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Review

Impacts of Energy Storage System on Power System Reliability: A Systematic Review

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Abstract: Research has found an extensive potential for utilizing energy storage within the power system sector to improve reliability. This study aims to provide a critical and systematic review of the reliability impacts of energy storage systems in this sector. The systematic literature review (SLR) is based on peer-reviewed papers published between 1996 and early 2018. Firstly, findings reveal that energy storage utilization in power systems is significant in improving system reliability and minimizing costs of transmission upgrades. Secondly, introduction of policies to shift from the use of fossil fuels to that of renewable energy positively affects energy storage system development. Thirdly, North America is an early pioneer of power system reliability and energy storage system studies. However, Asia has recently taken over the role, with China being the main driver. Research gaps within this field are also identified. This review can serve as basis for scholars in advancing the theoretical understanding of the reliability impacts of energy storage systems and in addressing the gaps within this field.

Keywords: energy storage systems; power system reliability; systematic literature review; smart grids

1. Introduction

In the electric utility industry, power outages are the main concern because consumers expect a continuously ready supply throughout the year. This ready supply is the 'reliability' of a power system in providing adequate output to consumers, as discussed in [1]. Several studies have provoked discussions about the consequences of power interruptions on consumers. Distribution systems have generally grown in an unplanned manner, thereby resulting in substantial technical and commercial losses and poor power quality. Other reasons include the lack of efficient tools for operational planning, which leads to increasing system losses [2]. A practical manner of reducing major power interruptions is increasing the reliability of power systems.

In the early 1980s, electrical energy storage was expensive and inefficient. However, advancement in micro-grid utilization has recently created a large market for energy storage systems, which are now viable in terms of financing and technology [3]. U.S. and China are key economic players in the world and have invested considerably in utilizing energy storage systems (ESS) for their system networks. By 2015, the U.S. annual ESS market had grown by 243% and is projected to reach 1.5 GW in 2020 [4]. Meanwhile, China had successfully installed a total of 22.85 GW of energy storage systems by 2015 [4]. These developments show how much ESS are advancing and expected to develop in other parts of the world as well.

The literature has identified various factors that stimulate energy storage system adoption on the basis of power system reliability. The most crucial factor is that researchers are looking forward to reducing interruptions as much as possible to relieve global energy demand. A significant reduction in net operational costs is also expected with the adoption of energy storage systems and delaying the expansion of transmission lines and integrating free and environment-friendly renewable energy resources. Many studies have focused on these factors. However, research gaps still exist in this field, such as global interest in energy storage system adoption and identification of other means of potential renewable resources, which are still in the infancy stage. Therefore, this systematic literature review (SLR) aims to critically synthesize two decades of empirical literature on the impacts of energy storage integration on power system reliability.

This paper is structured as follows. Section 2 describes the methods adopted in this SLR, Section 3 presents a descriptive analysis of the review, Section 4 synthesizes information from selected articles, and Section 5 presents the conclusions and avenues for future research.

2. Review Methodology

The review was conducted using the SLR methodology outlined by Moher et al. [5]. A reporting guideline for systematic review was developed by PRISMA Statement (www.prisma-statement.org). According to [5], a pre-defined methodological approach ensures that a review is systematically planned, thus producing a consistent conduct with accountability, research integrity and transparency. A protocol can reduce arbitrariness in the extraction of data from primary research and enable readers to identify any existing bias in completed reviews. Bias related to selective reporting outcome is a serious problem in systematic reviews [6,7]. This SLR was conducted in accordance with 17 items comprising the PRISMA-P checklist [8], which is divided into three main sections: administrative information, introduction, and methods.

To locate studies, we searched articles in the ScienceDirect, IEEE Xplore, and Scopus databases. To locate relevant publications, we applied a search string containing the search words 'energy storage' in the title and 'reliability' in the title-abstract. We selected journals with eligible articles in the domains of energy, energy conversion, and management and engineering. We included publications regardless of the journals' quality rating because the inclusion of a wide range of data forms provides a thorough understanding of phenomena of interests [9]. Nevertheless, we excluded other publications aside from journals and conference proceedings.

We selected 1996 as the starting point of our review because this year marks the establishment of an electric energy storage-related work program under the International Energy Agency. A main agendum of the program was enhancing electrical ESS in utility grids [10]. According to [11], the best manner of extracting data for systematic review is basing on original works rather than on interpretations of findings. Hence, we exclusively selected empirical articles whilst excluding reviews and theoretical studies. The field of interest was the power system sector. Thus, we excluded other sectors, such as manufacturing, transportation, and construction. Table 1 describes our study selection and evaluation criteria.

Table 1. Selection criteria of systematic literature review.

Issue	Inclusion Criterion
Publication type	Peer-reviewed publications
Language	English
Availability	Available online as full text
Research discipline	Energy, energy conversion, and management and engineering
Research methodology	Empirical
Time period	1996–2018
Sector	Power system
Relevance	Article addresses integration of energy storage systems to promote reliability of power systems

The first electronic database search yielded 459 articles, of which 408 remained after removal of duplicates. We reviewed the titles and abstracts of the articles and excluded works which did not fit the inclusion criteria presented in Table 1. This process led to the exclusion of 342 articles. The main reason for the large number of excluded studies was that the articles focused on sectors that were not related to power system reliability. Afterwards, we manually analyzed the full texts of the 66 remaining articles while examining their eligibility in accordance with the criteria described in Table 1.

We searched for relevant studies through manual screening of cross-references and found 17 additional articles. In examining the eligibility of the 83 articles, we conducted a careful full text analysis to ensure that these articles satisfied the criteria in Table 1.

We designed a form for assessing the risk of bias, which might occur in individual studies, because our studies were purely quantitative. The form was designed to determine whether the studies were free from selective reporting and inadequate outcome data. Two reviewers independently considered each item in the form and assigned an overall score. Disagreements were resolved by discussion, and the overall score was re-evaluated in case any conflict arose during the process. Extracted information was rated as 'high risk' or 'low risk'. 'Low risk' studies were those with a cumulative score of 3 and above, whilst 'high risk' referred to works with scores below 3. Table A2 provides data regarding the risk of bias of each study. The second, third, and fifth columns of the table are questions designed to detect any occurrence of selective reporting, whilst the fourth column ensures adequacy of the outcome data. The final score of each paper is provided in the last column. The information provides the scores of the final selected articles only. This process led to the final inclusion of 54 articles eligible for the review. The review protocol is illustrated in Figure 1 which summarizes the flow of review articles selections.

After identifying the eligible articles, we designed a data extraction form. Forms were created using DistillerSR, a web-based systematic review software by Evidence Partners from Ottawa, ON, Canada. The software helped simplify the data storage and structuring required for the analysis of the sample articles. In accordance with the objective of this review, we extracted the main contributions of energy storage systems from the articles, the types of ESS technologies utilized, resources used for the systems and other information relevant to this review. Table A1 in Appendix A lists the final articles included in this review.

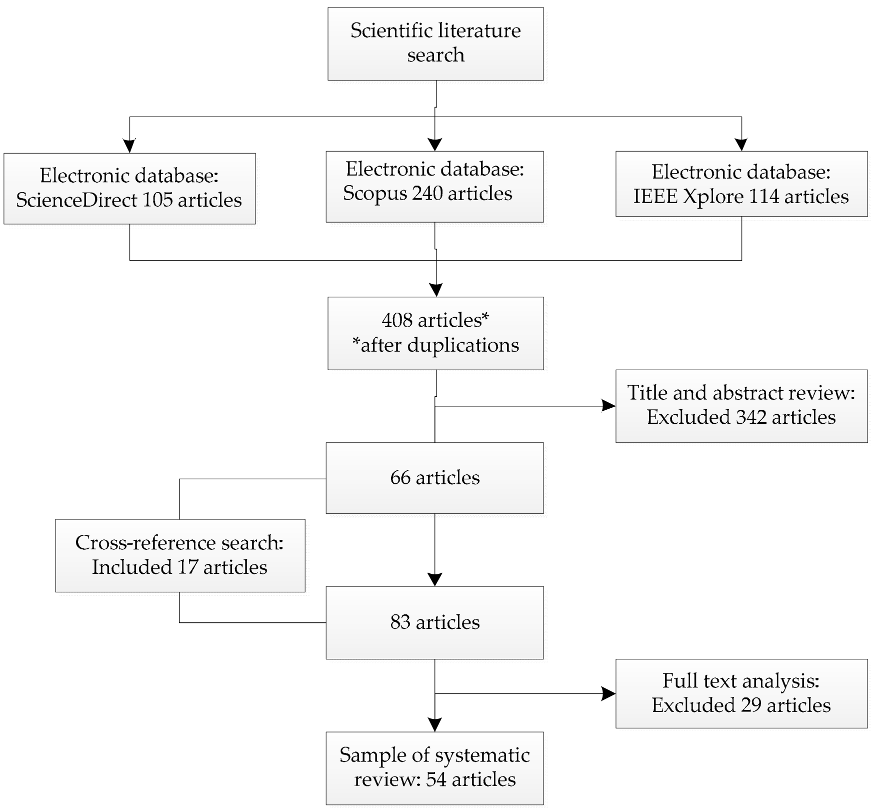

Figure 1. Flow diagram of review process.

3. Descriptive Analysis of Literature

To provide a critical literature review, we comprehensively evaluated (1) publication trends and their types and (2) geographical distributions and types of power networks analyzed in the empirical studies. The observations obtained are presented below.

3.1. Publication Trend, Year, Publications, and Authors

The number of annual publications on the reliability improvement of power systems utilizing energy storage has increased within the past two decades. The publication trend is depicted in Figure 2. During the first decade, the number of studies published was considerably low, with an average of one to two publications each year within 12 years. Starting year 2014, the number of publications has increased remarkably, with a maximum of 10 papers published annually in 2015 and 2016. Only one study was identified for 2018 because the literature covered by this review was up to early March 2018 only. The publication of academic papers in 2018 is expected to increase nonetheless. These trends reflect substantial interest in and pressing need for knowledge about the contributions of energy storage, hence encouraging the development of smart grids globally.

This review covers the period of 1996–2018 because funding mechanism for universities started only in 1996. Initially, studies were focused on three main regions: Europe, North America, and Japan, with the execution of Annex IX to enhance ESS implementation on utility networks [10]. Reference [10] added that Phase 2 of Annex IX was concluded in 1999, which explains why studies were made available only in 2000.

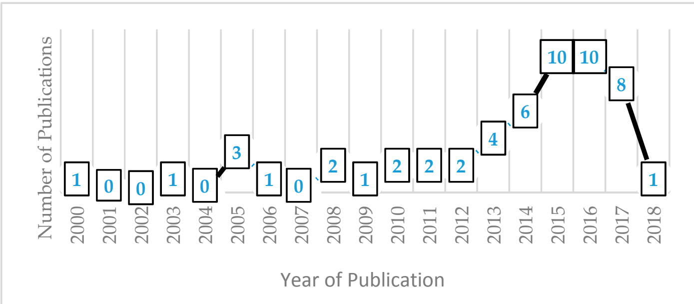

Figure 2. Number of annual publications.

Two types of publications were considered: academic journals and conference papers. These works were peer-reviewed and selected from selected electronic databases. Academic journals provide a large amount of studies, comprising 80% of the total literature reviewed. Data in Tables 2 and 3 provide information about the distribution of the selected publications. A total of 44 articles were selected from journals, of which seven published more than one relevant study. *IEEE Transactions of Sustainable Energy* published the largest number of relevant studies, followed by Energy. *IFAC and Probabilistic Methods Applied to Power Systems* conferences contributed most of the relevant works. In Tables 2 and 3, 'others' refers to journals or conferences that published only one selected study.

Table 2. Publishing journals.

Journal	Number of Articles
IEEE Transaction on Sustainable Energy	10
Energy	9
Renewable Energy	4
Journal of Modern Systems and Clean Energy	4
IEEE Transactions on Smart Grid	3
IEEE Transactions on Energy Conversions	3
Others	4

Table 3. Publishing conferences.

Conference	Number of Articles
IFAC	3
Probabilistic Methods Applied to Power Systems	3
Others	5

3.2. Empirical Data: Geographical and Power System Network Distributions

Figure 3 illustrates the regional distribution of the selected papers. The empirical data were selected from various regions, with Asia contributing most of the studies, followed by North America. Africa, South America, and Eastern Europe published the least number of relevant works, comprising only 2% of the 55 articles.

According to [10], the pace of energy storage technology development in the U.S. is faster than that in China. The U.S. Federal Energy Regulatory Commission has been regulating use of ESS technologies since early 2011. Meanwhile, China began listing ESS integration in electric grids only in 2014. This information is relevant to the illustration in Figure 4. The U.S. contributed 11 studies, whilst China published 10.

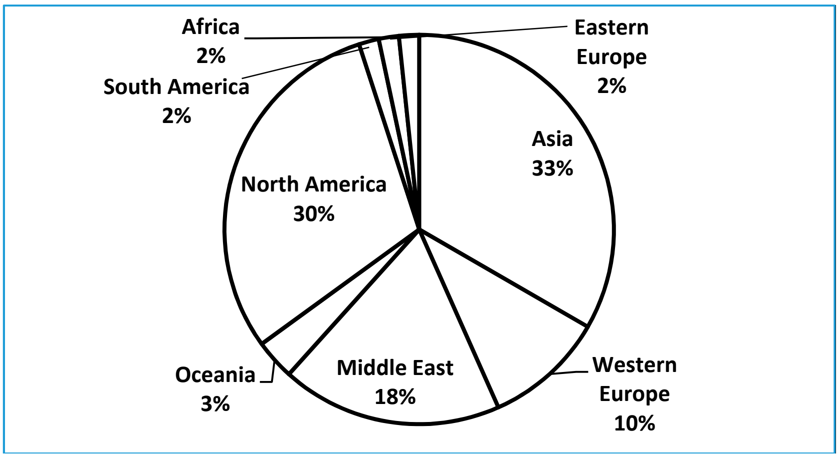

Figure 3. Regional distribution of empirical data.

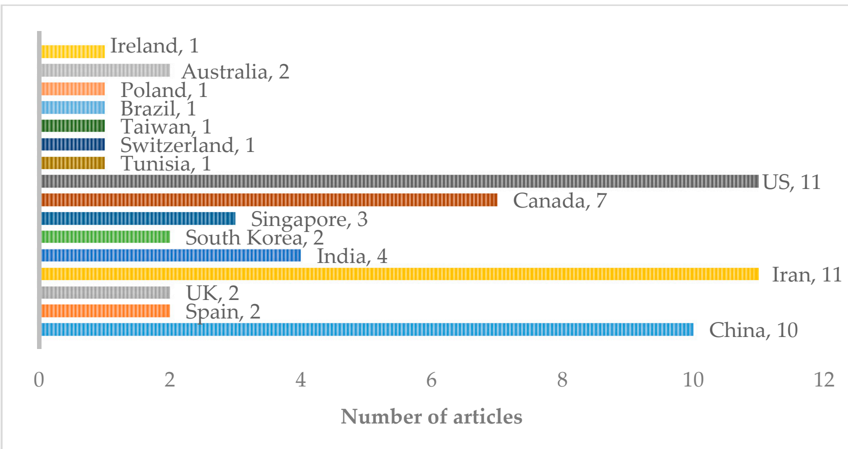

Figure 4. Distribution of empirical data by country.

Table 4 tabulates the distribution of ESS implementation on different types of power system networks. Three types of power system networks were identified: generation and transmission networks, distribution networks, and micro-grids. Applications of electrical energy storage are diverse, ranging from large-scale generation and transmission capacity to those primarily related to distribution networks [10]. The table shows that the application of energy storage in distribution networks is more prevalent than in transmission networks. According to [12], although ESS are likely to be installed in distribution networks, many of them are controlled by grid operators for the benefit of transmission networks. Micro-grids are active distribution networks that allow islanded operation but still participate in operative constraints [13]. Consequently, micro-grids are mostly preferred for ESS applications.

Table 4. Distribution of empirical studies by power system network.

Power System Network	Number of Applications
Transmission Network	15
Distribution Network	18
Micro-grid	21

3.3. Overview of Power System Reliability and Energy Storage Systems

Developments in power systems have expanded over the past decades. However, the main concern of electric power utility companies, which is providing uninterruptible power supply to end-loads, remains not practicable in real situations. Thus, utility companies strive for ways that consider costs and reliability in an effective manner [14]. Approaches to evaluating the reliability of power systems are available at different levels, i.e., generation, composite generation, and distribution. Reliability evaluation helps utility providers in decision making and future planning for the best optimal solution.

Reliability evaluation involves a consideration of system states and evaluation of their adequacy or security [15]. Adequacy refers to the sufficiency of energy supplied within the system for consumers, and security involves consideration of disturbances within the system [14]. The difference between adequacy and security division is that adequacy responds to static conditions, thereby neglecting the impacts of system disturbances.

Electric ESS are smart solutions for improving the reliability and energy efficiency of power systems. Electrical energy is usually stored in different forms: electromagnetic, kinetic, or potential energy [16]. References [3,17,18] described different technologies of energy storage systems according to storage medium. This information is presented in Table 5.

Table 5. Types of energy storage technologies.

Energy Storage	Descriptions
Supercapacitor energy storage	Supercapacitors store electrical energy directly and thus do not need to convert to other energy forms.
Superconducting magnetic energy storage systems (SMESs)	SMESs store electrical energy in the form of an electromagnetic field.
Flywheels	The flywheel stores energy in the form of mechanical energy.
Batteries	Energy is chemically stored.
Fuel cells	Electricity is generated through a reverse electrochemical reaction.
Thermal energy storage systems	Thermal energy is converted from electrical energy; the storage medium can be solid or liquid.
Pumped hydroelectric storage	Storage depends on the gravitational height between upper and lower reservoirs and work by potential energy.
Compressed air energy storage (CAES)	A CAES is an electromechanical device that produces electrical energy converted from mechanical energy.

Applications of energy storage are diverse and range from transmission systems to distribution systems. Reference [19] described various services offered by ESS, as depicted in Figure 5. Researchers are keen to explore the benefits of ESS utilizations to mitigate exploitation of renewable energy resources in utility grids. Renewable energies are intermittent in nature and therefore vulnerable to energy fluctuations and risk power system stability. ESSs are a solution that supports renewable energy systems during seasons with high energy demand.

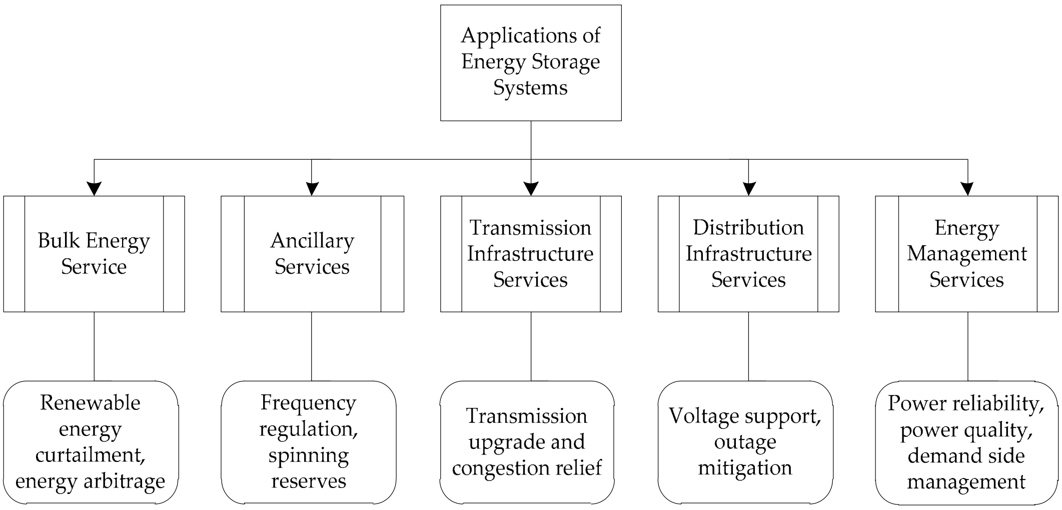

Figure 5. Applications of energy storage systems.

4. Analysis of Energy Storage Utilization in Improving Power System Reliability

4.1. Categorisation of Energy Storage Implementations

In this section, we synthesize the findings of the selected articles and present our analysis. Following the methodology described in Section 2, we selected 55 studies regarding energy storage utilization in improving power system reliability. We further classified these studies into three sub-topics: ESS technologies used, resources for ESS and reliability impacts for ESS. Each sub-topic was explored on the basis of evaluation and findings obtained from each paper. Figure 6 illustrates the classification of this review paper.

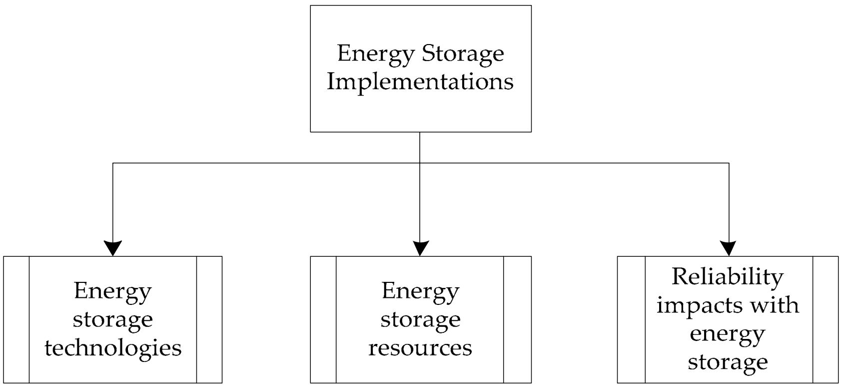

Figure 6. Classification of ESS information.

4.2. Energy Storage Technologies

The previous section mentions the presence of many existing electrical energy storage technologies, which are either still under-developed or already commercialized. To identify any reporting bias, we assessed the distribution of empirical studies by ESS technologies. The information provided in Table 4 was compared. Out of eight ESS technologies, only five were applied in the selected articles. The reasons for the unavailability were that the publications on other ESS were not directly related to power system reliability studies and some were not fully accessible. A review of the selected papers revealed five technologies being discussed: batteries, compressed-air energy storage (CAES), pumped hydro-energy storage (PHES), hydrogen-based fuel cells, and superconducting magnetic energy storage (SMES).

Figure 7 presents a pie chart illustrating the types of energy storage systems and the frequency of utilizing these technologies among the aforementioned studies. Battery ESSs (BESSs) are widely utilized in research. Among the 54 articles, 46 used BESS, followed by PHES, which was used four times. Hydrogen-based fuel cells and CAES were each used twice.

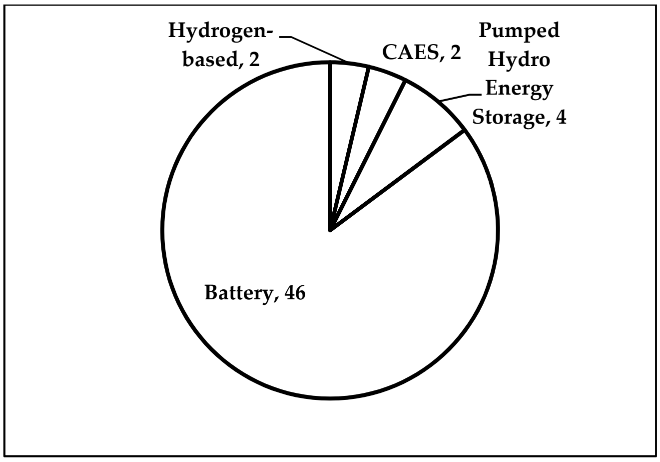

Figure 7. Distribution of empirical articles by ESS technologies.

4.2.1. Battery Energy Storage System

Batteries have wide applications in utility grids, ranging from hundreds of kilowatts to megawatts. For reliability studies, a battery condition is usually indicated by its state-of-charge (SOC). SOC can provide information about the current remaining capacity of the storage and directly reflect the soundness of the battery [20]. Power converters of BESS are similar to those of wind turbines and photovoltaic systems, thereby providing an advantage in terms of flexibility [21].

BESS is an electrochemical device designed to store chemical energy and release it as electrical energy when needed. Batteries are the most widely used among power system applications [22]. According to the papers reviewed, batteries are utilized for hybrid electric vehicles and electric grid network stabilization. BESSs are preferred over other ESS technologies due to fast response, high efficiency, and zero harmful emissions. However, they are costly and have a shorter lifespan than other ESSs [3]. In terms of power system reliability studies, works are being conducted to optimize the usage of BESS by introducing various working strategies to increase their lifetime whilst reducing expected energy not served to the system.

4.2.2. Pumped Hydro Energy Storage

PHES is an early technology that is commercially viable for utility grid applications. By 2015, the U.S. had launched and operated energy storage facilities mainly in the form of PHES and growing numbers of Li-ion batteries [4]. PHES operates in electromechanical devices, converting mechanical energy into electrical energy under discharging mode. In reliability studies, the condition of PHES has been indicated using the SOC of PHES [23]. Therefore, the amount of remaining stored energy is correlated with the previous charging or discharging amount of energy.

PHES has a high conversion efficiency of up to 85%, according to [24]. This technology is economically viable and practical, thereby becoming a preferred choice of technology. PHES can be hybridized with a wind turbine to form a wind hydro-pumped storage (WHPS) due to recent developments. WHPS was utilized to pump water from a lower to an upper reservoir to discharge energy during peak demand [17]. Reference [17] added that the drawbacks of PHES are the required large capital investment and limited choices for suitable sites.

4.2.3. Hydrogen-Based Fuel Cells

Fuel cells are electrochemical devices. Unlike batteries, fuel cells consume hydrogen primarily from external supply to generate electricity [17]. Fuel cells are a promising technology that facilitates the use of hydrogen, which is chemically safe and has zero emission [25]. In hydrogen-based systems, hydrogen is produced through an electrochemical process and is stored as gas or liquid, depending on the type of container [3]. Reference [26] described hydrogen system modelling that is relatively dependent on the amount of transferred energy from the hydrogen tank to the fuel cells.

Hydrogen fuel cells have sufficiently high dynamic response. They also have longer lifetimes than do BESS and can be stored for a long time [3]. However, similar to other technologies, hydrogen fuel cells also have drawbacks. The output efficiency of hydrogen fuel cells is relatively low, and investment cost is still high because they are a new technology [17].

4.2.4. Compressed Air Energy Storage (CAES)

Similar to PHES and electrochemical batteries, CAES is a mature high-energy-storage technology device [18]. It is an electromechanical device that produces electrical energy converted from mechanical energy. Reference [27] described CAES modelling under discharging mode as the ratio of energy generated to energy consumed from compressed air by a factor of K_A. CAES has a long life span and large power capacity and requires low investment and operational costs [28]. However, similar to PHES, CAES is limited to certain geographical areas [3].

4.3. Energy Storage Resources

Energy storage resources are energy resource integrated into ESS to improve power system reliability. Energy resources can be categorized into two types: conventional energy and renewable energy. Figure 8 illustrates the distribution of categorized energy resources. According to the figure, most energy storage systems are integrated to renewable energy. The reason for this phenomenon is that global interest has recently shifted to exploiting renewable energy for utility grids. However, power system stability might be at risk due to their intermittency. Energy storage systems are a solution to the fluctuations in energy generated by these resources [17].

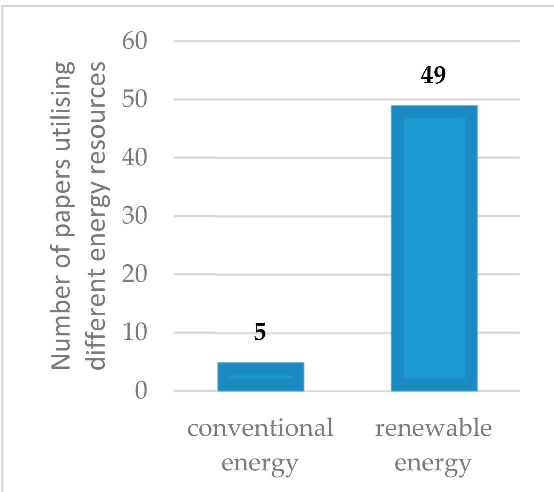

Figure 8. Distribution of empirical data by energy resource.

4.3.1. Conventional Energy

Conventional energy is non-renewable and mainly extracted from fossil fuels. It is a traditional source of energy on which most power systems still heavily depend. According to [29], fossil fuels contribute approximately 85% of the global energy demand. However, excessive fossil fuel consumption leads to the depletion of fossil fuel reserves, threatens health, and poses global climate change risks [30]. These reasons have driven researchers to find alternative solutions to fossil fuels. This development is relevant to the information provided in Figure 8, which shows that studies related to conventional energy comprise only 9% of the 54 studies.

In [31], an ESS is integrated to a conventional power system for demand peak-shaving. Results showed that utilization of ESS can sustain reliability level for nine years of 1% growth, thus reducing the need for transmission line upgrades. Meanwhile, another study [32] proposed optimization of ESS to active distribution networks, also for peak-shaving application, whilst improving system reliability. Unlike previous works, [33] focused on optimally locating ESS to radial distribution networks instead. In another study [34], large scale integration to conventional power systems was proposed to minimize operational and environmental emission costs. Lastly, a study [35] introduced electric vehicle (EV) integration to improve the reliability of existing conventional power systems and reduce the need for burning additional fossil fuels.

4.3.2. Renewable Energies

Renewable energy is sustainable because of its natural resources, such as the wind, sun, and water. Utilization of renewable sources for electric power supply has received increasing attention due to global environmental concerns associated with conventional energy generation [36]. As shown in Figure 8, 49 studies proposed integration of ESS with renewable energy. The main contribution of ESS is alleviating fluctuations in energy generation due to the intermittent nature of renewables [18]. Figure 9 illustrates the distribution of renewable energy resources utilized from the reviewed papers, which covered wind energy, solar energy, and hybrid renewable energy. For single renewable energy, only wind and solar energy are utilized. Hybrid renewable energy refers to multiple added renewable resources integrated to the system.

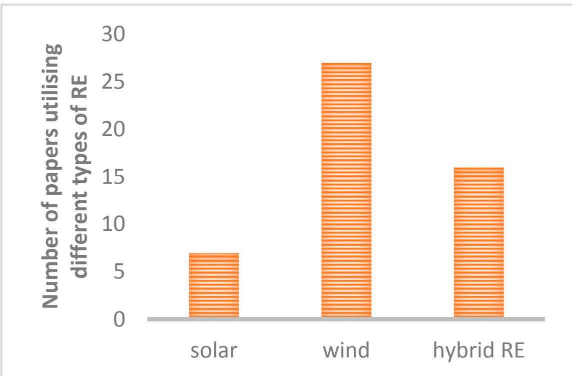

Figure 9. Distribution of empirical data by renewable energy resource.

Most of the extracted studies explored wind energy. Wind energy, which ranked second after hydroelectric energy in terms of installed capacity, is experiencing rapid growth [37]. In reliability studies, wind energy is usually considered under probability distribution function (PDF) due to its intermittency. Wind speed changes by the hour. Hence, various techniques have been proposed to model wind energy, which is usually modelled using the auto-regressive moving average (ARMA) model or the Weibull function. The ARMA model generates random wind speed as an auto-regressive and moving average model [38]. Meanwhile, the Weibull distribution considers wind speed, shape factor, and scale factor [39]. Other models are also applied, such as Rayleigh PDF [40] and available capacity probability tables [41].

Solar thermal energy is abundant and relatively available across countries. Solar energy is usually extracted using photovoltaic (PV) technology, which directly converts solar energy to electrical energy. The most familiar solar generation technique is the HOMER simulation program, which can generate hourly solar radiation at specific locations [42]. The reliability configuration of PV cells can also be modelled on the basis of other techniques, such as total cross-tied configuration [43] and statistical modelling of beta, Weibull and log normal functions [44].

Hybrid renewables are gaining attention due to their capability to compensate the shortcomings of other resources. Hybrid systems are usually adopted to supply energy for remote places and are isolated from utility grids, thereby forming their own micro-grids. Therefore, hybridization of solar and wind energy is a potential breakthrough for large-scale power systems, such as transmission and distribution networks [45]. Other renewable resources which are hybridized are tidal, hydro, and biomass energy. A hydro plant model can be obtained from a Box–Muller distribution [46]. Tidal energy is modelled using the Wakeby distribution [47]. Reference [48] does not mention a modelling technique for biomass.

4.4. Energy Storage Utilization in Improving Power System Reliability

In this section, we analyze the methods and impacts of utilizing ESS in each study. These papers were selected on the basis of the contributions of ESS utilization to improving power system reliability. The review reveals that varying methods can be implemented to exploit the usage of ESS in improving reliability. Optimizing ESS in terms of sizing storage capacity and siting its location in system networks are gaining considerable interest, according to the reviewed studies because optimization can improve reliability and reduce costs, such as interruption and operational costs, of a system. ESS is also flexible enough to be integrated with other smart solutions, such as real-time thermal rating (RTTR) and demand-side management (DSM) to form a smart grid, which has high reliability and efficient cost consumptions. Vehicle-to-grid (V2G) is also included in this review because it is a potential solution to curbing such issues as integration of renewables in distribution networks and peak shaving.

The review also reveals that all studies conducted focused on adequacy assessment; system facilities are expected to generate adequate amounts of energy, considering the associated transmission and distribution networks required to deliver energy to consumers [15].

Power systems are large and complex and thus usually distinguished by the concept of hierarchical levels (HL) to obtain a consistent means of identifying separate subsystems. The subsystems are generally known as generation systems, composite generation, and transmission and distribution systems [49]. Figure 10 illustrates HL, which becomes a relevant referring point of reliability studies [49].

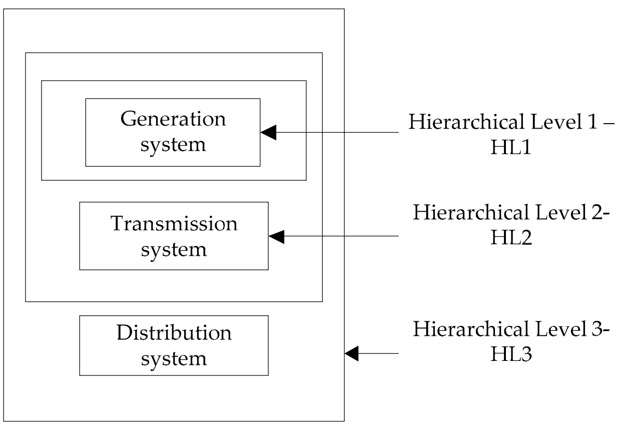

Figure 10. Power system reliability according to subsystems.

The synthesized results mainly consist of comparisons among studies, categorized by each subsystem or HL of power system reliability analyses.

4.4.1. Hierarchical Level 1

The first level (HL1) refers to generation facilities and their capability to supply adequate energy to end-loads [49]. Analysis at this level disregards transmission and distribution line conditions, which are assumed intact and fully reliable. Table 6 illustrates notable works of ESS contributions in generation subsystem (HL1).

Table 6. Comparison of notable works on impacts of ESS on HL1.

Source	Contribution	Benefit(s)	Limitation(s)
[20]	Reliability assessment of ESS in isolated solar power system	Applies Markov chain method, which has shorter computational time than do Monte Carlo simulations	Does not specify utilization of forced outage rate of system components
[23]	Determination of unit commitment of a power system with pumped storage	Discusses and differentiates capacity credit of a storage system from a conventional unit system	Does not consider uncertainty caused by wind farm
[50]	Reliability assessment of contribution of ESS to integrated wind power system for Jeju Island	Considers the chronological nature of output wind power and ESS by employing sequential MCS	May extend research by optimally sizing ESS capacity to improve reliability
[51]	Investigation of reliability benefits of wind and hydro coordination	Proposes simulation method while extending energy-limited hydro system model	May extend research to determine optimal reservoir capacities to improve system reliability and reduce costs
[52]	Investigation of the reliability of a system when coal-fired power stations are being replaced with renewable energies	Analytically verifies possibility of installing large share of wind generation by incorporating PHES	May extend research by considering the effect of varying storage capacities on system
[53]	Investigation of ESS in integrated wind power system using analytical method	Defines a new index ('expected energy not used') to present energy wasted in wind farm	May extend research by optimally locating and sizing ESS to further improve reliability

4.4.2. Hierarchical Level 2

Hierarchical level 2 (HL2) refers to composite generation and transmission and the capability to feed energy to bulk supply points [49]. Contrary to HL1, HL2 considers the capability of transmission lines to supply energy from the generating point to consumers. Optimal power flow will always be involved in this level to recognize any constraint that might happen in between generation and transmission lines, such as random generators and line failures. Table 7 illustrates notable works of ESS impacts on generation and transmission subsystems (HL2).

Table 7. Comparison of notable works on impacts of ESS on HL2.

Source	Contribution	Benefit(s)	Limitation(s)
[27]	Presents a stochastic method to maximize daily profit of a system containing renewable energy	Adopts stochastic dynamic programming to obtain optimal operation of ESS on the basis of wind energy time shifting	Does not specify utilization of forced outage rate of system components
[54]	Applies reliability assessment to determine adequate size of ESS and need for transmission upgrade	Evaluates different transmission line capacities to demonstrate reliability impacts; states that ESS can delay transmission line upgrade	Does not specify utilization of forced outage rate of system components
[55]	Utilizes loss of power supply probability (LPSP) to determine system reliability	Optimizes size of wind–solar capacity using LPSP	Does not specify utilization of forced outage rate of system components
[56]	Evaluates reliability impact of utilizing ESS with proposed intelligent operating strategy	Coordinates transmission and distribution network to ESS in parallel to relieve transmission congestion	May extend research in cost–benefit analysis while considering customer interruption costs

Table 7. *Cont.*

Source	Contribution	Benefit(s)	Limitation(s)
[57]	Evaluates impacts of pumped hydro energy storage against transmission line expansions	Applies multi-objective framework that considers different types of costs	The proposed planning method is intended for future expansion of 10 years to come; therefore, future study may consider the fact that the prices of each cost component can change.
[58]	An ESS is optimally scheduled considering system reliability	Expresses change in discretized SOC battery level on the basis of dynamic programming	May extend further research to optimally determine the size of ESS, which can improve total costs and reliability
[34]	Presents multi-stage generation expansion planning (GEP) and ESS scheduling	Expresses GEP-ESS planning as nonlinear optimization problem solved by PSO to minimize total costs of system and environmental pollution	Does not specify utilization of forced outage rate of system components
[28]	Presents a probabilistic optimal power flow to optimally size and locate ESS and thus minimize the cost of operations and interruptions	Proposes a stochastic framework to evaluate reliability of a system consisting of renewable energy resources and ESS	Does not consider fluctuating costs of conventional generation

4.4.3. Hierarchical Level 3

Hierarchical level 3 (HL3) refers to a complete system (including distribution) and the capability to satisfy the demand of individual consumers [49]. However, generation and transmission levels are always assumed to be fully reliable due to modelling complexity and the time-consuming process [59]. Therefore, analysis is solely focused on the capability of distribution networks to deliver energy to consumer point. Micro-grids are included in this level because they are usually isolated from main grids and have their own designated loads to be served. Table 8 illustrates the impacts of ESS on distribution subsystem (HL3).

Table 8. Comparison of notable works on impacts of ESS on HL3.

Source	Contribution	Benefit(s)	Limitation(s)
[60]	Solves energy dispatch problem in a smart grid consisting of renewable energy sources and ESS	Adopts economic model predictive control to optimize economic costs	Does not specify utilization of forced outage rate of system components
[61]	Proposes integration of tactical and operational management of a micro-grid	Uses sample-average approximation (SAA) to optimally improve reliability and system profit	Does not specify utilization of forced outage rate of system components
[62]	Presents a cost–benefit analysis in active distribution system	Applies single PSO to identify optimal ESS siting and system net profit	Does not specify how solar power is modelled
[31]	Integrates the use of RTTR alongside ESS to increase the availability of ESS and improve reliability	Presents a probabilistic approach of a demand and operational constraints of the ESS	May extend research to optimally locate RTTR and thus further improve reliability
[63]	Reliability evaluation of integrated renewable energy with electric vehicle (EV) operating strategy	Investigates the impact of EV parking lots on system reliability during outage events due to variability output power of renewable energy	Applies non-sequential Monte Carlo simulation, which does not consider the intermittency of renewable energy
[47]	Assessing reliability contribution of ESS in hybrid tidal–wave integrated power system	Derives reliability model of an ESS and converters	May extend research by including the effect of manipulating ESS capacity on the system
[64]	Adopts cuckoo search to optimally size a micro-grid component while minimizing costs	Compares its performance with other optimization algorithms	May extend research by optimally locating ESS to improve reliability
[65]	Presents an optimization of storage reserve sizing to minimize total costs	Adopts Markovian steady-state sizing method, which has smaller computational time consumption than Monte Carlo simulation	Does not specify utilization of forced outage rate of system components
[43]	Presents a probabilistic approach to determine adequacy in small solar system	Considers the impact of per minute ramp rates to accurately model load demand	May extend research by optimally sizing the capacity of ESS to improve reliability

Table 8. *Cont.*

Source	Contribution	Benefit(s)	Limitation(s)
[66]	Proposes the reliability benefits of mobile BESS in distribution network	Compares analytical and simulation methods to verify result accuracy	May include sensitivity studies, such as those considering the effect of wind penetration level on the system
[67]	Presents PSO to optimally size system components to minimize net cost of a micro-grid	Distinguishes interruptible and uninterruptible loads, which is practical for distribution network	May extend further research to include the effect of ESS siting on bus nodes on system reliability
[40]	Solves optimization problem of ESS sizing and siting while minimizing total system costs	Proposes a probabilistic technique which considers uncertainty of system components	May extend future research by considering fluctuating costs of diesel
[68]	Presents an optimal sizing solution for ESS serving a stand-alone wind power system	Considers battery's charge/discharge current and cycles to analyze their effects on battery's lifetime	Does not specify utilization of forced outage rate of system components
[69]	Presents a stochastic approximation method to size a hybrid system component	Uses pattern search to optimize sizing	May extend further research to include the effect of ESS siting on bus nodes on system reliability
[41]	Proposes an analytical model for reliability evaluation of ESS while optimally minimizing system present cost using genetic algorithm	Includes battery lifetime consideration on the basis of Ah throughput aging model	Does not consider fluctuating costs of diesel
[41]	Presents an optimization technique to size a stand-alone solar system consisting of PV panels and batteries	The technique utilizes statistical modelling of the solar radiation.	Does not specify utilization of forced outage rate of system components
[70]	Integrates a distribution network with the use of ESS and dynamic network reconfiguration	Proposes operating strategy of ESS to smooth out the variability of wind generation and increase the reliability	Does not specify utilization of forced outage rate of system components
[71]	Presents an innovative operating strategy that is based on MPC	Distribution network is modelled according to several segments; from upward to downward	May extend future work by optimally size the wind and ESS capacity to improve reliability and costs of the system
[72]	Proposes different operating strategies of diesel with ESS back-up	Proposes solution by making renewable energy as the priority to serve load; reduces the demand for diesel	Does not specify battery constraints, such as charging/discharging constraints and maximum/minimum capacity to be stored
[73]	Determines economic point of how much wind energy can be integrated to the system while improving reliability	Describes probabilistic production costing of a wind–diesel conversion system	Does not specify the constraints of ESS, such as the maximum rate of charging and discharging constraints
[74]	Presents a multi-objective approach to minimizing operation costs while improving reliability of a distribution network	The proposed algorithm is able to converge to the optimal solution rapidly, producing the lowest cost and good reliability improvement	Does not specify utilization of forced outage rate of system components
[75]	Presents stochastic capacity expansion planning of a micro-grid to reduce capital cost of a project	Considers operational and investment costs while satisfying reliability constraint	For future research, ESS expansion may include associated cost such as equipment transportation each time system is upgraded.
[32]	Applies mixed-integer linear planning to integrate ESS in multi-stage distribution network planning	Improves economic operation based on hourly variable electricity price on substation nodes	Does not specify utilization of forced outage rate of system components
[76]	Evaluates a reliability-constrained optimal ESS sizing in a micro-grid	Applies Monte Carlo simulation that considers uncertainties along with the optimization scheme	May extend further research to include the effect of ESS siting on bus nodes on system reliability and operational costs
[77]	Presents energy dispatch solutions for autonomous micro-grids by incorporating power loss and reliability statistics	Applies 'stem–leaves' approach to optimize energy dispatch across connected micro-grids	Does not specify utilization of forced outage rate of system components
[78]	Integrates demand response program with ESS to reduce total costs and improve reliability	Proposes DRP to optimally size and locate ESS in the micro-grid to improve economic benefit.	Does not specify the constraints of the ESS, such as the maximum charging and discharging rate of the battery
[33]	Optimization of ESS sizing and siting for reliability improvement in distribution network	Optimizes the cost of ESS while minimizing the cost of interruptions	May extend further research by optimally locating ESS to improve reliability
[79]	Proposes a dispatch strategy to determine ESS capacity	Considers uncertainties in wind speed and load	For future research, unit operational constraints can be added

Table 8. *Cont.*

Source	Contribution	Benefit(s)	Limitation(s)
[80]	Optimizes the total cost of the system and cost of energy not supplied	Proposes a stochastic power flow to model uncertainty of wind turbine, PV panels and charging/discharging pattern of EVs	Does not specify utilization of forced outage rate of system components
[26]	Multi-objective PSO is applied to minimize costs and reliability indices of the system.	Outages of PV arrays, wind turbines, and converters are also considered	Does not consider the uncertainty in wind speed, solar radiation and load data demand
[81]	Presents an optimal expansion planning for grid-connected micro-grid which aims to maximize reliability and minimize costs	Proposes a real-time energy exchange with the utility on the basis of tariff variability	In future work, several solutions can be implemented to solve ILP over-estimate of solution bounds.
[48]	Proposes operating strategies for supply-adequate micro-grids considering real and reactive power	Uncertain characteristics of distribution generation units and loads are considered	Does not specify the constraints of ESS, such as the maximum rate of charging and discharging constraints
[36]	Investigates the impacts of ESS on power systems utilizing wind and/or solar energy	Proposes a sequential MCS, recognizing the time-varying nature of renewable energy power output	Does not specify the constraints of the ESS, such as the maximum charging and discharging rate of the battery
[82]	Analyses the contribution of ESS to reliability of solar power system	Considers behavior of solar irradiance and outages due to hardware failure	Applies non-sequential Monte Carlo simulation, which does not recognize fluctuations of generated power
[83]	Evaluates reliability of a hybrid solar–wind isolated power system with ESS	Proposes discrete speed frame analysis to model wind speed	Does not consider maintenance and repair characteristics of system components
[84]	Calculates the sizing of batteries on the basis of loss of load probability	Analyzes the impact of increase in peak demand on the system	Applies non-sequential Monte Carlo simulation, which does not recognize fluctuations in generated power
[85]	Proposes a simulation method which extends well-being analysis to renewable energy generation	Considers different energy compositions and storage capacity levels	Does not specify the constraints of the ESS, such as the maximum charging and discharging rate of the battery
[35]	Evaluates reliability impact of EVs under battery exchange (BE) mode	Defines a new index to quantify interruption effects on users ('user demand not satisfied')	May extend future research by optimally sizing BE station capacity to improve reliability among users and utility's point of view
[86]	Proposes cost/worth evaluation of generating system consisting of wind energy and ESS	Presents a new approach that considers utility and cost interruptions in the evaluation	Does not consider fluctuating costs of diesel
[13]	Evaluates reliability of micro-grid consisting of renewable energy generation and ESS	Islanding mode is incorporated on the basis of the probabilities of switching process quality indicators	Applies non-sequential Monte Carlo simulation, which does not satisfy the chronological nature of solar output power

5. Conclusions

5.1. Synthesis of Findings

Empirical studies show an increasing trend of publications regarding utilization of ESS in power networks. China has invested a considerable amount of grant for these studies to encourage their researchers collaborate with foreign researchers. The review shows that Asia, especially large-population countries such as China and India, are committed to improving the reliability of ESS and incorporating renewables into their systems. Therefore, Asia's current position as the leading continent in terms of power system reliability studies (followed by North America) is not surprising. North America is the pioneer for reliability studies and energy storage systems, with U.S. and Canada as the main contributors. They started publishing papers as early as the year 2000. Other dominating countries in renewable energy sector, particularly the North European (Finland, Swedish, and Germany) contributes less number of papers, which is far below expectation due to language barriers. Most related papers were published in their native languages, and hence not included for this review paper. Meanwhile, Iran shows a remarkably large number of studies starting in 2015, which is at par with China. Iran is one of the biggest electrical consumers in the world and therefore needs to find alternative solutions by utilizing their rich renewable reserves [87].

The review reveals that of all three hierarchical levels, the distribution level is the main focus of existing studies because of the increasing interest in integrating micro-grids to improve reliability at the distribution level and to reducing the purchase of energy from utility. Moreover, micro-grids' capability to supply energy in remote areas drives researchers to optimize the integration of ESS to improve the reachability and reliability of electrical energy in these areas. We also observe an increasing trend of utilizing various techniques to optimize ESS, especially in terms of sizing and siting on system nodes. In addition to these optimization techniques, methods considering economic constraints are also introduced, such as model predictive control and stochastic dynamic programming, because of the anticipation of minimizing total costs involved whilst maximizing reliability indices. Studies are also dedicated to determining the impacts of integrating other smart solutions alongside ESS, such as V2G, RTTR, and DSM. These so-called smart solutions are key points for building smart grids in the future.

5.2. Limitations of Current Study and Avenues for Future Research

After reviewing literature about energy storage utilization in the power system reliability sector, we find shortcomings and gaps that future research can address.

Firstly, future research should address the potential of utilizing this technology in sectors located in developing and under-developed countries because access to electricity is still poor among these regions and development of energy storage facilities as a body of knowledge can solve this issue. For example, while Asia has contributed the most publications, their research mainly comes from China. A large gap still exists in terms of academic participation from other parts of Asia, particularly Southeast Asia.

Secondly, future research should include other renewable energy resources. Currently, studies highly utilize wind and solar energy and a significant gap characterizes the search for other potential renewable energy resources, probably due to insufficient studies in terms of models and technologies that can convert and integrate these resources to systems.

Thirdly, future research should also consider the potential of utilizing hybrid energy storage systems for reliability studies. To the authors' best knowledge, significant interest is invested in hybridizing ESS in terms of technological development and modelling. Hybrid energy storage can bring considerable benefits to counter the shortcomings of electric storage systems.

Lastly, studies on integration of smart solutions along with ESS are still new and can further be developed. The use of cars as a mode of transportation is uncontrollably increasing, and V2G is a smart and green solution for peak shaving and can increase the integration of renewables to distribution networks.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Articles included in systematic literature review (SLR).

No.	Title	Authors	Type of ESS
1.	Reliability Evaluation of the Solar Power System Based on the Markov Chain Method	L. Wu, C. Wen, H. Ren (2017)	Battery
2.	Robust Optimization based Energy Dispatch in Smart Grids Considering Simultaneously Multiple Uncertainties: Load Demands and Energy Prices	M. Nassourou, V. Puig, J. Blesa (2017)	Battery
3.	Tactical and Operational Management of Wind Energy Systems with Storage using a Probabilistic Forecast of the Energy Resource	C. Azcárate, F. Mallor, P. Mateo (2016)	Hydrogen-based FC

Table A1. *Cont.*

No.	Title	Authors	Type of ESS
4.	Optimal Planning of Battery Energy Storage Considering Reliability Benefit and Operation Strategy in Active Distribution System	W. Liu, S. Niu, H. Xu (2016)	Battery
5.	A Probabilistic Method Combining Electrical Energy Storage and Real-Time Thermal Ratings to Defer Network Reinforcement	D.M. Greenwood, N.S. Wade, P.C. Taylor, P. Papadopoulos, N. Heyward (2017)	Battery
6.	Reliability Studies of Modern Distribution Systems Integrated With Renewable Generation and Parking Lots	H. Farzin, M. Fotuhi-Firuzabad, M. Moeini-Aghtaie (2016)	EV battery
7.	Reliability Evaluation of Tidal and Wind Power Generation System with Battery Energy Storage	M. Liu, W. Li, J. Yu, Z. Ren, R. Xu (2016)	Battery
8.	Maiden application of Cuckoo Search Algorithm for Optimal Sizing of a Remote Hybrid Renewable Energy System	S. Sanajaoba, E. Fernandez(2016)	Battery
9.	Storage-Reserve Sizing with Qualified Reliability for Connected High Renewable Penetration Micro-Grid	J. Dong, F. Gao, X. Guan, Q. Zhai, J. Wu (2015)	Battery
10.	Reliability Contribution Function considering Wind Turbine Generators and Battery Energy Storage System in Power System	U. Oh, J. Choi, H.-H. Kim (2016)	Battery
11.	Operational Adequacy Studies of a PV-based and Energy Storage Stand-Alone Microgrid	L.H. Koh, P. Wang, F.H. Choo, K.-J. Tseng, Z. Gao, H.B. Püttgen (2015)	Battery
12.	Optimal Integration of Mobile Battery Energy Storage in Distribution System with Renewables	Y. Zheng, Z. Dong, S. Huang, K. Meng, F. Luo, J. Huang, D. Hill (2015)	Battery
13.	Evaluation of Reliability Parameters in Micro-Grid	H. Hassanzadeh Fard, S.A. Bahreyni, R. Dashti, H.A. Shayanfar (2015)	Battery
14.	Optimal ESS Allocation for Load Management Application	A.S.A. Awad, T.H.M. El-Fouly, M.M.A. Salama (2013)	Battery
15.	A Wind-battery Optimal Design Algorithm for Power Generation System	K.M. Kamble, H.T. Jadhav (2015)	Battery
16.	Stochastic Performance Assessment and Sizing for a Hybrid Power System of Solar/Wind/Energy Storage	A. Arabali, M. Ghofrani, M. Etezadi-Amoli, M.S. Fadali (2014)	Battery
17.	Optimal Operation Strategy of Energy Storage System for Grid-Connected Wind Power Plants	Z. Shu, P. Jirutitijaroen (2013)	CAES
18.	Optimal Planning of Stand-Alone Micro-Grids Incorporating Reliability	C. Wang, B. Jiao, L. Guo, K. Yuan, B. Sun (2014)	Battery
19.	Optimal Sizing of a Stand-alone Photovoltaic System Using Statistical Approach	S. Fezai, J. Belhadj (2014)	Battery
20.	Reliability Assessment in Smart Distribution Networks	H. Guo, V. Levi, M. Buhari (2013)	Battery
21.	Adequacy and Economy Analysis of Distribution Systems Integrated with Electric Energy Storage and Renewable Energy Resources	Y. Xu, C. Singh (2012)	Battery
21.	Adequacy and Economy Analysis of Distribution Systems Integrated with Electric Energy Storage and Renewable Energy Resources	Y. Xu, C. Singh (2012)	Battery
22.	Reliability Modeling and Control Schemes of Composite Energy Storage and Wind Generation System with Adequate Transmission Upgrades	Y. Zhang, S. Zhu, A.A. Chowdhury (2011)	Battery
23.	Reliability Evaluation Considering Wind and Hydro Power Coordination	R. Karki, P. Hu, R. Billinton (2010)	PHES
24.	Evaluation of Different Operating Strategies in Small Stand-Alone Power Systems	Bagen, R. Billinton (2005)	Battery
25.	Weather Data and Probability Analysis of Hybrid Photovoltaic-Wind Power Generation Systems in Hong Kong	H.X. Yang, L. Lu, J. Burnett (2003)	Battery
26.	Probabilistic Production Costing of Diesel–Wind Energy Conversion Systems	S.H. Karaki, R.B. Chedid, R. Ramadan (2000)	Battery
27.	Power System Reliability Impact of Energy Storage Integration With Intelligent Operation Strategy	Y. Xu, C. Singh (2014)	Battery

Table A1. *Cont.*

No.	Title	Authors	Type of ESS
28.	A New Bi-Objective Approach to Energy Management in Distribution Networks with Energy Storage Systems	A. Azizivahed, E. Naderi, H. Narimani, M. Fathi, M.R. Narimani (2018)	Battery
29.	Stochastic Capacity Expansion Planning of Remote Microgrids with Wind Farms and Energy Storage	E. Hajipour, M. Bozorg, M. Fotuhi-Firuzabad (2015)	Battery
30.	Expansion Planning of Active Distribution Networks with Centralized and Distributed Energy Storage Systems	X. Shen, M. Shahidehpour, Y. Han, S. Zhu, J. Zheng (2017)	Battery
31.	On the Use of Pumped Storage for Wind Energy Maximization in Transmission-Constrained Power Systems	M. A. Hozouri, A. Abbaspour, M. Fotuhi-Firuzabad, M. Moeini-Aghtaie (2015)	PHES
32.	Reliability-Constrained Optimal Sizing of Energy Storage System in a Microgrid	S. Bahramirad, W. Reder, A. Khodaei (2012)	Battery
33.	Operation Scheduling for an Energy Storage System Considering Reliability and Aging	W.W Kim, J.S. Shin, S.Y. Kim, J.O. Kim (2017)	Battery
34.	Cooperative Energy Dispatch for Multiple Autonomous Micro-Grids with Distributed Renewable Sources and Storages	X. Fang, S. Ma, Q. Yang, J. Zhang (2016)	Battery
35.	An Efficient Cost–Reliability Optimization Model for Optimal Siting and Sizing of Energy Storage System in a Micro-Grid in the Presence of Responsible Load Management	S. Nojavan, M. Majidi, N.N. Esfetanaj (2017)	Battery
36.	Reliability Improvement in Radial Electrical Distribution Network by Optimal Planning of Energy Storage Systems	H. Saboori, R. Hemmati, M.A. Jirdehi (2015)	Battery
37.	Reducing Uncertainty Accumulation in Wind-Integrated Electrical Grid	T.C. Hung, J. Chong, K.Y. Chan (2017)	Battery
38.	Stochastic Scheduling of Local Distribution Systems Considering High Penetration of Plug-In Electric Vehicles and Renewable Energy Sources	S. Tabatabaee, S.S. Mortazavi, T. Niknam (2017)	EV Battery
39.	Reliability/Cost-Based Multi-Objective Pareto Optimal Design of Stand-Alone Wind/PV/FC Generation Micro-Grid System	H.R. Baghaee, M. Mirsalim, G.B. Gharehpetian, H.A. Talebi (2016)	Hydrogen-based FC
40.	Stochastic-Based Resource Expansion Planning for a Grid-Connected Micro-Grid using Interval Linear Programming	M.H.S. Boloukat, A.A. Foroud (2016)	Battery
41.	Trends of Changes in the Power Generation System Structure and Their Impact on the System Reliability	A. Rusin, A. Wojaczek (2015)	PHES
42.	Multistage Generation Expansion Planning Incorporating Large Scale Energy Storage Systems and Environmental Pollution	R. Hemmati, H. Saboori, M.A. Jirdehi (2016)	Battery
43.	DG Mix, Reactive Sources, and Energy Storage Units for Optimizing Microgrid Reliability and Supply Security	S. A. Arefifar, Y.A.R.I. Mohamed (2014)	Battery
44.	Energy Storage Application for Performance Enhancement of Wind Integration	M. Ghofrani, A. Arabali, M. Etezadi-Amoli, M.S. Fadali (2013)	CAES
45.	Impacts of Energy Storage on Power System Reliability Performance	Bagen, R. Billinton (2005)	Battery
46.	Reliability Evaluation of a Solar Photovoltaic System with and without Battery Storage	S. S. Singh, E. Fernandez (2015)	Battery
47.	Impact of Pumped Storage on Power Systems with Increasing Wind Penetration	A. Tuohy, M. O'Malley (2009)	PHES
48.	Reliability Evaluation of a Wind–Diesel Hybrid Power System with Battery Bank Using Discrete Wind Speed Frame Analysis	X. Liu, S. Islam (2006)	Battery
49.	Impacts of Energy Storage on Reliability of Power Systems with WTGs	Z.Y. Gao, P. Wang, J. Wang (2010)	Battery
50.	Method for Evaluating Battery Size based on Loss of Load Probability Concept for a Remote PV system	S.S. Singh, E. Fernandez (2014)	Battery
51.	Incorporating Well-Being Considerations in Generating Systems Using Energy Storage	Bagen, R. Billinton (2005)	Battery

Table A1. *Cont.*

No.	Title	Authors	Type of ESS
52.	Power System Reliability Assessment With Electric Vehicle Integration Using Battery Exchange Mode	L. Cheng, Y. Chang, J. Lin, C. Singh (2008)	EV battery
53.	Reliability Cost/Worth Associated With Wind Energy and Energy Storage Utilization in Electric Power Systems	B. Bagen, R. Billinton (2008)	Battery
54.	Microgrid Reliability Evaluation with Renewable Distributed Generation and Storage Systems	C.L.T. Borges, E. Cantarino (2011)	Battery

Table A2. Bias risk assessment data.

RefID	Does the Paper Provide Successful Outcomes?	Does the Paper State any Constraint?	Does the Paper Provide Adequate Outcome Data?	Does the Paper Provide Future Avenues?	Total
8	YES	YES	YES	NO	3
22	YES	YES	YES	YES	4
29	YES	YES	YES	NO	3
30	YES	YES	YES	YES	4
34	YES	YES	YES	YES	4
36	YES	YES	YES	NO	3
46	YES	YES	YES	NO	3
47	YES	YES	YES	NO	2
55	YES	YES	YES	YES	5
64	YES	YES	YES	NO	3
73	YES	YES	YES	NO	3
77	YES	YES	YES	NO	3
80	YES	YES	YES	NO	3
81	YES	YES	YES	YES	4
87	YES	YES	YES	NO	3
101	YES	YES	YES	NO	3
106	YES	YES	YES	YES	4
111	YES	YES	YES	YES	4
125	YES	YES	YES	YES	4
136	YES	YES	YES	YES	4
153	YES	YES	YES	NO	3
159	YES	YES	YES	NO	4
169	YES	YES	YES	NO	4
206	YES	YES	YES	NO	4
216	YES	YES	YES	YES	4
226	YES	YES	YES	NO	3
242	YES	YES	YES	YES	4
246	YES	YES	YES	NO	3
267	YES	YES	YES	YES	4
274	YES	YES	YES	YES	4
282	YES	YES	YES	NO	3
286	YES	YES	YES	NO	3
307	YES	YES	YES	NO	4
318	YES	YES	YES	NO	3
323	YES	YES	YES	NO	3
328	YES	YES	YES	NO	3
330	YES	YES	YES	YES	4
357	YES	YES	YES	NO	3
359	YES	YES	YES	YES	4
361	YES	YES	YES	NO	3
362	YES	YES	YES	NO	3
387	YES	YES	YES	NO	3
442	YES	YES	YES	NO	3
455	YES	YES	YES	NO	3
462	YES	YES	YES	NO	3
463	YES	YES	YES	NO	3
465	YES	YES	YES	NO	3
466	YES	YES	YES	YES	4
467	YES	YES	YES	YES	4
469	YES	YES	YES	NO	3
470	YES	YES	YES	NO	3
473	YES	YES	YES	NO	3
474	YES	YES	YES	NO	3
477	YES	YES	YES	NO	3

References

1. Billinton, R.; Allan, R.N.; Salvaderi, L. *Applied Reliability Assessment in Electric Power Systems*; IEEE: Piscataway Township, NJ, USA, 1991.
2. Sekhar, P.C.; Deshpande, R.; Sankar, V. Evaluation and improvement of reliability indices of electrical power distribution system. In Proceedings of the 2016 National Power Systems Conference (NPSC), Bhubaneswar, India, 19–21 December 2016; pp. 1–6.
3. Farrokhabadi, M.; Solanki, B.V.; Canizares, C.A.; Bhattacharya, K.; Koenig, S.; Sauter, P.S.; Leibfried, T.; Hohmann, S. Energy storage in microgrids: Compensating for generation and demand fluctuations while providing ancillary services. *IEEE Power Energy Mag.* **2017**, *15*, 81–91. [CrossRef]
4. Zhang, Y.; Gevorgian, V.; Wang, C.; Lei, X.; Chou, E.; Yang, R.; Li, Q.; Jiang, L. Grid-level application of electrical energy storage: Example use cases in the United States and China. *IEEE Power Energy Mag.* **2017**, *15*, 51–58. [CrossRef]
5. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev.* **2015**, *4*. [CrossRef] [PubMed]
6. Kirkham, J.J.; Altman, D.G.; Williamson, P.R. Bias due to changes in specified outcomes during the systematic review process. *PLoS ONE* **2010**, *5*, e9810. [CrossRef] [PubMed]
7. Kirkham, J.J.; Dwan, K.M.; Altman, D.G.; Gamble, C.; Dodd, S.; Smyth, R.; Williamson, P.R. The impact of outcome reporting bias in randomised controlled trials on a cohort of systematic reviews. *Br. Med. J.* **2010**, *340*, c365. [CrossRef] [PubMed]
8. Shamseer, L.; Moher, D.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: Elaboration and explanation. *Br. Med. J.* **2015**, *349*, g7647. [CrossRef] [PubMed]
9. Denyer, D.; Tranfield, D. Producing a systematic review. In *The Sage Handbook of Organizational Research Methods*; Sage Publications Ltd.: Thousand Oaks, CA, USA, 2009.
10. Baker, J.; Collinson, A. Electrical energy storage at the turn of the millennium. *Power Eng. J.* **1999**, *13*, 107–112. [CrossRef]
11. Fink, A. *Conducting Research Literature Reviews: From the Internet to Paper*; Sage: Thousand Oaks, CA, USA, 2005.
12. Dugan, R.C.; Taylor, J.A.; Montenegro, D. Energy storage modeling for distribution planning. *IEEE Trans. Ind. Appl.* **2017**, *53*, 954–962. [CrossRef]
13. Carmen, L.T.B.; Eduardo, C. Microgrids reliability evaluation with renewable distributed generation and storage systems. *IFAC Proc. Vol.* **2011**, *44*, 11695–11700.
14. Lata, P.; Vadhera, S. In Issues of concerns in power system reliability. In Proceedings of the 2015 International Conference on Power, Instrumentation, Control and Computing (PICC), Thrissur, India, 9–11 December 2015; pp. 1–6.
15. Bhavaraju, M. Composite system reliability evaluation. *Int. J. Electr. Power Energy Syst.* **1988**, *10*, 174–179. [CrossRef]
16. Ribeiro, P.F.; Johnson, B.K.; Crow, M.L.; Arsoy, A.; Liu, Y. Energy storage systems for advanced power applications. *Proc. IEEE* **2001**, *89*, 1744–1756. [CrossRef]
17. Suberu, M.Y.; Mustafa, M.W.; Bashir, N. Energy storage systems for renewable energy power sector integration and mitigation of intermittency. *Renew. Sustain. Energy Rev.* **2014**, *35*, 499–514. [CrossRef]
18. Farhadi, M.; Mohammed, O. Energy storage technologies for high-power applications. *IEEE Trans. Ind. Appl.* **2016**, *52*, 1953–1961. [CrossRef]
19. Xu, X.; Bishop, M.; Oikarinen, D.G.; Hao, C. Application and modeling of battery energy storage in power systems. *CSEE J. Power Energy Syst.* **2016**, *2*, 82–90. [CrossRef]
20. Wu, L.; Wen, C.; Ren, H. Reliability evaluation of the solar power system based on the markov chain method. *Int. J. Energy Res.* **2017**, *41*, 2509–2516. [CrossRef]
21. Pourbeik, P.; Williams, S.E.; Weber, J.; Sanchez-Gasca, J.; Senthil, J.; Huang, S.; Bolton, K. Modeling and dynamic behavior of battery energy storage: A simple model for large-scale time-domain stability studies. *IEEE Electrification Mag.* **2015**, *3*, 47–51. [CrossRef]
22. Divya, K.; Østergaard, J. Battery energy storage technology for power systems—An overview. *Electr. Power Syst. Res.* **2009**, *79*, 511–520. [CrossRef]

23. Tuohy, A.; Malley, M.O. Impact of pumped storage on power systems with increasing wind penetration. In Proceedings of the 2009 IEEE Power & Energy Society General Meeting, Calgary, AB, Canada, 26–30 July 2009.
24. Ibrahim, H.; Ilinca, A.; Perron, J. Energy storage systems—Characteristics and comparisons. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1221–1250. [CrossRef]
25. Li, G.; Lu, X.; Coyle, C.A.; Kim, J.Y.; Lemmon, J.P.; Sprenkle, V.L.; Yang, Z. Novel ternary molten salt electrolytes for intermediate-temperature sodium/nickel chloride batteries. *J. Power Source* **2012**, *220*, 193–198. [CrossRef]
26. Baghaee, H.R.; Mirsalim, M.; Gharehpetian, G.B.; Talebi, H.A. Reliability/cost-based multi-objective pareto optimal design of stand-alone wind/pv/fc generation microgrid system. *Energy* **2016**, *115*, 1022–1041. [CrossRef]
27. Shu, Z.; Jirutitijaroen, P. Optimal operation strategy of energy storage system for grid-connected wind power plants. *IEEE Trans. Sustain. Energy* **2014**, *5*, 190–199. [CrossRef]
28. Ghofrani, M.; Arabali, A.; Etezadi-Amoli, M.; Fadali, M.S. Energy storage application for performance enhancement of wind integration. *IEEE Trans. Power Syst.* **2013**, *28*, 4803–4811. [CrossRef]
29. Sen, S.; Ganguly, S. Opportunities, barriers and issues with renewable energy development—A discussion. *Renew. Sustain. Energy Rev.* **2017**, *69*, 1170–1181. [CrossRef]
30. Intergovernmental Panel on Climate Change Working Group 3. *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: Summary for Policymakers and Technical Summary*; Cambridge University Press: Cambridge, UK, 2007.
31. Greenwood, D.M.; Wade, N.S.; Taylor, P.C.; Papadopoulos, P.; Heyward, N. A probabilistic method combining electrical energy storage and real-time thermal ratings to defer network reinforcement. *IEEE Trans. Sustain. Energy* **2017**, *8*, 374–384. [CrossRef]
32. Shen, X.; Shahidehpour, M.; Han, Y.; Zhu, S.; Zheng, J. Expansion planning of active distribution networks with centralized and distributed energy storage systems. *IEEE Trans. Sustain. Energy* **2017**, *8*, 126–134. [CrossRef]
33. Hedayat, S.; Reza, H.; Mehdi Ahmadi, J. Reliability improvement in radial electrical distribution network by optimal planning of energy storage systems. *Energy* **2015**, *93*, 2299–2312.
34. Reza, H.; Hedayat, S.; Mehdi Ahmadi, J. Multistage generation expansion planning incorporating large scale energy storage systems and environmental pollution. *Renew. Energy* **2016**, *97*, 636–645.
35. Cheng, L.; Chang, Y.; Lin, J.; Singh, C. Power system reliability assessment with electric vehicle integration using battery exchange mode. *IEEE Trans. Sustain. Energy* **2013**, *4*, 1034–1042. [CrossRef]
36. Bagen, R.B. Impacts of energy storage on power system reliability performance. In Proceedings of the 2005 Canadian Conference on Electrical and Computer Engineering, Saskatoon, SK, Canada, 1–4 May 2005; pp. 494–497.
37. Panwar, N.; Kaushik, S.; Kothari, S. Role of renewable energy sources in environmental protection: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1513–1524. [CrossRef]
38. Karki, R.; Dhungana, D.; Billinton, R. An appropriate wind model for wind integrated power systems reliability evaluation considering wind speed correlations. *Appl. Sci.* **2013**, *3*, 107–121. [CrossRef]
39. Lun, I.Y.; Lam, J.C. A study of weibull parameters using long-term wind observations. *Renew. Energy* **2000**, *20*, 145–153. [CrossRef]
40. Awad, A.S.A.; El-Fouly, T.H.M.; Salama, M.M.A. Optimal ess allocation for load management application. *IEEE Trans. Power Syst.* **2015**, *30*, 327–336. [CrossRef]
41. Wang, C.; Jiao, B.; Guo, L.; Yuan, K.; Sun, B. Optimal planning of stand-alone microgrids incorporating reliability. *J. Mod. Power Syst. Clean Energy* **2014**, *2*, 195–205. [CrossRef]
42. Graham, V.; Hollands, K. A method to generate synthetic hourly solar radiation globally. *Solar Energy* **1990**, *44*, 333–341. [CrossRef]
43. Koh, L.H.; Wang, P.; Choo, F.H.; Tseng, K.J.; Gao, Z.; Püttgen, H.B. Operational adequacy studies of a PV-based and energy storage stand-alone microgrid. *IEEE Trans. Power Syst.* **2015**, *30*, 892–900. [CrossRef]
44. Fezai, S.; Belhadj, J. Optimal sizing of a stand-alone photovoltaic system using statistical approach. *Int. J. Renew. Energy Res.* **2014**, *4*, 329–337.
45. Force, R.T. The IEEE reliability test system-1996. *IEEE Trans. Power Syst.* **1999**, *14*, 1010–1020.
46. Allan, R.; Roman, J. Reliability assessment of generation systems containing multiple hydro plant using simulation techniques. *IEEE Trans. Power Syst.* **1989**, *4*, 1074–1080. [CrossRef]
47. Liu, M.; Li, W.; Yu, J.; Ren, Z.; Xu, R. Reliability evaluation of tidal and wind power generation system with battery energy storage. *J. Mod. Power Syst. Clean Energy* **2016**, *4*, 636–647. [CrossRef]

48. Arefifar, S.A.; Mohamed, Y.A.R.I. Dg mix, reactive sources and energy storage units for optimizing microgrid reliability and supply security. *IEEE Trans. Smart Grid* **2014**, *5*, 1835–1844. [CrossRef]
49. Billinton, R.; Allan, R.N. Power-system reliability in perspective. *Electron. Power* **1984**, *30*, 231–236. [CrossRef]
50. Oh, U.; Choi, J.; Kim, H.H. Reliability contribution function considering wind turbine generators and battery energy storage system in power system. *IFAC-PapersOnLine* **2016**, *49*, 301–306. [CrossRef]
51. Karki, R.; Hu, P.; Billinton, R. Reliability evaluation considering wind and hydro power coordination. *IEEE Trans. Power Syst.* **2010**, *25*, 685–693. [CrossRef]
52. Andrzej, R.; Adam, W. Trends of changes in the power generation system structure and their impact on the system reliability. *Energy* **2015**, *92*, 128–134.
53. Gao, Z.Y.; Peng, W.; Jianhui, W. Impacts of energy storage on reliability of power systems with WTGS. In Proceedings of the 2010 IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems, Singapore, 14–17 June 2010; p. 65.
54. Zhang, Y.; Zhu, S.; Chowdhury, A.A. Reliability modeling and control schemes of composite energy storage and wind generation system with adequate transmission upgrades. *IEEE Trans. Sustain. Energy* **2011**, *2*, 520–526. [CrossRef]
55. Yang, H.X.; Lu, L.; Burnett, J. Weather data and probability analysis of hybrid photovoltaic-wind power generation systems in Hong Kong. *Renew. Energy* **2003**, *28*, 1813–1824. [CrossRef]
56. Xu, Y.; Singh, C. Power system reliability impact of energy storage integration with intelligent operation strategy. *IEEE Trans. Smart Grid* **2014**, *5*, 1129–1137. [CrossRef]
57. Hozouri, M.A.; Abbaspour, A.; Fotuhi-Firuzabad, M.; Moeini-Aghtaie, M. On the use of pumped storage for wind energy maximization in transmission-constrained power systems. *IEEE Trans. Power Syst.* **2015**, *30*, 1017–1025. [CrossRef]
58. Wook-Won, K.; Je-Seok, S.; Sung-Yul, K.; Jin, O.K. Operation scheduling for an energy storage system considering reliability and aging. *Energy* **2017**, *141*, 389–397.
59. Allan, R.N. *Reliability Evaluation of Power Systems*; Springer: Berlin/Heidelberg, Germany, 2013.
60. Nassourou, M.; Puig, V.; Blesa, J. Robust optimization based energy dispatch in smart grids considering simultaneously multiple uncertainties: Load demands and energy prices. *IFAC-PapersOnLine* **2017**, *50*, 6755–6760. [CrossRef]
61. Azcárate, C.; Mallor, F.; Mateo, P. Tactical and operational management of wind energy systems with storage using a probabilistic forecast of the energy resource. *Renew. Energy* **2017**, *102*, 445–456. [CrossRef]
62. Liu, W.; Niu, S.; Xu, H. Optimal planning of battery energy storage considering reliability benefit and operation strategy in active distribution system. *J. Mod. Power Syst. Clean Energy* **2017**, *5*, 177–186. [CrossRef]
63. Farzin, H.; Fotuhi-Firuzabad, M.; Moeini-Aghtaie, M. Reliability studies of modern distribution systems integrated with renewable generation and parking lots. *IEEE Trans. Sustain. Energy* **2017**, *8*, 431–440. [CrossRef]
64. Sanajaoba, S.; Fernandez, E. Maiden application of cuckoo search algorithm for optimal sizing of a remote hybrid renewable energy system. *Renew. Energy* **2016**, *96*, 1–10. [CrossRef]
65. Dong, J.; Gao, F.; Guan, X.; Zhai, Q.; Wu, J. Storage-reserve sizing with qualified reliability for connected high renewable penetration micro-grid. *IEEE Trans. Sustain. Energy* **2016**, *7*, 732–743. [CrossRef]
66. Zheng, Y.; Dong, Z.; Huang, S.; Meng, K.; Luo, F.; Huang, J.; Hill, D. Optimal integration of mobile battery energy storage in distribution system with renewables. *J. Mod. Power Syst. Clean Energy* **2015**, *3*, 589–596. [CrossRef]
67. Fard, H.H.; Bahreyni, S.A.; Dashti, R.; Shayanfar, H.A. Evaluation of reliability parameters in micro-grid. *Iran. J. Electr. Electron. Eng.* **2015**, *11*, 127–136.
68. Kamble, K.M.; Jadhav, H.T. A wind-battery optimal design algorithm for power generation system. *ARPN J. Eng. Appl. Sci.* **2015**, *10*, 3566–3571.
69. Arabali, A.; Ghofrani, M.; Etezadi-Amoli, M.; Fadali, M.S. Stochastic performance assessment and sizing for a hybrid power system of solar/wind/energy storage. *IEEE Trans. Sustain. Energy* **2014**, *5*, 363–371. [CrossRef]
70. Guo, H.; Levi, V.; Buhari, M. Reliability assessment of smart distribution networks. In Proceedings of the 2015 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA), Bangkok, Thailand, 3–6 November 2015; pp. 1–6.
71. Xu, Y.; Singh, C. Adequacy and economy analysis of distribution systems integrated with electric energy storage and renewable energy resources. *IEEE Trans. Power Syst.* **2012**, *27*, 2332–2341. [CrossRef]

72. Bagen, R.B. Evaluation of different operating strategies in small stand-alone power systems. *IEEE Trans. Energy Convers.* **2005**, *20*, 654–660. [CrossRef]
73. Karaki, S.H.; Chedid, R.B.; Ramadan, R. Probabilistic production costing of diesel-wind energy conversion systems. *IEEE Trans. Energy Convers.* **2000**, *15*, 284–289. [CrossRef]
74. Azizivahed, A.; Naderi, E.; Narimani, H.; Fathi, M.; Narimani, M.R. A new bi-objective approach to energy management in distribution networks with energy storage systems. *IEEE Trans. Sustain. Energy* **2018**, *9*, 56–64. [CrossRef]
75. Hajipour, E.; Bozorg, M.; Fotuhi-Firuzabad, M. Stochastic capacity expansion planning of remote microgrids with wind farms and energy storage. *IEEE Trans. Sustain. Energy* **2015**, *6*, 491–498. [CrossRef]
76. Bahramirad, S.; Reder, W.; Khodaei, A. Reliability-constrained optimal sizing of energy storage system in a microgrid. *IEEE Trans. Smart Grid* **2012**, *3*, 2056–2062. [CrossRef]
77. Fang, X.; Ma, S.; Yang, Q.; Zhang, J. Cooperative energy dispatch for multiple autonomous microgrids with distributed renewable sources and storages. *Energy* **2016**, *99*, 48–57. [CrossRef]
78. Sayyad, N.; Majid, M.; Naser Nourani, E. An efficient cost-reliability optimization model for optimal siting and sizing of energy storage system in a microgrid in the presence of responsible load management. *Energy* **2017**, *139*, 89–97.
79. Tzu-Chieh, H.; John, C.; Kuei-Yuan, C. Reducing uncertainty accumulation in wind-integrated electrical grid. *Energy* **2017**, *141*, 1072–1083.
80. Sajad, T.; Seyed Saeedallah, M.; Taher, N. Stochastic scheduling of local distribution systems considering high penetration of plug-in electric vehicles and renewable energy sources. *Energy* **2017**, *121*, 480–490.
81. Mohammad Hadi Shaban, B.; Asghar Akbari, F. Stochastic-based resource expansion planning for a grid-connected microgrid using interval linear programming. *Energy* **2016**, *113*, 776–787. [CrossRef]
82. Singh, S.S.; Fernandez, E. Reliability evaluation of a solar photovoltaic system with and without battery storage. In Proceedings of the 2015 Annual IEEE India Conference (INDICON), New Delhi, India, 17–20 December 2015.
83. Liu, X.; Islam, S. Reliability evaluation of a wind-diesel hybrid power system with battery bank using discrete wind speed frame analysis. In Proceedings of the 2006 International Conference on Probabilistic Methods Applied to Power Systems, Stockholm, Sweden, 11–15 June 2006.
84. Singh, S.S.; Fernandez, E. Method for evaluating battery size based on loss of load probability concept for a remote PV system. In Proceedings of the 2014 6th IEEE Power India International Conference (PIICON), Delhi, India, 5–7 December 2014.
85. Bagen, R.B. Incorporating well-being considerations in generating systems using energy storage. *IEEE Trans. Energy Convers.* **2005**, *20*, 225–230. [CrossRef]
86. Bagen, B.; Billinton, R. Reliability cost/worth associated with wind energy and energy storage utilization in electric power systems. In Proceedings of the 10th International Conference on Probablistic Methods Applied to Power Systems, Rincon, Puerto Rico, 25–29 May 2008; pp. 1–7.
87. Mostafaeipour, A.; Mostafaeipour, N. Renewable energy issues and electricity production in middle east compared with Iran. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1641–1645. [CrossRef]