University of Sindh Journal of Information and Communication Technology (USJICT)
Volume 2, Issue 3, July 2018
ISSN-E: 2523-1235, ISSN-P: 2521-5582
Website: http://sujo.usindh.edu.pk/index.php/USJICT/

Renewable Energy's Reliability Issue and Possible Solutions: A Meta-Analytic Review

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Abstract: Deployment of Renewable Energy (RE) is considered a vital initiative to control carbon emissions by avoiding fossil fuel consumption. Depletion of natural resources and environmental issues like climate change have forced global energy strategists to focus on sustainable energy practices. Based on data collected during this review process, it is evidently concluded that RE cannot be considered a reliable source yet as suggested by 93% of the reviewed studies. The identified solutions are forecasting and storage system (43%); smart grids with curtailment, peak shaving and power smoothing for grid stability (43%); and hybrid RE grids with extensive transmission and distribution. Also, grid related solutions are suggested by 31% of studies, which are grid integrated storage options and interconnected micro girds for power regulation and management. Storage enhancement techniques like battery storage and electric vehicle based domestic storage for power compensation during low power generation and for back-up purposes is proposed by 25% of reviewed articles. Lastly, algorithm integrated forecasting system for smart management and resource distribution are supported by 18% of analyzed studies. Implementation of these solutions can improve the chances of achieving a 100% renewable national grid without a conventional energy backup within next few years.

Keywords: renewable energy; reliability; solutions; grid stability; hybrid grid; smart grids; storage techniques.

I. INTRODUCTION

Global economy has always been dependent on energy resources and development of these resources into useable energy forms. This has led to an over reliance on conventional energy sources which has in turn, severely impacted the environment while destroying its primary source. Depletion of natural resources and environmental issues like climate change are now evident [1]. Such circumstances have forced energy enthusiast and strategists across the globe to rethink their approach and to meet energy requirements in a different, more sustainable manner [2]. There are various sources of renewable energy mainly solar, wind, and hydro. In this study, these sources are considered as they are the major contributors in the current global energy mix [3]. Also, these sources are primarily focused by countries that are moving towards achieving a 100% renewable grid with each passing day [3].

The reason behind recent developments to achieve renewable energy dependent national grids is based on the concept of survival and sustainability of the current environment and resources. With continuously depleting oil reserves and excessively oil dependent economies around the world, it is high time that countries shift towards a system that is free from exhaustion of its primary source hence, leading to energy independence [4]. A secure and reliable energy source ensures economic freedom and power independence. Renewable Energy (RE) provides an opportunity of producing electricity without exhausting the primary source but, the utilization of this produced electricity is based on its reliability. This concept has led to countries like Norway, Costa Rica, Brazil, and Canada to have a national grid based on hydro power and to have a 97%, 93%, 76% and 62% renewable grid respectively [5]. But, questions have been raised regarding the RE dependent national grids of Germany and Costa Rica and it has been suggested that a 100% conventional energy based backup is essential due to volatile nature of RE specially in Germany's case [6, 7]. This raises concerns in relation to the sole purpose of RE deployment which is to reduce conventional energy use and Figure 1 presents Germany's recent energy mix and combining this with the highlighted problem, the reliability issue becomes quite evident [8].

Hence, this paper explores the reliability related aspects of RE so that it's actual potential can be fulfilled without the need for conventional backup or at least with very limited conventional energy backup.

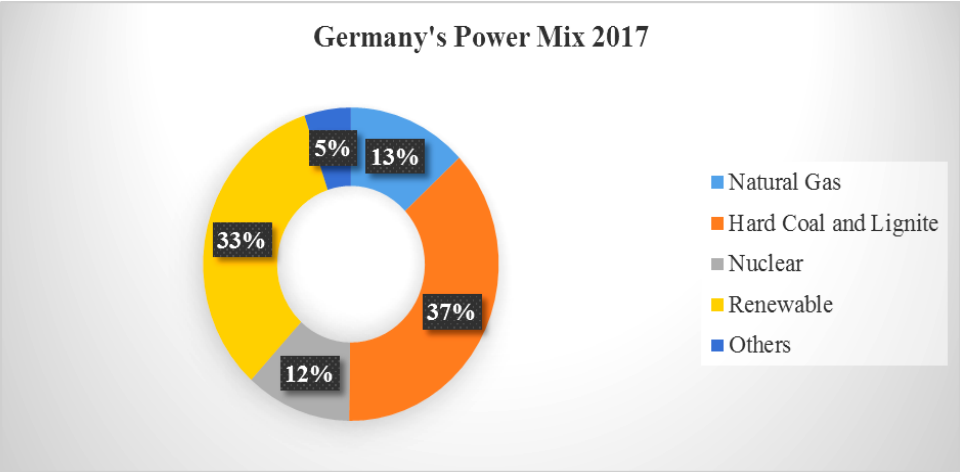

Figure 1 Germany's Energy Mix 2017 [8]

II. METHODOLOGY

A. *Research Design and Data Collection*

The research design selected for this study is a meta-analytic review design. It allows the researcher to identify the concerns related to reliability aspects of RE as well as any proposed solution that the reviewed study has proposed. In addition to this, a statistical outcome would be achieved that will assist in identification of possibilities for improvement in the current RE infrastructure and can guide policy makers, technologists and strategists in future.

For the purpose of data collection, a total of 16 research studies have been selected based on the inclusion criteria below.

B. *Inclusion Criteria*

The studies that were included in the meta-analysis fulfilled the below points:

- Research study must have published during or after 2014 so that the analyzed data is up-to-date.
- The research study must directly address the subject matter and relevance to the study topic must be easily identifiable.
- Research study must provide clear conclusion in regards to the questions asked in that research.

III. FINDINGS

There are a total of 16 research studies which have been analyzed for the purpose of data collection. The studies included in this group are focused on the topic of reliability of RE when considering large scale deployment and production. On the basis of the review of these selected studies, some ground breaking factors were identified. Out of the 16 selected studies in this group, 15 suggested that renewable energy cannot be considered reliable (93.75%). This is a major indication of the issues surrounding RE and the evident perception of scholars in regards to RE in current settings as all the studies included in this analysis paper have been published since beginning of 2014. Figure 2 sheds light on the visual difference between the number of studies providing evidence against reliability of RE. This asserts the

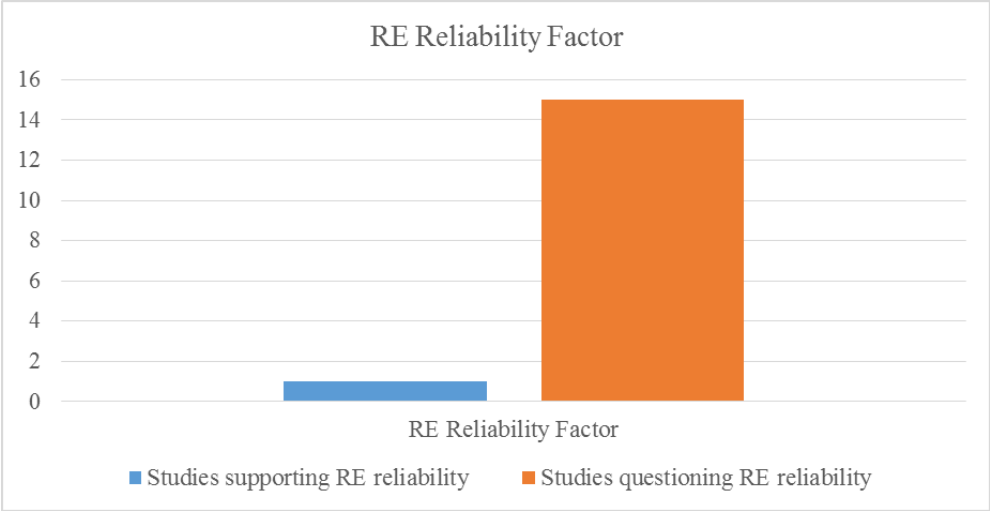

Figure 2 RE Reliability Aspect Recognition

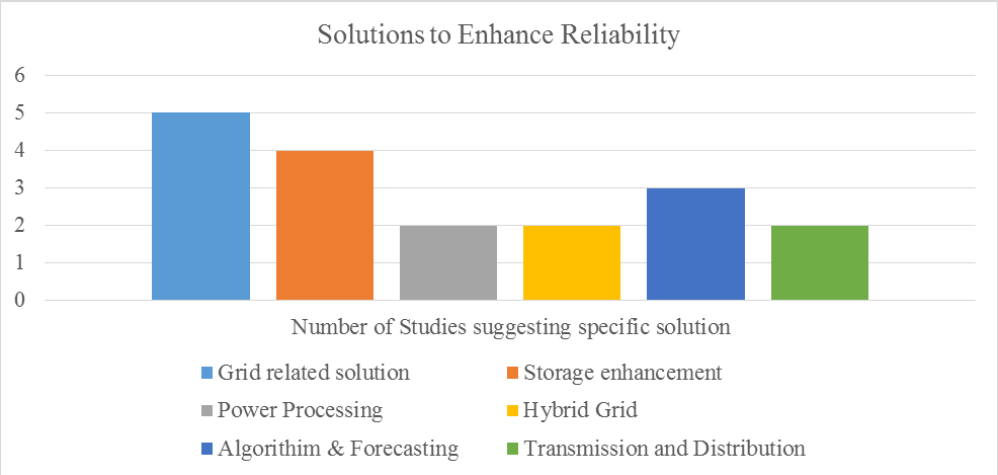

Figure 3 Solutions Presented by Studies to Improve Reliability

claims of researchers regarding RE reliability [6, 7]. There are a number of issues that the analyzed research studies have highlighted and discussed due to which RE has been deemed unreliable. Some of these factors are dependency on weather conditions leading to system instability, variable power production and fluctuations causing power management failures, high production during certain periods and extremely low production during periods of abnormal environment or climates. In addition to this, 14 out of 16 studies (87.5%) shed light on one or more solutions to these problems found in this research. Figure 3 provides a graph representing the solutions identified through analysis of the selected research papers. These solutions are an essential part of this paper as it provides a deeper understanding of the concerns and presents an opportunity to correct the resulting difficulties. The proposed solutions in these 16 studies are grid related solutions, storage enhancement techniques, power processing procedures, hybrid grid systems, algorithms and forecasting; and transmission and distribution infrastructure improvements.

The Table 1 provides a detailed account of the identified issues and the proposed solutions by each individual article examined in this meta-analysis. In addition to this, the results summarized in Figure 3 are now expanded so that a well-developed discussion can be presented afterwards. Grid related solutions have been proposed by 5 out of 16 studies (31.25%) with smart grids, grid integrated storage options and interconnected micro girds for power regulation and management of system stability being the main problem solving options. Storage enhancement techniques like battery storage and electric vehicle based domestic storage for power compensation during low power generation and for back-up purposes has been suggested by 4 out of 16 studies (25%). Power processing procedures like curtailment, power smoothing and peak shaving to provide constant stable power to the grid have been suggested by 2 out of 16 studies (12.5%).

Similarly, Hybrid grid of solar, wind or hydro power has been recommended by 2 studies (12.5%) as a possible solution so that in case of disturbances in electrical generation from one source of energy, power can be generated and covered by another renewable source. Algorithms and forecasting system development for smart management of production and resource distribution has been advised by 3 studies (18.75%). Extensive transmission and distribution improvement and framework has been recommended by 2 studies (12.5%) as well.

On the other hand, 2 research studies included in this

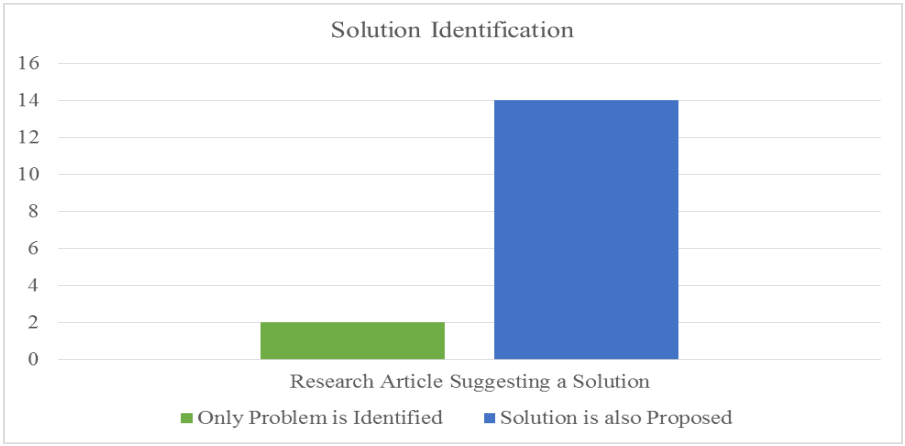

Figure 4 Research Studies providing solution

Table 1 Identified Problem or Solution by each article

Article Details	Identified Problem/Solution
Che et al., 2017 [9]	An interconnected system with six micro-grids can ensure stability
Li et al., 2015 [10]	Curtailed electrical energy estimation and implementation of reduction strategies
Fan et al., 2018 [11]	Estimation of variation in branch power flows and overload through probability algorithms
Neves, Silva and Connors, 2014 [12]	Detailed demand information and adequacy of storage system
Al Busaidi et al., 2016 [13]	Hybrid PV–Wind grid to improve stability and reliability
Subburaj, Pushpakaran and Bayne, 2015 [14]	Grid connected storage battery systems
Sopher, 2015 [15]	Extensive transmission and distribution infrastructure to minimize grid congestion and destabilization
Reddy et al., 2014 [16]	Smart grids for weather dependent renewable production
Reihani et al., 2016 [17]	Load forecasting method for peak shaving and power smoothing of distribution load
Castillo and Gayme, 2014 [18]	Grid-integrated storage system for smooth output
Lund et al., 2015 [19]	Utilization of electric vehicles as wide ranged energy storage
Liu et al., 2015 [20]	Use of micro gird and Simulink controlled smart grids
Martinot, 2016 [21]	Flexible options with controlled grid operations and transmission, electric vehicle storage, demand forecast etc.
Gowrisankaran, Reynolds and Samano, 2016 [22]	Weather dependency leads to need for output forecasting system
Clack et al., 2017 [23]	Hybrid model of wind, solar, and hydroelectric power has similar shortcomings and is unreliable
Jacobson et al., 2015 [24]	Hybrid system with wind, hydro and solar power is a possible solution

review did not provide any solutions with one of them discarding the forecasting solutions by concluding that upcoming climatic changes will lead to unforeseeable conditions and the other study discarding water, wind and solar hybrid system model by suggesting that 100% grid based on renewable hybrid system is not practical and/or secure. The Figure 4 is a visual presentation of the number of studies that have provided a solution in regards to the issues associated with RE's reliability against those research articles that have only shed light on the associated problems. Based on these findings, a discussion is now presented.

IV. DISCUSSION AND ANALYSIS

In total, 16 research studies were included in this analysis and out of all, 15 studies suggested that renewable energy cannot be considered as a reliable and dependable source of energy generation until grid instability and production fluctuations are minimized. This is evident in the chart shown in Figure 2. For the purpose of identification of a possible solution, a number of key factors have been debated in the reviewed research papers. A summarized explanation of the main focus of each research article has been presented in Table 1. Moreover, 87.5% of the reviewed articles have pointed towards some solution in regards to the unreliable nature of RE but when considering the conclusions the fact that all of these studies have been published since 2014 and all the technological and operational aspects have been considered, the outcomes become clearer and more result oriented. The conclusion that RE is yet not a reliable source is evident and is supported by 93.75% of all studies in this meta-analysis. Also, some of the solutions provided in these research studies are also evaluated for enhancement of RE's reliability in future and are discussed here.

Furthermore, the evidence retrieved from reviewed studies is matched with other research work as well to gain additional substance to assert the claim. The main focus of this review is to establish that whether RE can be considered as a major energy source with a stable and reliable future but, the review evidence suggests otherwise. Alizadeh et al. has presented additional support to this inference that the reliability and dependability of RE based power systems need to be investigated and explored further [25]. Also, Papaefthymiou, and Dragoon have advocated that transformation of current conventional energy system and infrastructure to RE based system has yet to overcome technological hindrance and that 100% dependability on RE

systems is still not feasible [26]. Founded on this analysis, some proposed solutions are now explored.

A. *Forecasting and storage system for decreasing weather dependency*

Forecasting algorithms for power generation, peak load and demand estimation have been opted as a possible method. In addition to system related and population based approximation, forecasting of climatic shift in advance has been pointed so that power can be shifted or compensated by backup storage if required. Renewable energy based storage systems like grid integrated batteries and electric vehicle based power storage has been considered for providing backup in such cases. Other researchers have also identified electric vehicle based power storage and distribution as a feasible idea for electrical energy management [27, 28] Combining these two options, 43.75% studies have provided theoretical support for utilization of forecasting algorithms and a variety of storage system based options for enhancement of RE reliability and system stability for large scale deployment. This has been highlighted by Matos, Silva, and Ribeiro as well and added research evidence provides ground for establishing the efficiency and effectively of the process [29].

B. *Smart grids, peak shaving and power smoothing for grid stability*

Software controlled smart grids for power integration are proposed along with power processing tools like curtailment, power smoothing and peak shaving as other options as for constant power and steadiness. These are vital when considering grid stability and these possibilities have been advocated by 43.75% studies. The use of smart grids for increasing grid stability along with power processing tools and software systems has been support by other scholars as well [30]. Also, Thale, Wandhare and Agarwal have proposed that a micro grid supported by a combination of a hybrid communication layer based on CAN, RS-485, and MODBUS protocols can increase the reliability of the system with high effectiveness [31].

C. *Hybrid renewable energy grids*

Although Hybrid systems have been considered as a vital part of future approaches towards resolving technical and weather related issues associated with RE source however, little support has been found in this study for hybrid systems. Only 12.5% of studies have supported using hybrid systems to increase reliability, and to minimize dependence on conventional backup systems and weather conditions. Supporting this little evidence, a hybrid system based on photovoltaic panels, wind generator and biomass gasification plant along with a battery bank for energy storage has been successfully tasted in laboratory settings [32]. However, the system is yet to be implemented in non-experimental and uncontrolled situations. Also, wind and solar energy based hybrid systems are also being experimented in controlled environments [33]. On the other hand, another piece of research has unfolded a number of issues associated with hybrid renewable grids and its utilization [34].

D. *Development of transmission and distribution systems*

Lastly, it has been unearthed in the review that development of extensive transmission and distribution systems and smart operational capabilities can improve the performance of the renewable sources leading to stable and constant power generation under most scenarios. Combination of this procedure with other viable options can result in increment of RE system stability and can increase its reliability in most situation as per 12.5% studies. However, it is vital to consider that extensive transmission and performance enhancement alone cannot make much difference but when utilized with grid integration or other innovative storage techniques, it can certainly make a difference. Although, little support has been provided to this aspect by the research articles included in this study, but it remains an option to be experimented upon. Other researchers have also identified the need for an extensive transmission and distribution system to improve residual load issues and excess power generation problems by import and export process between countries based on this system of transmission and distribution [35, 36].

V. CONCLUSION

This review paper has explored some very daunting questions about renewable energy and has analyzed the aspects associated with the future of the RE technology. The reliability of RE, the concerns regarding renewable energy and the modifications that can be utilized for development of RE towards fulfilment of its potential have all been examined in this research. The study has concluded with evidence that renewable energy cannot be considered as a reliable and dependable energy source yet because of the weather condition reliance and grid instability with over 93% studies providing evidence of lack of reliability. Moreover, for the purpose of identification of possible solution to resolve reliability related concerns, a number of propositions have been considered which have been derived from the studies included in this meta-analysis.

The proposed solution with most evidence that is 43.75% each, are forecasting and storage system for decreasing weather disruptions and dependency; and smart grids along with power processing tools like curtailment, peak shaving and power smoothing for grid stability. Hybrid Renewable Energy Grids and development of extensive Transmission and Distribution Systems are also found to be viable solutions. The proposed options to resolve the impending problem of lack of reliability of RE can reduce risk when moving towards large scale deployment. Such steps if taken can place RE deployment across the globe on fast track and can improve the chances of achieving a 100% renewable national grid without a conventional energy backup within next few years.

ACKNOWLEDGMENT

The authors are thankful to Almighty God for this opportunity to research and express their gratitude towards the global scholar community for creating such platforms to share knowledge and to spread awareness.

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