, whereas renewables only contribute 6% [21]. During the last few decades, fossil fuel consumption has increased resulting in depletion of the natural reserves and contributing to the CO_2 emission that has increased by an average of 1.5% per year between 2000 and 2020, which is shown in Figure 4.

Thus, it is necessary to increase the use of renewable, eco-friendly energy sources so that planet earth can be protected. As energy is consumed in different forms, electrical energy is the most convenient form being used today. Electricity production has seen an average growth of 2.8% per year in which the contribution from renewable has grown by 1.5 times between 2000 and 2020. The year-wise total electricity production status of the entire world has shown in Figure 5.

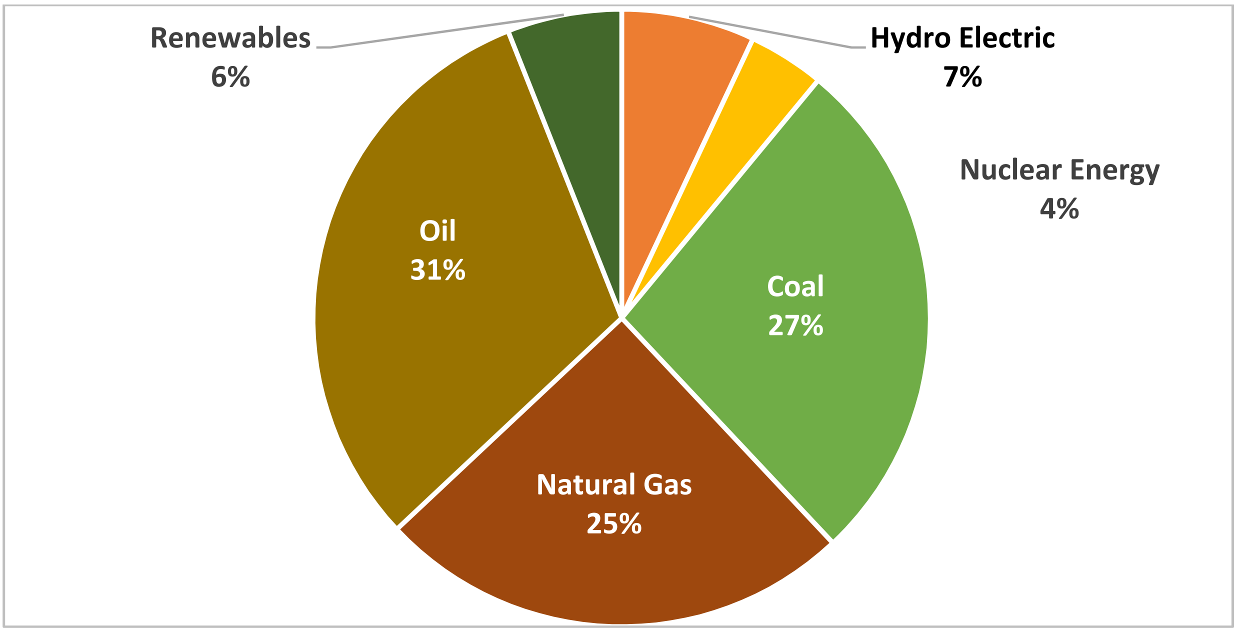

Figure 3. Share of Global Primary Energy.

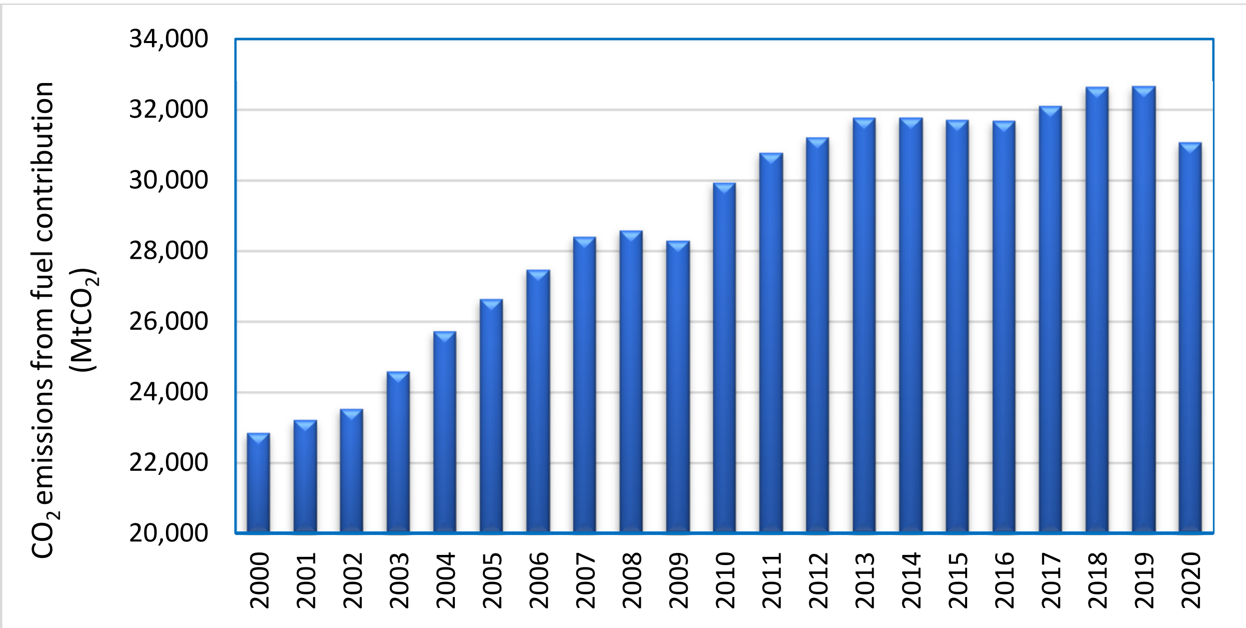

Figure 4. CO_2 Emissions from Fuel Contribution Mtoe.

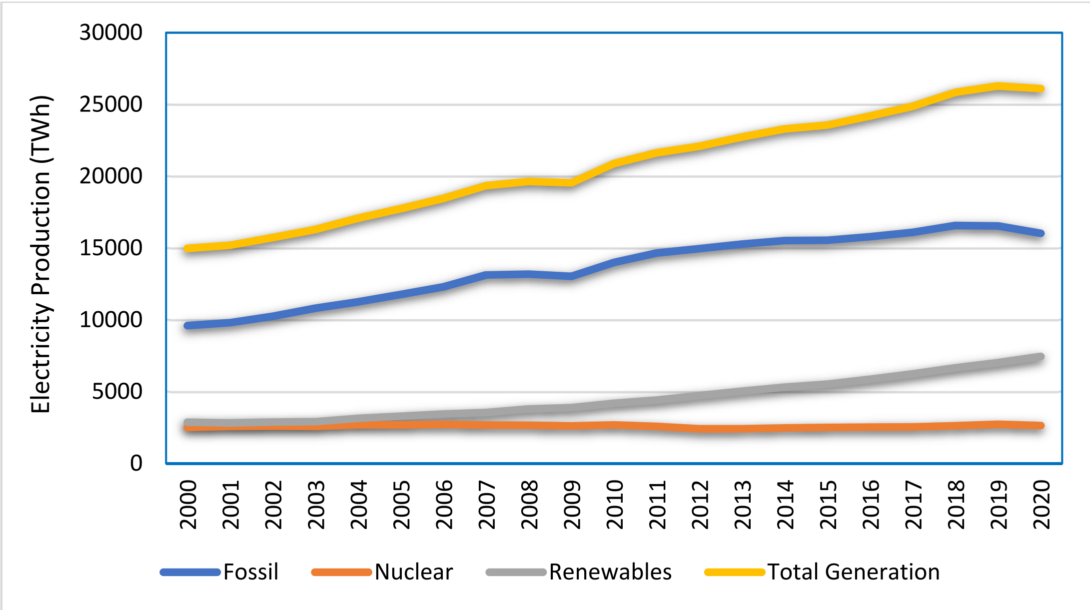

Figure 5. Yearly Total Electricity Production in World in TWh.

From Figure 5 it is seen that the electricity production from fossil fuels and nuclear energy has not increased in recent times, but renewable energy sources provide the additional electricity to fulfill the increased power demand. By looking into the percentage sharing of renewable energy sources in electricity production, it is clear that day-by-day renewable energy sources contribute much more toward electricity demand fulfillment. Figure 6 presents the yearly share of renewables in electricity production throughout the globe. There is a clear indication of making renewable dominated electrical sector with a 10% usage increment from 2000 to 2020. The contribution of several renewable energy sources in the present world's electrical sector is shown in Figure 7. Hydro, wind, and solar power are the main sources of renewable energy with a 98% contribution at the end of 2020 [21].

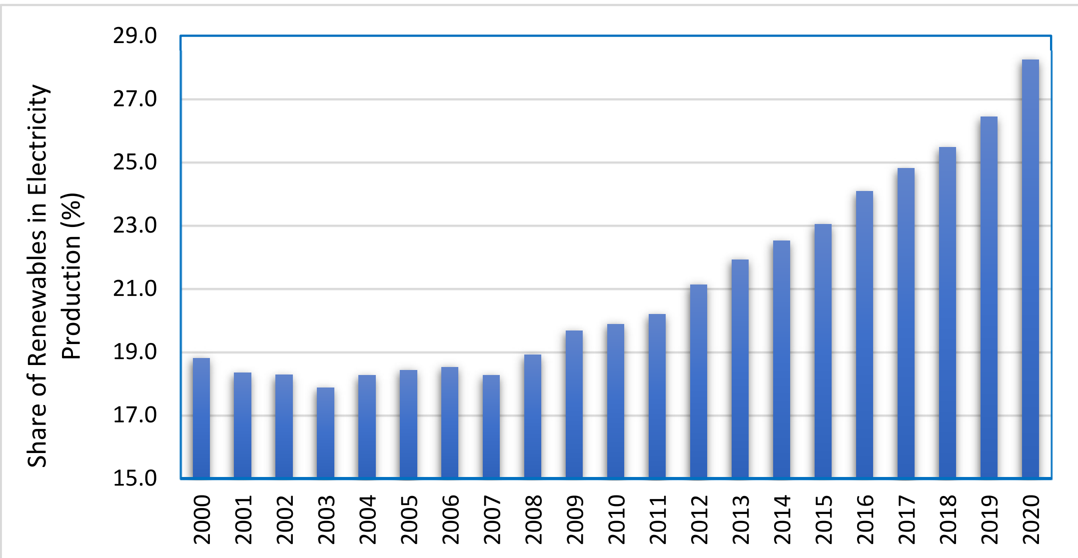

Figure 6. Share of Renewables in Electricity Production (%).

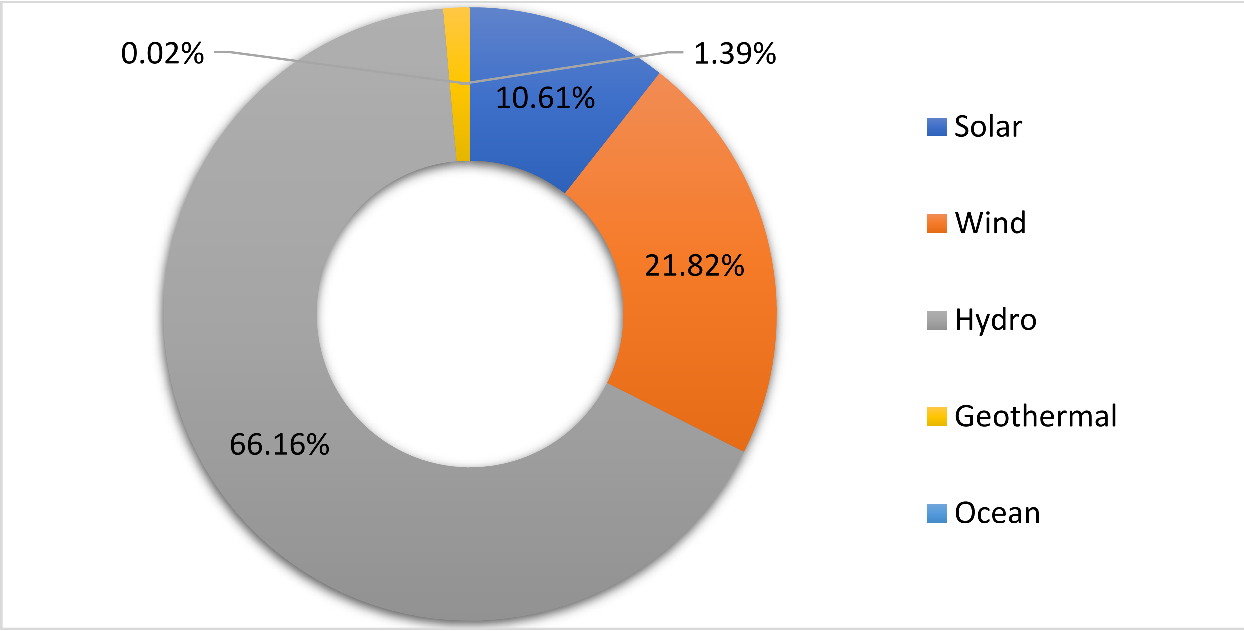

Figure 7. Contribution by Different Renewable Energy Sources at the End of 2020.

Renewable energy can become an important contributor to the global energy supply as it can optimize energy structures, reduce the gap between demand and supply, and most importantly protect the environment. According to the International Renewable Energy Agency (Global energy transformation: a roadmap to 2050, 2018 International Renewable Energy Agency), by 2050, renewable must contribute two-thirds of the global energy requirement and for that there is a need of adding 825 GW of renewable energy every year till 2050 [22]. If we look at the global potential for different energy sources, it can be seen that the fossil fuel reserves may last for a few generations, whereas if we can exploit only a small part of renewable sources, we can meet the energy demand with sufficient room for growth in the future [23–25]. Nowadays the entire world is going toward the use of renewable energy due to its environment-friendly nature. Table 1 depicts the comparative analysis of the emissions and land uses for different types of energy sources. It has been seen that in some cases renewable energy requires the same land as compared conventional energy sources, but emissions are always less for any renewable energy sources [26].

Table 1. Comparative Emissions and Land-use Details for Different Energy Sources.

Source	Type	EMISSIONS	LAND USE
Coal	Fossil		
Petroleum	Fossil		
Natural gas	Fossil		
Nuclear	Alternative		
Solar	Renewable		
Wind	Renewable		
Hydro	Renewable		
Biomass	Renewable		

One of the major obstacle renewable energy sources faces is their substantially greater initial cost. The methods needed to harness this electricity are typically far more expensive than regular energy generators. However, different studies have shown [27] that few utility-scale renewables are competitive when they are compared in terms of their levelized costs of electricity (LCOE) production. Figure 8 summarizes the average LCOE for different electricity generation systems [28].

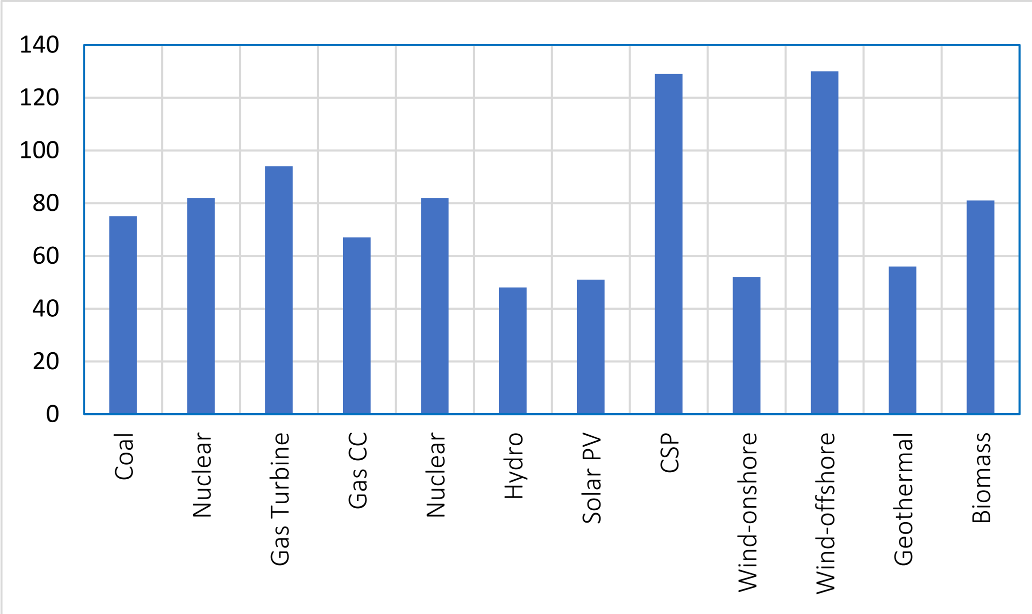

Figure 8. Levelized Costs of Electricity in USD/MWh.

Being the second-most populous country globally, India is the third-largest in terms of energy production and consumption. India has achieved a cumulative installed renewable energy capacity (excluding large hydro) of 92.54 GW until January 2021. Globally, today India stands fourth in renewable power capacity, fourth in wind power generation, and fifth in solar power capacity. India has one of the highest rates of growth for renewable energy in the world [29]. The mode-wise power generation in India is presented in Figure 9.

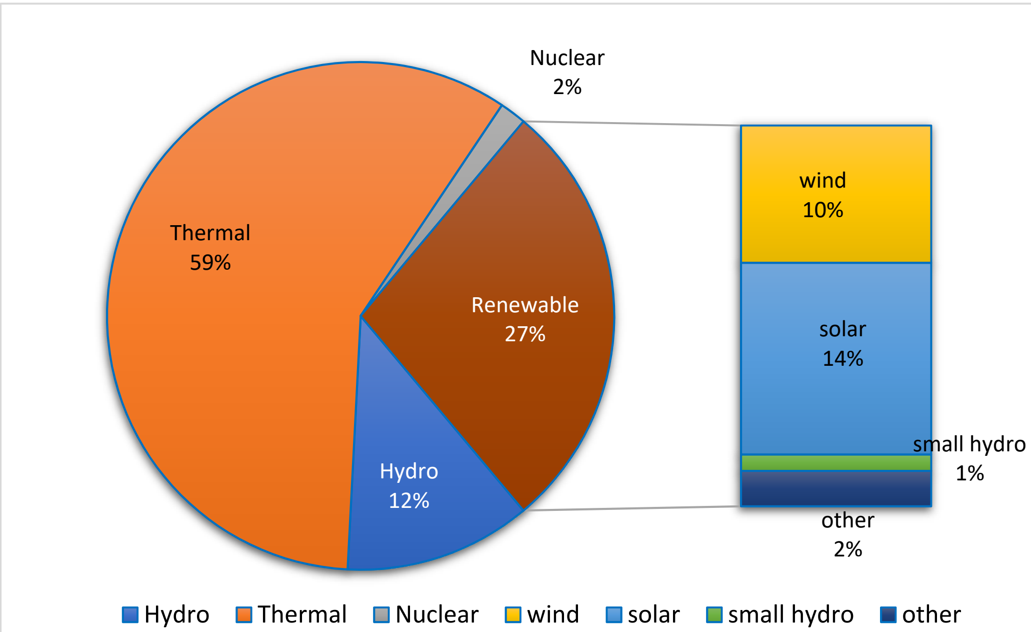

Figure 9. Mode-wise Power Generation in India (As on 31 May 2021).

India's electricity demand is projected to grow by almost 5% per year to 2040 [30]. According to the International Renewable Energy Agency (IRENA), a quarter of India's energy demand can be met with renewable energy. The country could potentially increase its share of renewable power generation to over one-third by 2030. The country has set an ambitious target to achieve a capacity of 175 GW worth of renewable energy by the end of 2022, which expands to 500 GW by 2030. Table 2 shows the renewable energy potential and installed capacity in India till 31 December 2020 [29]. It is seen that there is a huge gap between the potential and installed capacity in the renewable energy area, which may be improved by adopting new technologies and motivating society toward a renewable-dominated world.

Table 2. Renewable Energy Potential and Installed Capacity in India (As on 31 December 2020).

Source	Potential (GW)	Installed Capacity (MW)
Solar	750	37,464.6
Wind (100 m AGL)	302	38,624.2
Small Hydro	21	4750.5
Bio-energy	25	22.2
Waste to Energy		291.34

When compared to fossil fuel technologies that have already attained economies of scale, renewable energy projects have significant financial, technological, and uncertainty costs [30]. Several regulatory and market methods could be used to increase the integration of renewable energy into the power grid. Deregulation allows for the expansion of transmission line infrastructure, which allows for the utilization of renewable energy sources from remote geographical regions. Deregulation at the retail level also allows consumers to choose their electricity supplier, this could enhance the adoption of renewable energy sources. Renewable purchasing alternatives for consumers are more limited in controlled marketplaces since generation resources are not diverse. Pollution control regulations and the adoption of a carbon price can also speed up the integration of renewables in deregulated power markets.

3. Status of Flexible AC Transmission System (FACTS) Devices

In recent years, the electricity requirement is increasing at a rapid rate, but the installation of new transmission lines faces a lot of problems due to its economical, social, and political barriers. In this scenario, FACTS devices play a very significant role to increase the power flow capacity in the existing transmission lines. Flexible AC Transmission System (FACTS) is defined by IEEE as “alternating current transmission systems incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability” [31].

With the deregulation of the power industry, power systems will require FACTS controllers to manage power flow to use transmission lines closer to their thermal limits. FACTS devices can control active and reactive power flow in a transmission line by adjusting the series and shunt parameters [32]. Because of their unique properties, FACTS devices play an important role in the design and operation of deregulated electric power networks. FACTS controllers can control network conditions very quickly and have been used for efficient energy utilization, demand control, voltage stabilization, power quality enhancement, power factor correction, and harmonic abatement. Power loss reduction, voltage regulation, reactive power planning, congestion management, power flow control, and quality improvement are some of the other applications. This enables for greater usage of the existing network closer to its thermal loading capacity, minimizing the need for new transmission lines [33,34].

It is well-known fact that FACTS devices can be used for reactive power compensation. Table 3 gives a clear idea about the cost of various reactive power sources including all

FACTS devices. Figure 10 presents the different types of FACTS devices based on their connection to the power system.

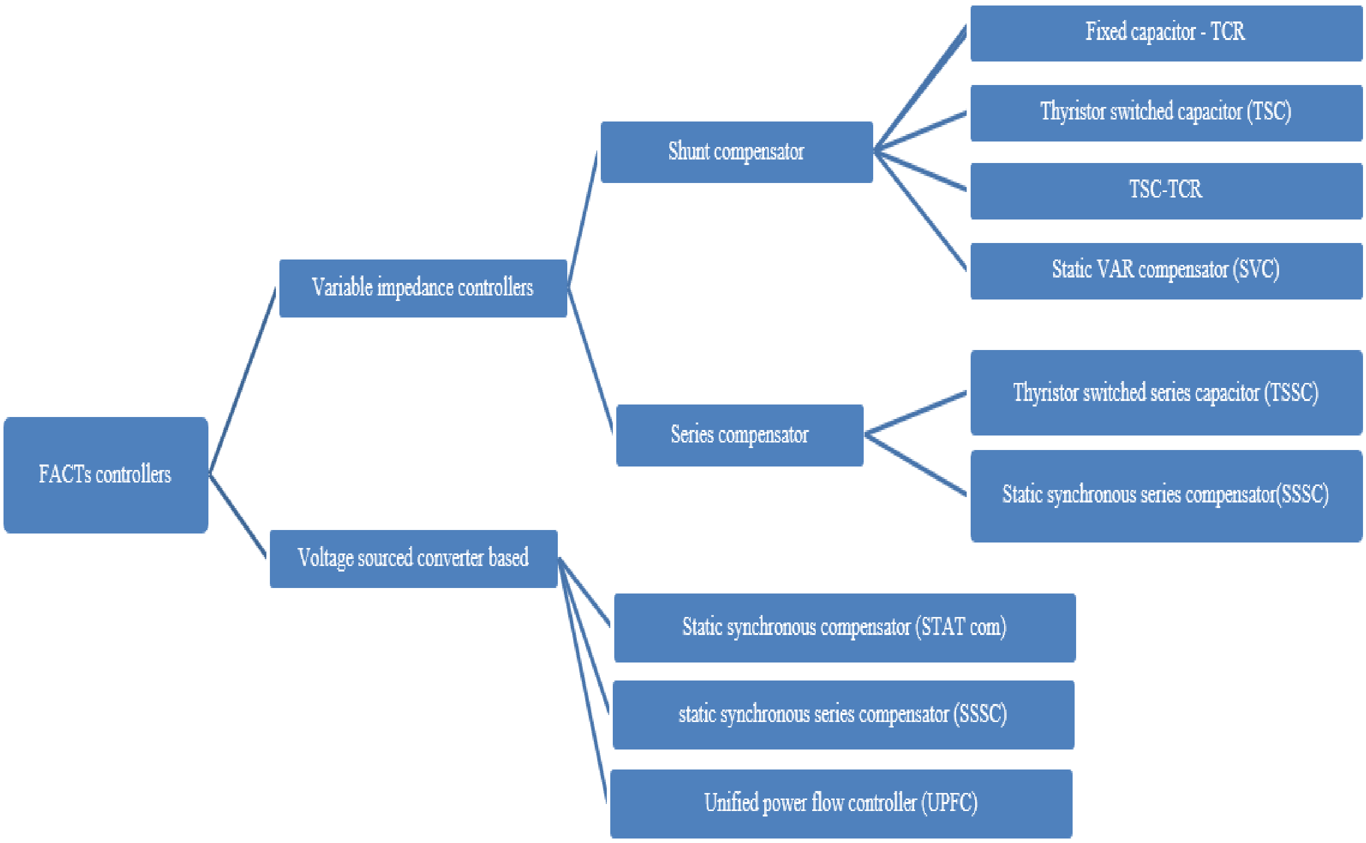

Figure 10. Different Types of FACTS Devices Based on Their Connection.

Table 3. Cost of Different Reactive Power Sources Including FACTS Devices.

FACTS Device	Cost (Rs/kVAR)
Shunt Capacitor	432
Series Capacitor	1080
SVC	2160
TCSC	2160
STATCOM	2700
UPFC	2700

Power systems are forced to run at their maximum operational parameters when power demand rises. This produces voltage instability and voltage collapse in the power supply. To avoid this issue, FACTS devices have been employed in power systems to boost system stability, while requiring significantly lower economic ratings. To accomplish this, the FACTS devices must be precisely located [35,36]. A typical flowchart for determining the optimal location for FACTS devices are shown in Figure 11.

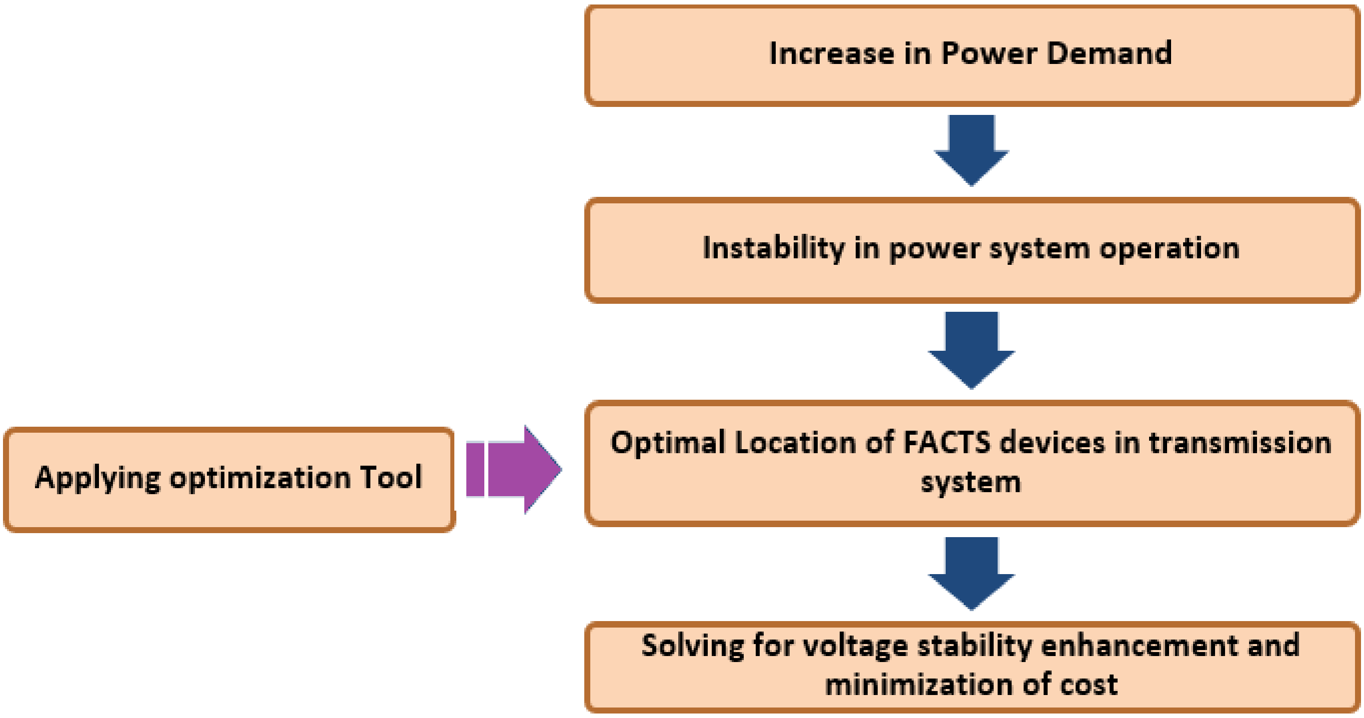

Figure 11. Flowchart for Determining the Optimal Location for FACTS Devices.

4. Status of Energy Storage Devices

Electric power system operation entails a complex process of anticipating energy demand and scheduling and operating a large number of power plants to meet that variable demand. The steady supply of electricity must always match the ever-changing demand. Utilities build and run several power plant types to meet this need. To supply the high consistent demand for power, baseload generators (typically nuclear and coal-fired plants) are employed. The ability of these facilities to adjust output, as well as their cheap variable costs, encourages continuous operation. Load-following or 'cycling' plants are commonly used to deal with load variations. These are usually hydroelectric generators or facilities that run on natural gas or oil. In addition to satisfying the known daily, weekly, and seasonal variations in demand, utilities must keep additional plants available to handle unanticipated increases in demand, the loss of conventional plants and transmission lines, and other eventualities. Operating reserves are a type of responsive reserve that comprises satisfying frequency regulation, load forecasting mistakes, and contingencies [37]. Both frequency regulation and contingency reserves are part of a larger category of services known as ancillary services, which require units that can alter output quickly.

Because of the rapid reaction required by both regulation and contingency reserves, plants that are up and 'spinning' produce a major portion of these reserves. The requirement for reserves raises the costs and reduces the efficiency of an electric power system when compared to a system that is entirely predictable and does not encounter unforeseen contingencies. The requirement for operational reserves, along with the wide variation in demand, limits the contribution of low-cost baseload units and raises the demand for units that can alter output to provide both load-following and ancillary services. As a result, utility operators have long sought energy storage as a potential technique for better-utilizing baseload facilities and giving an alternative to lower-efficiency thermal generators for managing demand fluctuations. With the emergence of wholesale power markets and increased volatility in natural gas prices, new opportunities and interest in energy storage have emerged. Energy storage system (ESS) devices are classified based on the form in which the energy is stored (shown in Figure 12) [38–43].

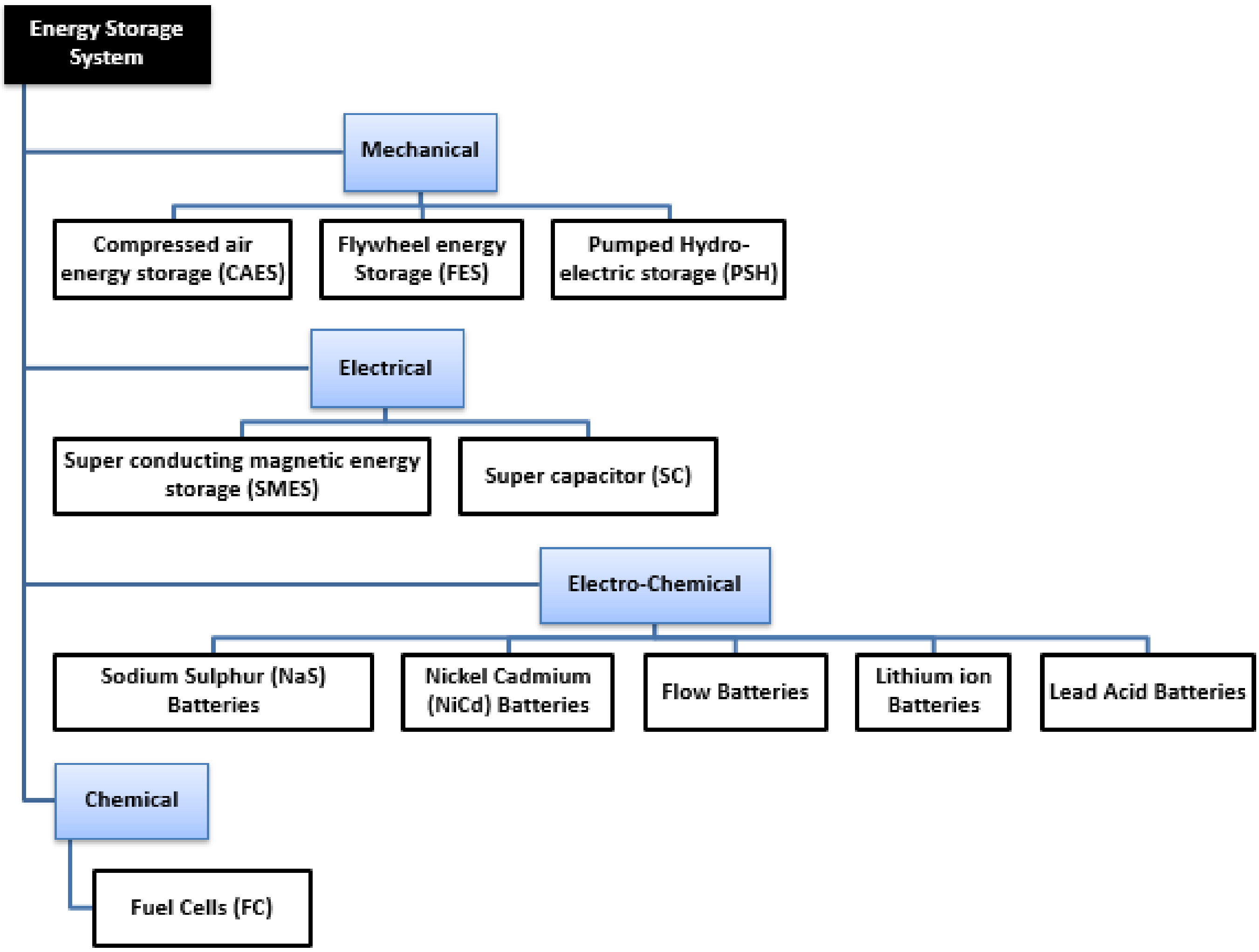

Figure 12. Different Types of Energy Storage Systems.

Increased system dependability, dynamic stability, improved power quality, transmission capacity enhancement, and area protection are among the potential performance benefits generated by advanced energy storage technologies. An energy storage device can also save money and help the environment by lowering fuel consumption and emissions due to reduced line losses and reduced generating availability for frequency stabilization. The selection of ESS is largely governed by the capital cost for installation. Figure 13 shows the capital cost and system power ratings of popular energy storage devices [44,45].

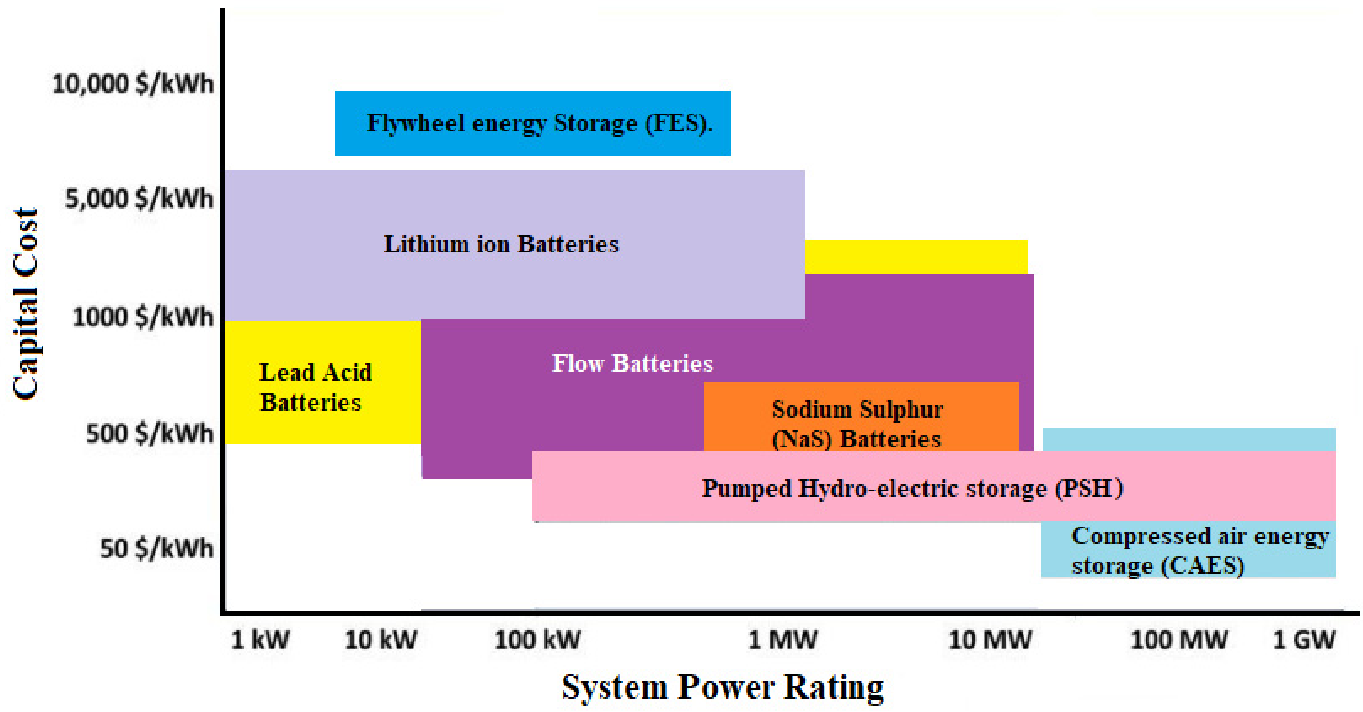

Figure 13. Capital cost vs. System Power Ratings of Energy Storage Systems.

As deregulation occurs, generation and transmission resources will be used at higher efficiency rates, resulting in tighter and more precise control of surplus capacity. Energy storage devices can help with this process, allowing the utility to make the best use of its resources.

5. Comprehensive Studies of Renewables and FACTS Devices in Deregulated System

A detailed literature review was conducted on deregulated power systems with the integration of renewable energy sources. The survey also includes the placement of a FACTS controller and the inclusion of an energy storage device for the maximization of social welfare. The main objectives of the reviews are the maximization of system profit, maximization of social welfare and minimization of system generation cost and loss by optimal placement of energy storage devices and FACTS controllers.

Joon et al. [46] studied the pricing of real and reactive powers on a real-time basis to maximize societal benefit with a consideration of participants having constant power factor demand. The objective function is maximized to determine the price of electricity. By including the load power factor as a constraint, the real and reactive power cost can be determined simultaneously. Paper [47] introduced a special ramp following controller (RFC) in place of load-frequency control (LFC) used for automatic generation control (AGC) in interconnected power systems with HVDC connection. In a deregulated context, it is difficult to implement area control error-based LFC. RFC guarantees that load changes on HVDC connections are automatically followed by chosen generators. The control of frequency and real power is the main topic of this work. Xiaohong Guan [48] establishes the energy delivery capacity in terms of recursive equations using ramp-rate constraints. It is possible to obtain sufficient and necessary conditions to realize an energy delivery schedule as required in the deregulated power market. Daoyuan Zhang [49] suggests a model and approach for utility self-scheduling and optimization-based bidding. The model considers ISO bid selections as well as other market participants' uncertain bidding information. Tak Niimura et al. [50] suggest a fuzzy set-based model to illustrate exceedingly volatile demand–price relationships in a deregulated system. The demand information is divided into two categories: low and high. The regression curves for the two clusters are connected using a Takagi–Sugeno–Kang (TSK) fuzzy model. James D.

Weber [51] presented an algorithm for electrical spot markets, that allows market players to optimize their welfare. It starts with a model of the spot market using optimal power flow (OPF) along with transmission system representation and bidding data, which determines Nash equilibria, which are then studied under the assumption that all participants are attempting to maximize their profit.

Paper [52] provided an overview of the concept of electricity wheeling taking place in a deregulated electric grid. T. McGovern [53] examines the worldwide electricity supply industry's deregulation and reorganization, as well as the effects on fuel consumption, generation technologies, and power plant suppliers. Zuwei Yu [54] presents a welfare maximization model for the inclusion of FACTs devices in the deregulated system that takes into account real power losses. It represents the functioning principle of deregulated electricity markets by modeling demand on system buses as a function of prices. The proposed paradigm is distinct from typical cost-minimization models. It demonstrates that transmission losses can also have an impact on the best location. A multiobjective model for optimal compensation system design at the distribution level in a deregulated market setting is developed by A. Augugliaro [55], and a feasible solution technique is also described by the authors.

Peter B. Luh [56] proposes an effective strategy for directly minimizing payment expenses, using augmented Lagrangian relaxation. The offer and market clearing price (MCP) subproblems are formed and solved using the surrogate optimization framework. The approach has been updated to account for more realistic scenarios, such as demand bids and partial compensation of startup costs. Ref. [57] looked at the variables influencing the environment as a result of fossil fuel-based generation following the restructuring of electric utilities. The introduction of control technologies and changes in energy demand and generation, demand-side management programs, the fuel mix, the share of generation from non-hydroelectric renewables, and regulatory policies resulted in a lower trend in emissions from 1993 to 2002. A. Al-Sunaidy et al. [58] discuss the expansion of electricity deregulation in OECD nations in this article. The need for effective regulation of the transmission and distribution systems is also covered, along with some of the challenges brought by competition in generating and retailing. A. Demiroren [59] implements automatic generation control (AGC) in a three-area power system following deregulation using the genetic algorithm (GA), which is employed for optimizing integral gains and bias factors. The traditional three-area AGC approach is altered to account for the dynamics of bilateral contracts. Paper [60] examining the effects of deregulation on technical efficiency and how it has changed over time for large-scale U.S. electric power utilities between 1992 and 2000 is the main goal of this study. The authors examine the effectiveness of three distinct functions—generation, transmission and distribution, and general administration—as well as the effects of deregulatory changes on each.

Hongrui Liu [61] inspected the influence of transmission augmentation in a competitive energy market on social welfare. The utility functions and a formulation of social welfare are derived in this study. The suggested method evaluates social welfare by analyzing the transmission congestion status under the optimal condition of the current system. Hadi Besharat [62] proposes a method for determining the ideal position of thyristor-controlled series compensators (TCSCs) considering real power performance index and reducing total system VAR power losses in the deregulated electricity system. Huibin Sui [63] proposes a versatile and cost-effective AMI system based on multi-communication media. The AMI system not only saves money by reducing labor costs and improving electrical meter reading accuracy, but it also delivers precise load-profile information and billing data to assist consumers to control their energy usage. The AMI system's distributed structure makes it simple to implement in a variety of utility systems of various sizes. An approach to cost allocation for reactive power is put forth in the paper [64]. The approach is based on the precise cost estimation that will be imposed on generators as a result of providing reactive power. The suggested approach is straightforward to formulate, fair, accurate, and realistic. Additionally, a method for pricing reactive power that uses a tracing algorithm and reflects the price of active and reactive losses assigned to each generator is proposed. Nima Amjady [65] proposed a forecasting tool to predict spinning reserve in a deregulated system. The tool uses a multi-layer perceptron (MLP) neural network using the Levenberg–Marquadt (LM) learning algorithm and the real coded genetic algorithm (RCGA). Yog Raj Sood [66] proposes an optimal model for managing congestion in a deregulated power system involving both conventional (thermal) and renewable sources. The social benefit is maximized, while dispatching the pool by combining bilateral and multilateral contracts. This approach determines locational marginal pricing (LMP), non-firm transaction sizes, generations, and demand of the pool. An effort has been made by Ashwani Kumar in [67] to provide an overview of India's renewable energy options, including their availability, current state, significant accomplishments, and promises for the future. This report also evaluates particular legislative initiatives for removing obstacles and boosting the deployment of renewable energy in the future. R. Baños [68] reviews the state-of-the-art computational optimization methods used in renewable and sustainable energy, highlighting the most recent developments in the field. Sandhya et al. [69] analyze the costs of various energy storage technologies and pinpoint the crucial factors that have an impact on their economic viability.

Through a review of the current research, several significant factors influencing the growth of renewable energy generation are identified by Rong-Gang Cong [70]. Following a thorough investigation, a novel optimization model is created to optimize future renewable energy generation through the best capacity planning, subject to various limitations, such as economic, technological, and others. Helder Lopes [71] presents various energy storage systems that have varied properties and are in various degrees of maturity have been thoroughly compared. Power rating, discharge length, energy density in terms of weight and volume, power density, effectiveness, durability in terms of time and cycles, and availability have all been compared by the authors. An overview of different price-forecasting methodologies used in the deregulated system is presented in [72] and key issues have been analyzed. S.M.H. Nabavi [73] maximizes system social welfare using a fuzzy-based genetic algorithm via the best positioning and sizing of FACTS devices, considering their cost of investment.

Lixin Tang [74] proposed a policy for the deregulated system to reduce CO_2 emission in generator scheduling for thermal plants. The policy envisaged a new emission-based penalty factor. The scheduling maximizes profits from the generation calculated from revenue earned from the sale, cost of generation and the emissions penalty. Mala De [75] developed a method based on reactive power procurement (RPP) satisfying the requirement of reactive power in the system and enhancing voltage stability. The control variables of the optimization problem include parameters responsible for the system's reactive power output. Many elements are considered when analyzing the formulas, which include the voltage profile, the power loss in the system, the L-index, and the availability of the system's dynamic reactive power reserve. Prabhakar Karthikeyan [76] presents the effect of FACTS devices on the generator's market power, and it has been suggested that one of the key considerations in choosing the best location for the FACTS devices is to take market power into account. Enrique B. CEDEÑO [77] addresses the intricate interactions between the various parts of the deregulated power sector, an integrated model for the increase of generation and transmission capabilities has been proposed in this work. This model's goal is to assess and identify the best macroeconomic indicative investment ideas. Pavlos S. Georgilakis [78] suggests a genetic algorithm (GA) solution to the price-based unit commitment problem, which is employed by each generating company to maximize its profit in a deregulated market by optimizing its generation schedule. A thorough comparison has been performed by Xing Luo in [79] about the most cutting-edge energy storage methods. The study assists in reducing the issue of choosing appropriate EES technology for a specific application and determining where they would be best integrated into a power generating and distribution system. Moein Parastegari [80] proposes an optimization model for the energy market, including ancillary services. The model is used for the operation of wind farms (WF), pump-storage units (PSU), photovoltaic (PV) resources, and energy storage devices (ESD) jointly. The model considers WPG, pricing for energy and reserve, and uncertainty in PV generation. M. Rezaei Adaryani [81] proposes an artificial bee colony (ABC) algorithm-based approach to handle optimal power flow (OPF) issues with varying levels of complications. The method used cost of fuel, power loss, emission, improvement in voltage profile and stability in normal situations as well as in contingency settings. In [82], butterfly optimization algorithm (BOA) is utilized to perform active power management to suppress system frequency deviations in a virtual power plant with various renewable energy sources. In [83], sine-cosine algorithmic technique (SCA) is implemented for optimal regulation of frequency in a hybrid microgrid. Several optimization techniques have been compared for performance and a novel two stage integral-proportional-derivative with one plus integral (IPD-(1+I)) controller is used.

A. Zahedi [84] studied the possible benefits of grid-connected renewable energy-distributed generation (RE-DG). It also investigated the causes driving the increased usage of RE-DG, the technical issues associated with high RE-DG penetration, and the influence of RE-DG connecting points on system voltage. Two approaches for optimum sitting and sizing of distributed generators (DGs) for restructured power networks to manage congestion are provided in [85], based on locational marginal pricing (LMP) and congestion rent. The proposed priority list makes it easier to locate DGs in the best possible location and to set their output power levels, boosting security in a deregulated system. Piyasak Poonpun [86] presented a study on the life-cycle cost of different grid-connected electric energy storage is presented. The results are expressed as a cost per kilowatt hour of electricity stored and discharged. In [87], Y. Lia looks at the information on cost of power from deregulated power markets on an hourly or half-hourly basis. After examining the data, it examines average diurnal patterns, their dependency on load, unpredictability, and uniformity across time. The average price difference between off and on peak power use, as well as weekend vs. weekday power usage, can be seen in diurnal patterns. M. Esfahani [88] proposes a method for forecasting locational marginal prices (LMP) generated after the bid which dictates power costs at a node or in an area, using segmental feed-forward neural networks (FFNN) and fuzzy inference systems (FIS). The FFNN model is used to estimate power prices over a limited time horizon, whereas the FIS model is used to forecast prices on special days. The technology of stationary electrical energy storage is examined by Haisheng Chen in [89]. The comparison of pumped hydropower storage, compressed air energy storage, battery, flow battery, fuel cell, solar fuel, superconducting magnetic energy storage, flywheel, capacitor/supercapacitor, and thermal energy storage have been discussed by the authors.

Stephen Frank et al. [90] offer a thorough examination of several optimization strategies that have been used for optimal power flow (OPF), with a focus on their benefits, drawbacks, and computational features. It starts with an overview and then goes into the deterministic optimization approaches that have been used on OPF. Stephen Frank [91] examines numerous optimization algorithms that have been applied to optimal power flow (OPF) in this work, focusing on their merits, downsides, and computational characteristics. The survey looks at the recent trend in OPF search approaches that are stochastic or non-deterministic, as well as hybrid methods. Ramesh Kumar Selvaraju [92] studied the effectiveness to improve the performance of a deregulated power system integrated with various energy storage devices. The artificial cooperative search method, a new two-population-based optimization approach, is developed for finding the LFC controller gain values in the deregulated environment. G.T. Chandra Sekhar [93] proposed an optimal hybrid fuzzy PID controller with derivative filter (PIDF) using the firefly algorithm (FA) for load frequency control (LFC) in a deregulated multi-source system for multi-area setting. The controller considers physical constraints and nonlinearity. The proposed approach was found to be superior to tuned genetic algorithm (GA) techniques. Paper [94] proposes a strategy to reconfigure ideal distribution in the deregulated environment for true and reactive power price. As the reconfiguration problem includes both continuous and discrete variables hence non-dominated sorting genetic algorithm (NSGA) is preferred for optimization. The method reduces the cost of operation based on the active and reactive power drawn by the distribution system, as well as increases operational dependability by lowering the overall cost of interruption. M. Packiasudha [95] presents a cumulative gravitational search algorithm (CGSA) in place of opposition-based GSA (OGSA) for the ideal placement of FACTS devices by enhancing real power and compensating reactive power in a deregulated environment. Miaomiao Ma [96] formulated the load frequency control (LFC) problem for the deregulated power system as a large-scale tracking control problem involving both external disturbances. The LFC problem with contractual and uncontracted load needs is solved using the distributed model predictive control (DMPC) scheme. Lakshmi Chinmoy [97] reviews the effect of investment, policies, performance, and social benefits in a deregulated system integrated with wind energy systems. This study discusses regional aggregation and suggests the depiction of consequence in unit commitment from the large wind. Critical cost modeling for integration of wind energy systems and techniques used to mitigate market risk follow the study. Finally, the social impact of large-scale wind integration is examined, as well as energy security compliance.

Chunyi Huang [98] introduces a unique coordinated expansion planning approach that takes into account non-network solutions in a deregulated environment. To mimic the bidirectional interaction between distribution system operators and stakeholders, a double-nested game model is built. Ofir D. Rubin [99] develops a new theoretical framework for modeling corporate behavior in deregulated electricity markets. The framework may be used to investigate real-world issues. The model is adaptable to a variety of assumptions about the electric sector and the features of each given delivery period. The distributions of the spot price at different delivery periods in the model deviate substantially, just as they do in real-world energy markets. In addition, the model creates a wedge between the forward and predicted spot prices. Simon R. Sinsel et al. [100] identify the challenges of integrating variable renewable energy (VRE) sources into current power networks, as well as the solutions available to meet these challenges. As a result, the study gives an overview of the technological requirements of power systems with rising VRE shares and adds transparency to the difficult VRE integration process. Various methods for the optimal solution of a problem involving placement and sizing of distributed renewable energy generation units are presented in [101]. Various factors that led to the growing integration of distributed generators including the ways to overcome challenges are analyzed. It summarizes the several conventional and heuristic techniques used for optimization. Dalia Eltigani [102] explores various methods applied for enhancing the performance of power systems having a large amount of generation from renewable sources. The study particularly addresses the methods utilized to improve wind and PV low-voltage ride-through capabilities to satisfy grid code requirements and the role they play in the power system's small signal stability in terms of inter-area oscillation dampening. A.K. Singha [103] has discussed the robustness, sustainability, and reliability of DG from various aspects along with a different scenario of contingency. The study showcases the way to achieve demand response using flexible demand, demand side management (DSM) incorporating DGs to capable the grid. The review also presents different techniques adopted for the allocation of DGs to analyze power flow.

Anuj Banshwar [104] presents a market-based technique for renewable power producers (RPPs) for clearing energy and ancillary services (AS) in a disaggregated day-ahead market. The method relies on the successful clearing of the energy market (EM) and the ancillary service market (ASM) to reduce the cost of these services and arrive at a realistic solution. The optimal power flow (OPF) technique is used to define and solve this optimization problem taking into account the transmission constraints and limits in power flow. In [105], a penalty-based energy procurement on a real-time basis and operating reserve from renewable power producers and conventional power plants are used in a short-term market context using a sequential market clearing technique. An economical model has been developed for exploring the techno-economic effect of the imbalance generated by the wind power plant on associated revenues. To minimize reserve procurement costs, an independent system operator delivers energy maximizing societal welfare. In Ref. [106], B. Murugananthama uses different load flow methods to investigate the parameters in the Distribution Network (DN). The numerous obstacles of DN with the incorporation of RES are highlighted in this research. It thoroughly examines the various pricing mechanisms for provided power in DN. This study examines the significance of demand side management (DSM) and energy storage in DN.

Yasir Muhammad [107] compiled the work on optimal reactive power dispatch (ORPD), ORPD incorporating FACTS, mathematical models of ORPD issues, including matching constraints, the mathematical model of FACTS in ORPD, and ORPD uses. Finally, a novel fractional calculus-based computing tool has been presented to boost performance. Vikas Khare et al. [108] provide a full examination of different areas, including feasibility analysis optimum sizing, modeling, control qualities, and reliability concerns of a Hybrid renewable energy system (HRES). It also discusses the use of different techniques and game theory in hybrid renewable energy. S. Yin [109] reviews the operation of the electrical market solar integration and current industry practices. A comprehensive analysis of the global solar energy electrical markets is presented. A thorough examination of solar uncertainty modeling in the short-term power market is provided, as well as viable solution techniques. T. Zhang [110] proposed a reactive power supply market clearing method along with its formulation. The cost of reactive power supply from generators and sources in the transmission system is factored into this formula. It also suggests that the participation of transformers be compensated based on the actions of changing the tap position. Paper [111] presents a novel approach for determining the best capacity sizing and capital investments for distributed generation (DG). The optimization technique can minimize the total cost of investment for DG, the O and M cost of DG, power purchase by distribution companies (DISCOs) from transmission companies (TRANSCOs), and system power losses.

X. Li et al. [112] discuss how to allocate transmission losses and costs in a hybrid deregulated power market using the pool and bilateral contracts. In a DC power network, transmission loss is distributed between node power and line power flow. The entire loss is assigned to the generator or the load or both nodes. Paper [113] looks into effective demand response (DR) scheduling schemes in a deregulated setting. The introduction of a new concept—demand response exchange (DRX)—a segregated market for trading DR equally and flexibly across all beneficiaries—overcomes the constraints of partial schemes, which are currently being implemented in many existing markets. A pool-based market clearing system is used to implement the DRX idea. The relationship between the two opposing objectives is examined under different scenarios involving the structure of the electrical market and the grade of the producer's market power presented in [114]. A complementarity approach was used to investigate a merchant model for transmission investment that included wind capacity that was managed separately by electricity providers. Qianfan Wang [115] suggested a strategy to bid optimally by independent power producers (IPPs) in the deregulated environment to maximize profits. The strategy considers price and uncertainty in power output by the wind. A stochastic programming model incorporating day-ahead price, real-time price, and wind power output is envisaged, while addressing the unit commitment problem with the constraints in wind power utilization. The model uses a sample average approximation (SAA) algorithm for profit maximization.

Tables 4–6 display the summary of reports for considered objective functions, applied system details, and used optimization techniques for the considered pieces of literature.

Mahmoud Ghofrani [116] investigates the ideal location of energy storage inside a deregulated electricity system to minimize the social cost on an hourly basis. Both wind and load were stochastically modeled considering historical data and curve fitting. A GA-enhanced market-oriented probabilistic optimal power flow is used. Shafiqur Rehman [117] conducted an in-depth examination of pumped hydroelectric energy storage (PHES) systems, with a focus on existing technologies and practices as well as the operation and maintenance, benefits and drawbacks, environmental considerations, and economics of using PHES systems to store energy generated by wind and solar photovoltaic power plants. Paper [118] examines several control strategies for designing automatic generation control (AGC) in a deregulated electricity system. The models and control methodologies concerning AGC problem design and implementation have been examined, as well as difficulties and benefits discussed. The latest uses of modern heuristic optimization algorithms (HOAs) for the solution of OPF issues are discussed in [119]. The most commonly used HOAs for resolving the OPF problem, such as the genetic algorithm (GA), differential evolution (DE), particle swarm optimization (PSO), and evolutionary programming (EP), are explored and briefly explained. Mohd Tauseef Khan [120] provides a sensitivity factor-based attempt for placing series FACTS devices optimally in a deregulated power system by alleviating congestion with the lowest installation cost. The reactance model of the thyristor-controlled series capacitor (TCSC) is studied for improving the line's power capability. The usage of two common FACTS devices, TCSC, and STATCOM, for controlling the flow of power in an electrical system, as well as their potential to decongest the system, is examined in [121]. It recommends the best position for each TCSC and STATCOM to alleviate congestion, having the least amount of power loss, voltage regulation, and device cost. The use of several sorts of game theory approaches to the solution of electric power system problems is covered in depth by Saeed Abapour in [122]. Ehsan Jafari [123] suggested an algorithm for determining the best approach for a microgrid (MG), which includes wind farms (WFs), photovoltaic (PV), fuel cell (FC), combined heat and power (CHP) units, tidal steam turbine (TST), as well as boiler and energy storage devices (ESDs), while taking into account economic and technical constraints and demand response (DR) program. A stochastic optimization problem is envisaged to discover the ideal placement of the generator, while maximizing predicted profit. The uncertainties are anticipated using WT-ANN and WT ANN-ICA hybrid prediction approaches. D. Fathema Farzana [124] proposes a framework to reschedule generation with and without renewable energy sources to keep transmission line power flows within specified limits in a deregulated setting. The rescheduling challenge is posed to lower congestion costs. To achieve optimal outcomes, the firefly algorithm (FA) and particle swarm optimization (PSO) algorithms are used. Mohammad Tolou ASKARI [125] suggested a new approach for estimating strategy for optimal investment for integrated wind-thermal enterprises. The medium-term reorganized power market was simulated using the Monte Carlo approach, with stochastic and rational uncertainties considered. The data mining method is used to assess wind uncertainty, while electricity demand and fuel prices were replicated using the Monte Carlo method. Paper [126] studied the non-cost-free strategy to reduce congestion by generator rescheduling for active power output. The rescheduling is done to minimize the rescheduling costs. HPSOGWO is a new hybrid algorithm created by combining two well-known algorithms, particle swarm optimization (PSO) and grey wolf optimization (GWO). The active power output is rescheduled to reduce congestion at the lowest possible cost.

Table 4. Summary of reports for considered objective function in the literature.

Paper ID	System Type: Regulated System	System Type: Deregulated System	Objective Function: Profit Maximization	Objective Function: Loss Minimization	Objective Function: Gen. Cost Minimization	Objective Function: Social Welfare Maximization	Remarks
[46]		√				√	Operating cost Minimization
[47,118]		√					AGC
[48,49]		√					Power generation scheduling
[50,52,53,63,72,75,87,99]		√					Study and Review Work
[51]						√	Optimal power flow
[54]		√				√	
[55]		√	√	√			
[56]		√					Offer cost and payment cost minimization
[57,58]	√	√					
[59]	√	√					AGC
[60]	√	√					Generation efficiency
[61]		√				√	Transmission enhancement
[62]		√		√			
[64,75]		√					Reactive power cost
[66]		√				√	
[73]		√				√	
[74]		√	√		√		
[78]	√	√	√				
[81]		√		√			Minimization of total fuel cost, Voltage stability enhancement, Emission cost minimization
[85]		√			√	√	
[94]		√		√			Operational cost minimization
[96]		√					Load Demand Control
[97]		√				√	Maximizing power generation
[104]		√	√			√	Operational cost minimization
[105]		√	√				Minimization of procurement cost
[107]	√			√			Cost minimization
[112]		√					Transmission loss allocation
[124]		√					Minimization of congestion cost

Table 5. Summary of reports for considered system details along with energy storage and FACTS devices.

Paper ID	Renewable Energy Sources						Energy Storage							FACTS	
	Generalized	**Wind**	**Solar**	**Hydro**	**Biomass**	**Geothermal**	**Generalized**	**PSH**	**Battery**	**SMES**	**TES**	**Fuel Cell**	**CAES**	**FACTS**	**Remarks**
[54]														√	
[62,120]														√	TCSC
[65,114]		√													
[66]	√														
[57]		√	√		√	√									
[58]		√	√	√	√	√									
[59]								√	√	√			√		
[70]		√	√		√										
[71]		√						√	√	√	√	√	√		
[73]														√	TCSC, SSSC
[76]														√	TCPAR, TCSC
[79]								√	√	√	√	√	√		
[80]		√	√		√		√	√							
[84]	√	√	√												
[86]	√	√	√				√	√	√						
[89]								√	√	√	√	√	√		
[92]									√	√					
[95]														√	SVC, SSSC, UPFC, STATCOM
[97,100]	√	√													
[102,108]		√	√												
[104]		√	√		√									√	
[105]		√	√	√				√							
[106]	√		√				√								
[107]														√	TCSC, TSSR, TCSR, TSSC, SVC, STATCOM, SSSC, UPFC
[109]			√												
[116]		√											√		
[117]		√	√					√							
[121]														√	TCSC STATCOM
[123]		√	√				√					√			
[124]	√														
[125]		√													

Table 6. Summary of reports for used optimization techniques in the literature.

Paper ID	Optimization Techniques							Remarks
	PSO	ABC	BAT	GA	FA	ACO	Heuristic	
[49,56,74]							√	Lagrangian relaxation
[50,60,62,64,66,70,72,97, 98,105,110,111]							√	
[51]							√	Game Theory
[54]							√	Generalized decomposition method
[56]							√	Surrogate Optimization
[59,73,78,94,116,118]				√				
[61]							√	Sequential quadratic programming
[65]				√			√	
[68]	√	√		√		√	√	
[75]		√		√				
[77]							√	Constructive heuristic algorithm
[90]	√						√	
[81]	√	√		√			√	
[90,91]	√	√	√	√	√	√	√	
[93]				√	√			
[95]	√			√		√	√	Gravitational Search Algorithm
[101]	√	√	√	√	√	√	√	
[102]	√							
[104]	√			√		√		
[107]	√	√		√	√	√		
[108]	√			√				
[115]							√	Sample Average Approximation
[119]	√			√			√	
[123]	√			√				
[124]	√			√	√			
[126]	√							Grey Wolf Optimization

All the literature consists of several objective functions, which are presented in Figure 14. It has been observed that the objective functions are chosen to enhance economic sustainability, system security, and stability, which is required for any power system. There are different optimization techniques used for power systems in the literature [127–132].

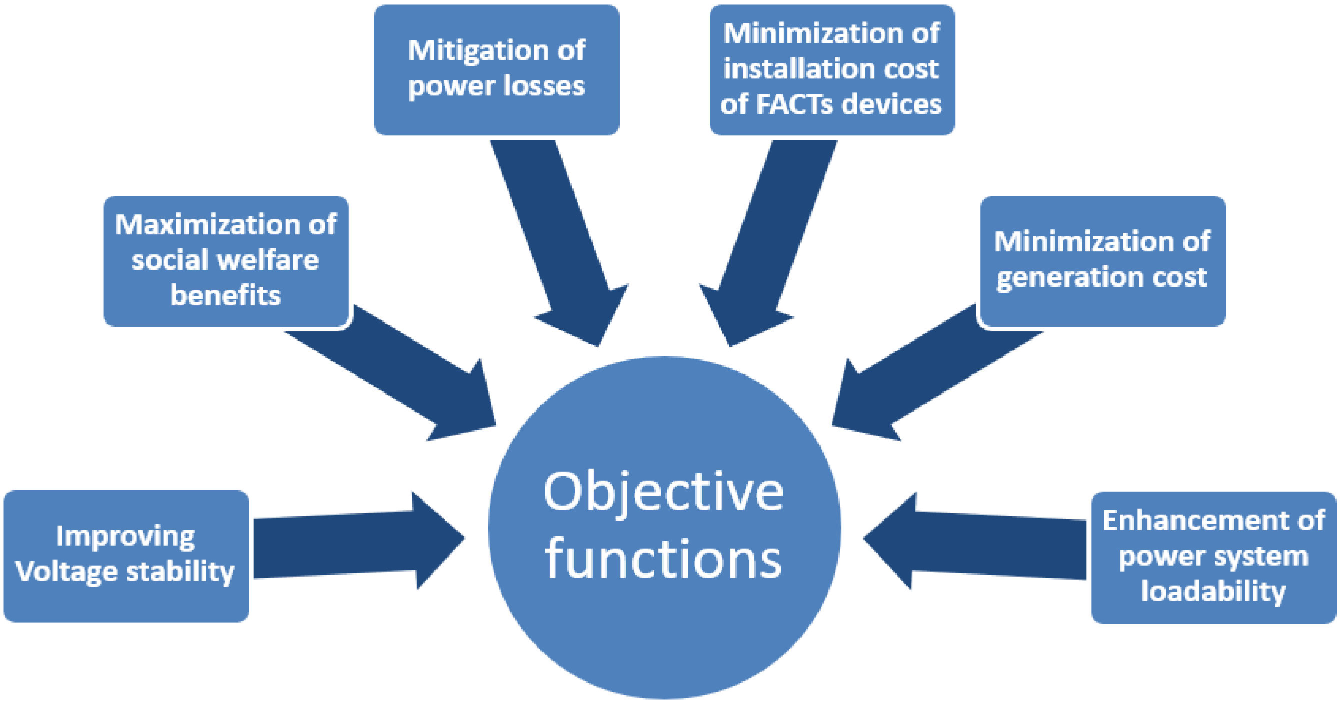

Figure 14. Considered objective functions of the literature.

Different optimization tools are used for solving the objective functions in a deregulated environment. For maximizing a generator's profit based on market clearing price Mousavi, S.H. [133] suggested an optimal bidding strategy model based on the concept of Nash equilibrium. Genetic algorithm (GA), simulated annealing (SA) and hybrid simulated annealing genetic algorithm (HSAGA) were used and compared to judge the performance of the model. The results show that GA outperforms SA and HSAGA. Singh, Satyendra [134] in his research presented an optimal coordinated bidding strategy for the power generators to maximize profit in a wind integrated system. Gravitational search algorithm (GSA) is used to solve the bidding model and is compared with that of using PSO and GA. The result obtained from GSA shows more robustness compared PSO and GA. To maximize social benefit along with minimization of loss in a renewable integrated competitive market, while addressing the inherent uncertainty of the renewable power generations as well as load demand, Das, A. [135] proposed a novel risk analysis and congestion management approach based on slime mould algorithm (SMA), sequential quadratic programming (SQP), and Artificial Bee Colony Algorithm (ABC). The result shows that the SMA and ABC algorithms give better results in terms of minimum risk and maximum social benefit with minimum losses. SQP stands to be less effective technique. Singh, N.K. [136] in his work used sequential quadratic programming (SQP), artificial bee colony algorithms (ABC), and moth flame optimization algorithms (MFO) to solve optimal power flow problems for minimizing the system risk and generation cost in a wind PHES integrated system. Results show that MFO provides better result than SQP and ABC. With increase in wind penetration the bidding strategy is becoming more complex, Singh, S. [137] proposed a novel opposition-based gravitational search algorithm (OGSA). Comparing the result with GSA, PSO, and GA, the OGSA technique is more effective, accurate, and suitable to obtaining higher profits. N.K. Singh [138] in his study presented an optimal bidding strategy to maximize the social welfare of the market participants by optimally locating the wind farm using Monte Carlo simulation (MCS). The analysis was done using artificial gorilla troops optimizer (AGTO) algorithm, honey badger algorithm (HBA), slime mould algorithm (SMA), artificial bee colony (ABC), and particle swarm optimizer (PSO) algorithm. It was evident from the result that the AGTO algorithm maximizes social welfare, while PSO provides minimum social welfare.

6. Conclusions

The deregulated power system consists of some entities, i.e., GENCOs, TRANCOs, retailers, DISCOs, etc. Once the system is integrated with renewable energy sources along with the placement of FACTs devices and energy storage systems, it is possible to determine models of various objective functions to solve. This paper provides an insight into various works on deregulated power systems integrated with renewable energy sources, FACTSs devices and energy storage systems. After detailed literature, it has been concluded that the assimilation of renewable energy along with the existing thermal plant is very complex, but these must be performed to minimize the burden on coal for power generation. Due to the uncertainty of renewable energy sources, some storage devices must be used to maintain system stability. It has also been observed that renewable energy integration along with energy storage devices and FACTS devices enhance the system's economic profit. Comparative studies between different optimization techniques have also been performed in this study. The meta-heuristic algorithms have provided better results as compared to heuristic and linear optimization methods with considered objective functions.

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