

Renewable Energy Integration in Nigeria: Technologies, Challenges and Prospects

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Abstract

The global drive to decarbonize the power supply chain witnessed an increased investment in Renewable Energy Technologies (RET). Nigeria has huge potentials of Renewable Energy Sources (RES) like Solar Photovoltaic (PV) and Wind Power (WP). However, power supply situation remains unreliable not only due to inadequacies and over reliance on conventional sources, but the problems associated with the structural and technological changes of RES integration. This paper provides a brief overview from existing reviews and surveys of the technologies, associated problems and mitigation approaches deployed to increase the penetration of RES integration into power system. Four categories of RES integration problems identified from the literature include, Power Quality, Power Flow, Stability and Power Balance. Existing mitigation technologies were then correlated with each category of the problem, thereby resulting in a Problem – Mitigation technology matrix. From the overview, some future prospects of RES and RET as its relate to decarbonizing the Nigerian power supply chain are outlined.

Contents

		<i>5.1.1. Flexibility Technologies</i>	15
1. Introduction	1	<i>5.1.2. Distributed solution technologies</i>	15
<i>1.1. Related Reviews on RE Integration Technologies and Challenges</i>	2	<i>5.1.3. Grid technologies</i>	15
2. Typical RE Technologies	5	<i>5.2. Observations from Problem View Point of Correlation matrix (Solution Space)</i>	16
3. Problems of RE Integration in Power Systems	9	<i>5.2.1. Power Quality Problem</i>	16
4. Mitigation Technologies to problems of RES integration in Power System	13	<i>5.2.2. Power Flow Problem</i>	16
5. Problem – Mitigation Correlation	15	<i>5.2.3. Stability Problem</i>	16
<i>5.1. Observations from Mitigation View Point of Correlation matrix (Solution Potential)</i>	15	<i>5.2.4. Power Balance Problem</i>	16
		6. Future Prospects	18
		7. Conclusions	18
		8. References	18

1. Introduction

The inadequacy of power supply, growth in demand for electricity and growing concern to decarbonize the power sector constitutes the major push towards deployment and integration of Renewable Energy and its associated technologies. Globally, two Renewable Energy Sources (RES), – Solar photovoltaic (PV) and Wind Power – and their enabling technologies witnessed unprecedented growth in extensive research, development and encouraging deployment [1]. In the last few decade, the global share of installed capacity of PV and wind power are 4% and 7%, while

average annual increase of 27% and 13% were projected, respectively [2]. Compared to the conventional power generation technologies, the output power from RES are characterized by: (1) the variability of their primary sources, (2) lack of adequate predictability, (3) modular and small sizes (4) geographically location specific, (5) no-synchronous with little or no inertia, and (6) reduced running cost. The aforementioned characteristics posed certain challenges to the efficient operations of the interconnected power systems [1]–[3]. For example, integration of RES and associated technologies presents new challenges in the dynamics of two broad areas. Firstly, technological change in power systems such as generating technologies, load growth pattern, models used simulation analysis (Static or dynamic models) and Flexible Alternating Current Transmission Systems (FACTS) Devices. Second is the structural change in power systems operations such as grid-connected operations of power systems, micro-grid operations or Islanding operation and contractual power polling in terms of bilateral/multilateral transactions [3]. While these challenges have hindered RES integration into power grid in developed economies, it contributes to the little or slow pace of RET integration in developing economies like the Nigerian interconnected power network.

Various solutions technologies are being deploy to address these challenges. New and modified technologies have been demonstrated to possess the potentials to mitigate multiple challenges. Although, deployment of solution technologies will ensure decarbonization target, it is equally associated with complications due to three reasons. Firstly, choice of technology is dependent on factors such as maturity, application range, preference in policy and cost. Secondly, prerogative of independent systems operators, regulators and market participants to decide on preferred technologies, such as Transmission Company of Nigeria (TCN), Distribution System Operators and Nigerian Electricity Regulation Commission (NERC). Thirdly, different needs based on region determines the solution technologies such as standalone island in micro-grid operations and the grid tied with strong interconnected systems.

Researchers have scrutinized each challenge to RES integration thereby suggesting a particular mitigation solution technology. For example, RES-based DGs involvement in voltage management as a solution for transmission and distribution grids with DG penetration [4]. Some of these analysis ignored the possibilities of a single solution technologies with the potential of addressing multiple challenges. For instance, while battery storage ensure continuity in supply during night for Solar PV, it can be deployed to address generation inadequacy. Consequently, this paper outline the findings of some limited but recently review papers which aimed to identify the challenges of RES integration and match available solution technologies capable of addressing the identified challenges.

1.1.Related Reviews on RE Integration Technologies and Challenges

Energy transition researchers, engineers, practitioners and regulators are making efforts to sufficiently understand and match the problems and the available mitigation technologies to tackle these problems. Some of these surveys can serve as enablers to the RES integration into the Nigerian power sector.

A review on renewable energy integration for combined heat and power is documented in [5]. The focus is on energy generation through solar, wind, and geothermal when operated as a cogeneration

system, or integrated with a combined heat and power system. The study primarily analyzes performance of the state-of-the-art designs, and present the current research trends in the field of solar, wind, and geothermal energies. The work elaborates on integration of single or multiple renewable energies in combined heat and power systems. Researches were classified based on utilization of renewable resources in single and multiple integration. Further classifications were carried out based on the trends in a particular RE field, to realize its challenges. The classification resulted into three primary research focus which are: model development and application in solar integrated systems, thermo-economic optimization in geothermal-integrated systems, and scheduling and minimizing curtailment in wind-integrated systems.

In a similar development, a review of data centers as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating was presented in [6]. The focus is on the lack of global optimization of the upstream renewable energy integration and downstream waste heat utilization. Hence, the advancements in different cooling techniques, integration of renewable energy and advanced controls, waste heat utilization and connections for district heating, real projects, performance metrics and economic, energy and environmental analyses are discussed. Based on the enormous amount of research on data centers in district energy systems, it has been found that: (1) global controls, which can manage the upstream renewable production, data centers' operation and waste heat generation and downstream waste heat utilization are still lacking; (2) regional climate studies represent an effective way to find the optimal integration of renewable energy and waste heat recovery technologies for improving the data centers' energy efficiency; (3) the development of global energy metrics will help to appropriately quantify the data center performances.

So in address control issues in renewable energy integration and micro-grid, [4] presented a review. As RE adds a remarkable scope in power system, RES act as the prime mover of a micro-grid, and the integration challenges of renewable energy sources and the control of micro-grid were outlined. The varied nature of RE system produces voltage and frequency deviation, while the unknown nature of the load produces un-modeled dynamics. This un-modeled dynamic introduces measurable effects on the performance of the micro-grid. Thus, an investigation of the performance of micro-grid against different scenarios is critical to integration aiming at decarbonized power sector. Different controllers enable voltage control of the micro-grid.

A critical review of the integration of RES with various technologies was reported in [7]. It was noted that decarbonization target is vulnerable to several challenges and failures. Thus, specific investigations on various technological solutions and challenges in the power system domain needs to be carry out. It noted that developing a matrix with various renewable technology solutions can help solve renewable energy challenges. The potential of the developed technological solutions was expected to be able to help and prioritize them especially cost-effective energy. In addition, technology solutions that are identified in groups can help reduce certain challenges. The categories developed in this study were used to assist in determining the specific needs and increasing transparency of the renewable energy integration process in the future. Similarly, [2] presents the challenges and solution technologies for the integration of variable RES among all domains of the power system. An interrelation matrix of challenges and solution technologies

developed provides important insights: First, solution technologies vary significantly in their potential to solve certain challenges. The solution potential of different technologies can therefore help prioritize solution technologies in addition to focusing on cost-effective options. Second, it is possible to identify groups of solution technologies that can help mitigate certain challenge groups. The categorization developed helps to better specify the need for specific solution technologies and enhances transparency of the complex process of renewable energy integration.

The application of reduced switch Multilevel Inverters (MLIs) for RE Integration and drives was surveyed in [8]. To assist in the selection of suitable inverter for various applications, significant understanding on these topologies was summarized based on the three categories, i.e., symmetrical, asymmetrical, and modified topologies. By a suitable combination of switches, the MLI produces a staircase output with low harmonic distortion. For a better understanding of the working principle, a single-phase RS MLI topology is experimentally illustrated for different level of generation using both fundamental and high switching frequency techniques which helps to understand MLI applications in RE integration.

The role of energy storage technology and application with renewable energy integration for empowering smart grid was established in [9]. Various types of energy storage technologies namely: battery, thermochemical, thermal, pumped energy storage, compressed air, hydrogen, chemical, magnetic energy storage, and a few others were considered. These energy storage technologies were categorized and comparative studies performed to understand each energy storage system's features, limitations, and advantages. Further, different energy storage system frameworks have been suggested based on its application in RES integration; thereby acting as a guide to researchers working in energy storage technologies. The future scope energy storage applications in RES integration suggests the need to develop innovative energy storage systems to face challenges in power system networks, to maintain reliability and power quality, as well as to meet the energy demand. Earlier, [10] presented an overview of large-scale underground energy storage technologies for integration of RE and criteria for reservoir identification. The introduced technologies for underground renewable energy integration include: Compressed Air Energy Storage (CAES); Underground Pumped Hydro Storage (UPHS); Underground Thermal Energy Storage (UTES); Underground Gas Storage (UGS) and Underground Hydrogen Storage (UHS), both connected to Power-to-gas (P2G) systems. For these different types of underground energy storage technologies there are several suitable geological reservoirs.

[11] discusses the applications, challenges and opportunities of Agrophotovoltaic (APV) systems. Presenting the current status of the potential opportunities in the application of APV systems, discussion emphasized on microclimatic alterations and the resulting impacts of APV on crop production. The main findings were (1) crop cultivation underneath APV can lead to declining crop yields as solar radiation is expected to be reduced by about one third underneath the panels. However, microclimatic heterogeneities and their impact on crop yields are missing and thus, remain uncertain. (2) Through combined energy and crop production, APV can increase land productivity by up to 70%. (3) Given the impacts of climate change and conditions in arid climates, potential benefits are likely for crop production through additional shading and observed improvements of water productivity. (4) In addition, APV enhances the economic value of farming

and can contribute to decentralized, off-grid electrification in developing and rural areas, thus further improving agricultural productivity. As such, APV can be a valuable technical approach for more sustainable agriculture, helping to meet current and prospective needs of energy and food production and simultaneously sparing land resources.

Regulatory challenges and opportunities for collective renewable energy prosumers in the EU was discussed in [12]. A cross-country comparison between the regulatory frameworks of nine countries and regions - Belgium (Flanders region only), Croatia, France, Germany, Italy, Portugal, Spain, Netherlands and the United Kingdom - reveals the main challenges and opportunities that these have posed to collective RE prosumers (i.e., renewable energy communities, citizen energy communities and jointly-acting renewable self-consumers). Four countries have had more favorable frameworks for collective prosumers: France, Germany, Netherlands and United Kingdom. The results indicate that the current legal framework at the EU level represents a clear opportunity for collective prosumers. Spain and Portugal have both already shifted from a restrictive regulation to implementing in 2019 a legal framework for collectives. The study provides a starting point model to distil policy implications for improving legal frameworks relevant for collective RES prosumers in Nigeria.

The current status, future prospects, challenges, employment, and investment opportunities for RE in India was presented in [13]. In the same vein, [14] presents the status of research within the exploitation of renewable energy sources with a focus on the status of: technologies exploiting renewable energy sources, assessment of the availability of renewable energy sources and provision of insight into the types of systems that can integrate renewable energy sources. In terms of technologies and resources, wind and wave power resources, wind technology, geothermal energy, solar heating, cooling and electricity and salinity gradient technologies were considered. Also, system integration, impacts and environmental performance of energy systems are assessed.

An insight into RES, technologies and public opinions towards sustainable energy was reported by [15]. The analysis showed that despite serious efforts at all levels to reduce reliance on fossil fuels by promoting renewable energy as its alternative, fossil fuels continue to contribute 73.5% to the worldwide electricity production in 2017. Conversely, renewable sources contributed only 26.5%. Furthermore, the study highlights the lack of clear understanding of the integrations and public awareness as a major barrier to the acceptance of renewable energy technologies. It is shown that global energy crises can be managed by integrating renewable energy sources in power generation. Moreover, in order to facilitate the development of renewable energy technologies, the importance of public opinion was demonstrated through a real-time analysis of public tweets.

2. Typical RE Technologies

- i. **Agrophotovoltaic (APV):** entails the combination of photovoltaics and crop production, provides a synergistic combination of renewable energy and food production. APV contribute to decentralized, off-grid electrification in developing and rural areas, thus further improving agricultural productivity [11]. In the APV systems, solar panels are mounted in about 2 – 5m, and underneath the panels food crops are grown. Figure 1 depicts a potato farm underneath an APV.



Figure 1: A Potatoes farm underneath an Agrophotovoltaic system [11]

- ii. **Energy Storage Systems (ESS):** provide a means of energy storage which serves as a support in stabilizing the power production and energy demand. It is realized by supplying to the grid or customers the deficit energy required to ensure balance between demand and production. The benefit of Energy storage to different stakeholders are in the power supply chain is described in Figure 2.

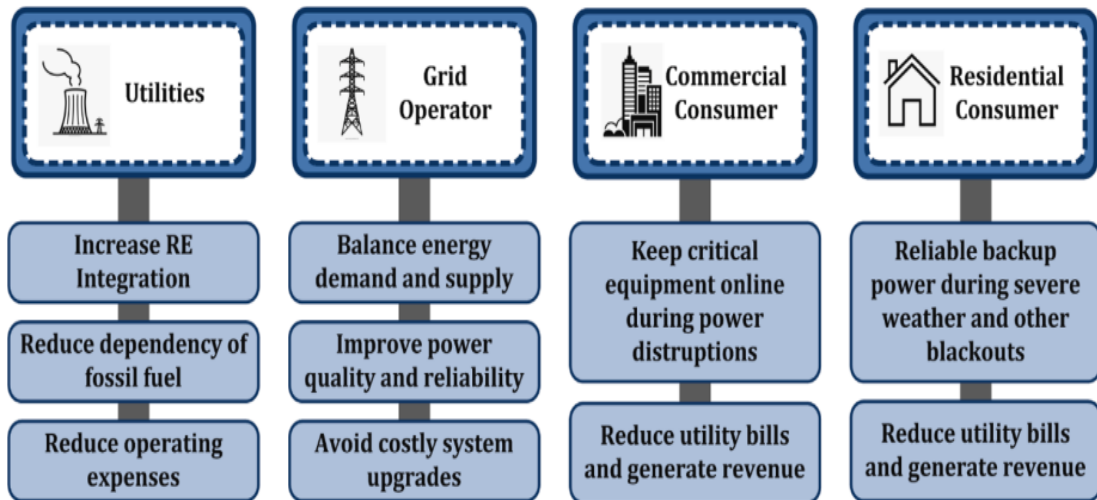


Figure 2: Benefit of Energy Storage to Stakeholders[9]

Similarly, the various forms of the ESS are depicted in *Figure 3*, which includes Electrochemical and electrical energy storage system Capacitors, Thermal energy storage system, Mechanical energy storage system, Chemical energy storage system, Electromagnetic energy storage system.

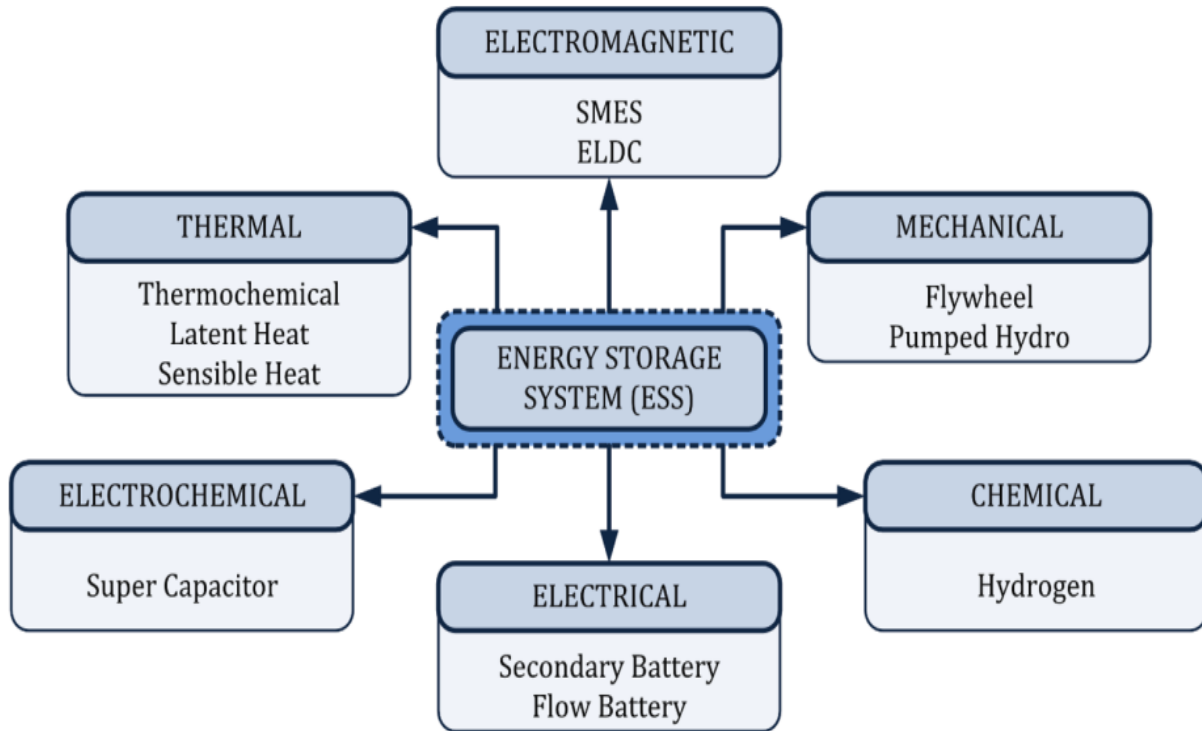


Figure 3: Forms of Energy Storage Systems[9]

- iii. **Multi-Level Inverter (MLIs):** MLIs interface the RES and the grid thereby commonly deployed as an advanced power converter topology, and are gaining applications in renewable power conversion system and drives [8]. Figure 4 depicts some RE sources with reduced switch MLI-based system.

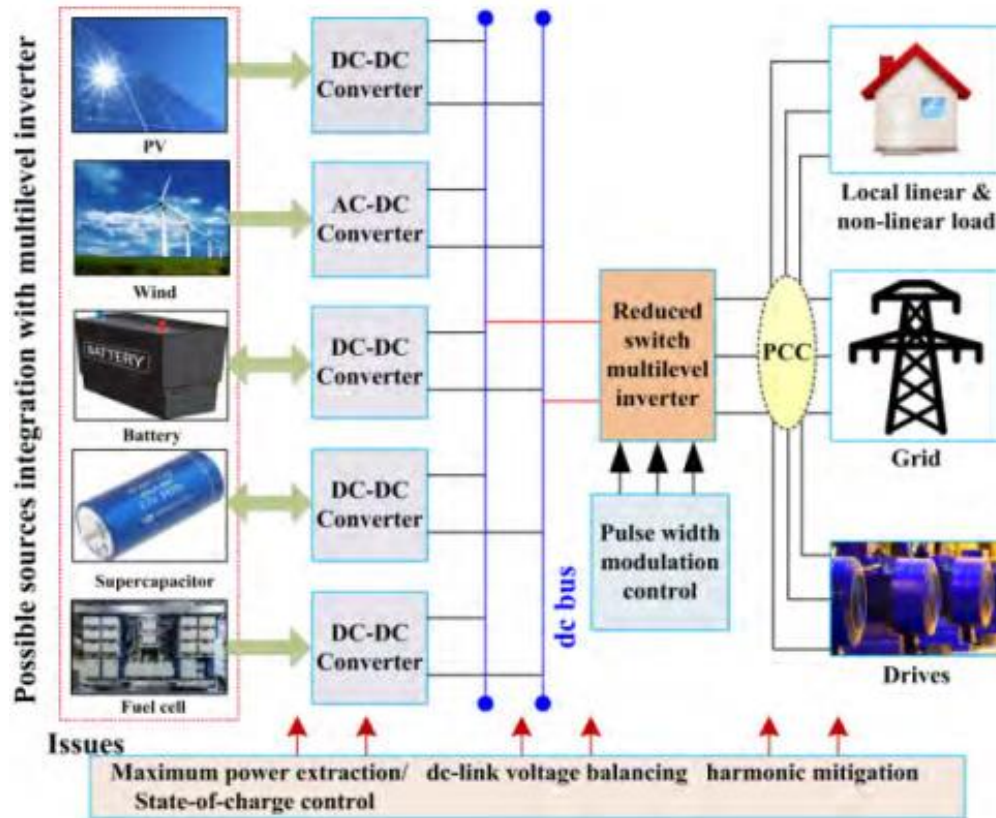


Figure 4: RE Sources with reduced switch MLI-based system[8]

- iv. **RES with Combine Heat and Power (CHP):** waste heat from power generation are recovered and stored to supply thermal energy during winter for residential application, or could be utilized for manufacturing processes in the industry. Example is solar-integrated CHP systems. Deploying the principle of cascading utilization of energy, the potential energy within RES can be exploited in three methods: prime mover, electricity source, and heat source. RES Integration as a prime mover unit in CHP ensures reduction of CO₂ emissions, increases energy efficiency, and lowers fuel consumption. Figure 5 depicts a block diagram description of some technologies for combine heat and power generation. Designs of solar PV systems are achievable to generate both electrical (PV) and thermal energies (PV/T). For instance, high- temperature solar cycles like the central tower and parabolic dish can produce steam as well as run steam generators [5] , while, the deployment of low-temperature cycles like the flat plates may serve as ancillary power sources for flexibility and carbon free generation

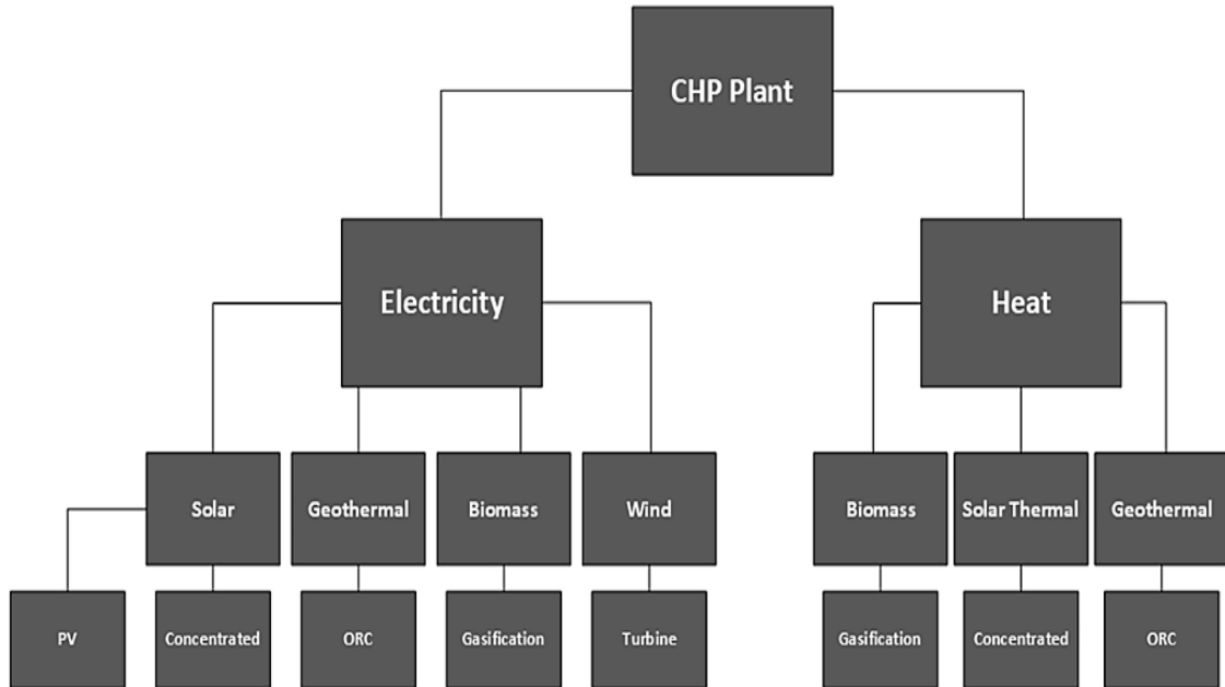


Figure 5: A description of some technologies for CHP plant [5]

3. Problems of RE Integration in Power Systems

The problems associated with the increased penetration of RES into power systems can be identified by the issues present during normal operations of a grid-tied RES. For example, the penetration of RES, distributed generators and the use of HVDC for interconnection, introduce new problems about frequency security and reliability. Furthermore, the variability of DG system causes deviations in voltage and frequency, while the continuous changes in load produces un-modeled dynamics. This un-modeled dynamic causes quantifiable effects on the performance of the micro-grid or the entire power systems in the case of a grid-tied [4]. These problems often appear in the form of already established issues associated with the abnormal power systems operations, and subsequently are categorized as such. RES integration problems are therefore grouped into four categories [2].

- i. **Power quality (PQ):** An important key performance indicator at consumer end, power quality problems compromise the ability of power grid to supply consumers efficiently, PQ is measured through stable voltage, current and frequency. The associated features of RES which majorly contribute to PQ problems are; the modular nature of RES generators which are also non-synchronous, fluctuations in output of RES such as Solar PV and lack of uniform frequency throughout the power systems interconnection with RES penetration. *Figure 6* depicts some common PQ problems arising from high RES penetration

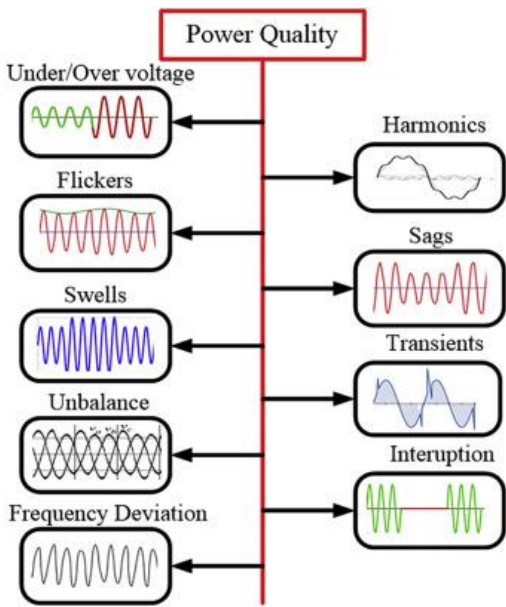


Figure 6: Common Power Quality Problems

ii. **Power Flow (PF):** Due to the increasing penetration of DG, power flows are now from the mix of conventional and DG sources. Local voltages can be measured due to significant levels of DG on feeders, and the voltage at the load end are likely to be higher than those at the normal supply side of the line. Hence this is known as the voltage rise and can result in reverse power flow [16]. The efficient transmission and distribution of power constitutes the PF problems. The major signs of power flow problems in a high RES penetrated power system include: voltage rise, reverse power flow, loop flows, power re-dispatch or curtailment due to congestion. Usually the causes power flow problems can differs depending on several factors. The RES characteristics contributing to PF are variability of RES, their modular nature, and location-constraints result in the largest share of flow challenges [2]. *Figure 7* illustrates some of the symptoms of power flow problems in power networks with high penetration of RES.

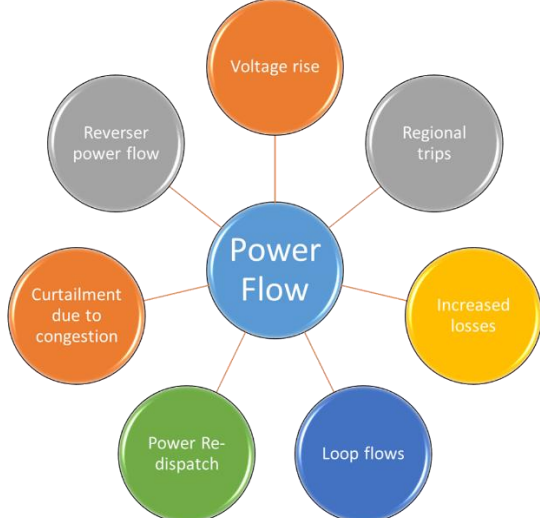


Figure 7: Typical symptoms of power flow problems from high RES penetration

- iii. **Power Stability:** An essential condition of power grids is the maintenance of stable operation notwithstanding variations in frequency, voltage, and demand. Major contributors to power stability are frequency fluctuation, voltage imbalance and the requirement to regain equilibrium or system recovery after blackouts. Problems of power stability arising from RES penetration are associated mostly the non-synchronous nature of RES generators, lack of inertia and their modular nature in power injection into the grid. Figure 8 outline the contributors to power systems stability issues arising from RES penetration. For instance, sudden drop in power injections from RES is a root causes of frequency variations, which is resulting from RES variability during peak or off-peak production periods

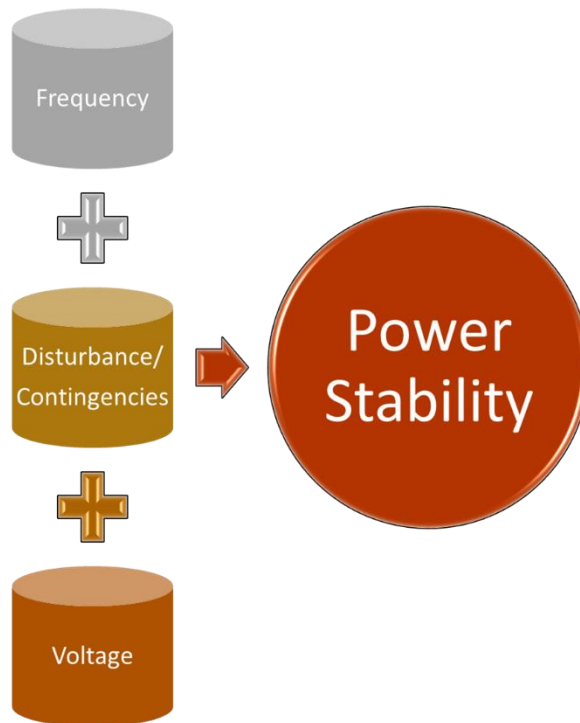


Figure 8: Causes of Stability Problems from penetration of RES

- iv. **Power Balance:** this group comprises problems related to increasing mismatches between supply and demand as illustrated in Figure 9. This can be a short or long term balance of active power supply and demand in the system, such as the coordination of ramp rate capacities in a system-wide approach, and the requirement of minimum generation levels in an interconnected power system. Power mismatching problems are initiated due to the variability, uncertainty and predictability. Figure 9. Illustrate the power mismatches resulting from generation mix comprising RES such as solar and wind,

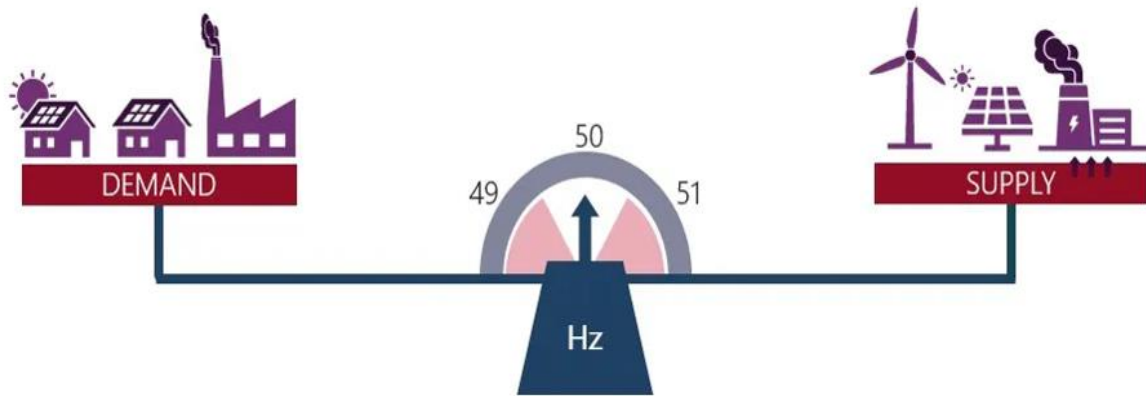


Figure 9: Power Mismatches due to Generation mix Comprising RES

In a root cause analysis, [2] provides a consistent bottom-top grouping of problems in regards to the impacts present in power systems with increasing RES penetration. A meticulous summary of the correlation between the problems and their fundamental RES characteristics is shown in Table 1. While the correlation wheel of RES characteristic features, integrating technologies and the associated challenges is depicted in Figure 10.

Table 1: Correlation between RES Problems and the Characteristic features

	Variability	Uncertainty	Location constraints	Modularity	Non-synchronous
	Available power output fluctuates with availability of its resource	Resource availability can only be predicted with high accuracy in the short term	Resource quality is not equal across locations	VRE generator scale is much smaller than conventional generators	VRE plants connect to the grid via power electronics
Quality	Increasing flicker content				•
	Increasing harmonic distortions				•
	Unreliable shut-down during blackouts			•	
	Increasing local voltage excursions			•	
Flow	Increasing regional voltage excursions		•	•	
	Missing distribution grid capacity	•	•		
	Increasingly volatile flow patterns from lower grid levels	•		•	
	Inadequate protection design	•		•	
	Increasing short circuit currents			•	
	Missing controllability of VRE output		•	•	
	Missing visibility of VRE output		•	•	
	Narrow voltage trip limits			•	
	Missing transmission grid capacity	•		•	
	Increasing transmission distances			•	
Stability	Insufficient reactive power provision		•		•
	Decreasing level of short-circuit power				•
	Decreasing level of inertia				•
	Inadequate coordination of frequency trip limits			•	
	Inadequate coordination of voltage trip limits			•	
	Decreasing frequency control reserves	•	•		
Balance	Increasing control interactions				•
	Insufficient short-term generation adequacy	•			
	Insufficient long-term generation adequacy	•			
	Insufficient firmness of VRE generators		•		
	Insufficient forecasting of VRE generation		•		
Restricted dispatchability of VRE generators	•	•			

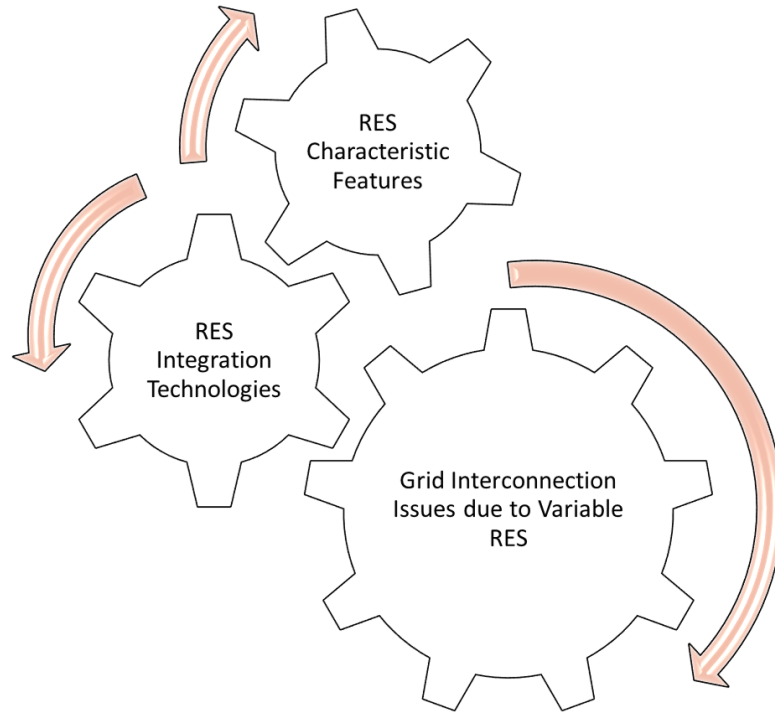


Figure 10: Correlation between RES characteristics, technologies and challenges

A typical root cause analysis for power mismatch problem due to the variable characteristics of RES is provided in Figure 11.

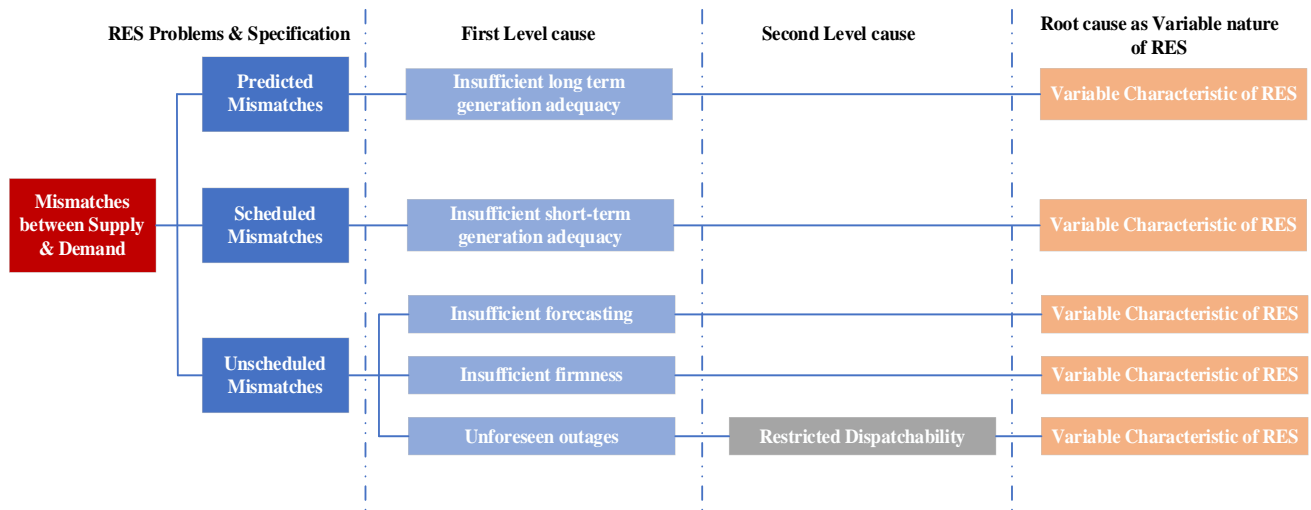


Figure 11: Root cause analysis of power mismatch due to RES Variability

4. Mitigation Technologies to problems of RES integration in Power System

Owing to the focus of different studies, the classification of mitigation technologies has been implied, such that different studies proposes implicit mitigation technologies [5], [6], [8]–[11], [16]. Consequently, using a top-down classification, two characteristics are identified for each

solution technology. First, due to the identified problems of RES integration, the choice of adopting a centralized or distributed framework of modern power system operations forms the basis for the development and deployment of any mitigation technology. Hence, the classification differentiate technology as either distributed or centralized, and whether deployable at transmission or distribution network levels. Similar to previous studies, the second characteristic aligns to the grouping into generation technologies on one side, and transmission and distribution technologies on the flip side. Consequently, mitigation technologies are grouped as either flexibility technologies – technologies contributing to flexibility through generation or consumption of active power – or as grid technologies. Based on the assignment of two characteristics per technology, [2] divided the mitigation technologies into four groups. Figure 12 provide a schematic description of the hierarchy and the identify mitigation technologies. The RES mitigations technologies under the grid technologies of the centralized framework include Reactive power controller, Inertia or short-circuit power providers, Central feed-in monitoring & control which were not shown in Figure 12.

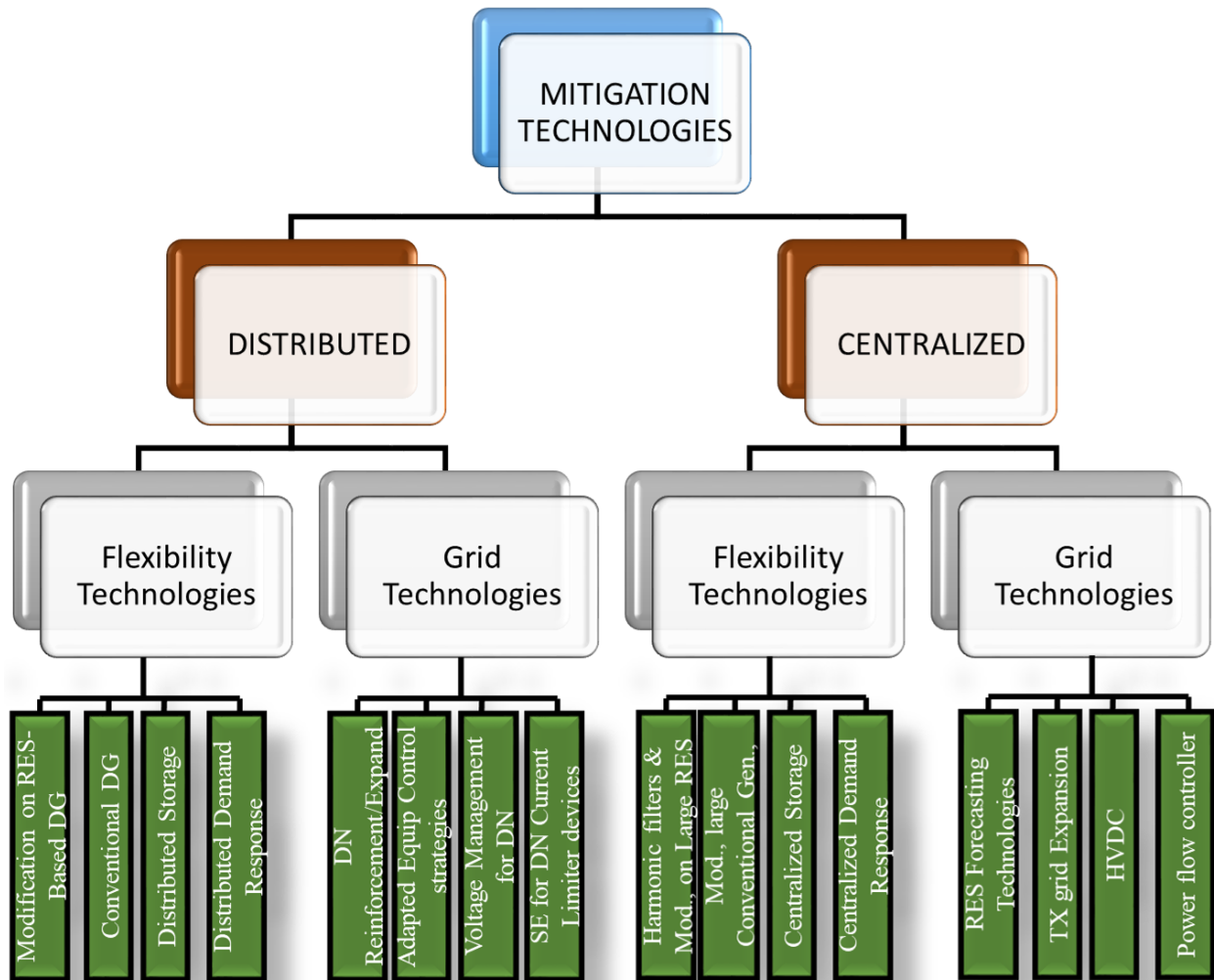


Figure 12: Mitigation Technologies for RES Integration [2]

A simple yet important observation is the similarity between flexibility technologies under the distributed and centralized mitigation framework. A critical analysis outline three distinction between flexibility technologies under the distributed and centralized mitigation: (1) Design difference between distributed and centralized flexibility technologies, (2) Different applications capability and, (3) Prerogative of the deploying operators (TSO or DSO). A typical case is between storage technologies under distributed or centralized framework. The distributed storage technologies often define battery units deployed at individual consumer end; deployed for optimum consumption of the consumer load; and owned by the end consumers. The centralized storage can be hydro pump-storage units or large connected batteries banks; applied for short-term supply during peak periods or for system stability; and owned by utilities or system operators.

5. Problem – Mitigation Correlation

From the review of the problems and the available mitigation technologies outlined, [2] provides an analysis of matching mitigation technologies to identified problems, thereby formulating a Problem – Mitigation Correlation (PMC). Accordingly, the “*solution space*” of any RES integration problem denotes the number of mitigation technologies that can be deployed in solving a given problem; while the “*solution potential*” of any mitigation technology is the number of challenges a given mitigation technology could potentially address. Due to the qualitative nature of solution potential and solution space, numeric comparisons are of limited use. The values assigned to solution space and potential are only qualitative alternatives to detect high, medium, or low solution space or potential. Figure give the matrix of the Problem – Mitigation Correlation.

5.1.Observations from Mitigation View Point of Correlation matrix (Solution Potential)

5.1.1. Flexibility Technologies

1. Flexibility technologies have the highest *solution potential* overall and within single problem categories.
2. Within the flexibility technology group, modifications to distributed VRE generators and distributed conventional generators have the highest *solution potential*.
3. Centralized demand response and new or modified large conventional generators have the lowest solution potential.

5.1.2. Distributed solution technologies

4. Distributed mitigation technologies tend to have a higher *solution potential* than centralized mitigation technologies,
5. Observation (4) above is with the exception of specific distributed grid technologies such as current limiter devices or harmonic filters

5.1.3. Grid technologies

6. Grid technologies have a unique value in specific problem, such as power flow controllers and high-voltage direct current (HVDC) systems, for solving the issue of increasing transmission distances.
7. Most problems can be addressed with flexibility technologies.

5.2.Observations from Problem View Point of Correlation matrix (Solution Space)

5.2.1. Power Quality Problem

1. Power Quality problems are local and site-specific, they have a narrow solution space and can only be solved by distributed solution technologies. These can either be modified distributed VRE generators or add-on solution technologies, such as harmonic filters.

5.2.2. Power Flow Problem

2. Power Flow problems can be solved with technologies from all groups; one notable exception is that of centralized flexibility technologies, which have limited contributions to solving flow problems.
3. Problems in the power flow category have differing solution spaces, from rather narrow (e.g. for increasing transmission distances) to rather broad (e.g. for increasing regional voltage excursions).

5.2.3. Stability Problem

4. Stability problems can only be solved by solution technologies coordinated on a system level, i.e. in a centralized manner. Therefore, unlike with power flow problems, distributed grid technologies do not help to solve stability problem unless they get aggregated on a system level.
5. Problems in the stability category have a rather broad solution space, with the exception of increasing control interactions.

5.2.4. Power Balance Problem

6. Balancing problem can be only solved by flexibility technologies since solving these problems requires the generation or consumption of active power; a notable exception is improved VRE forecasting.
7. Problems in the balance category generally have a broad solution space, except for long-term generation adequacy, which may be indicative of the relative complexity for solving this challenge in comparison to others.

	Distributed technologies											Centralized technologies										Solution Potential		
	Flexibility technologies				Grid technologies							Flexibility technologies				Grid technologies								
	Modifications to distributed VRE generators	Distributed conventional generators	Distributed storage	Distributed demand response	Distribution grid reinforcement / expansion	Adapted equipment protection strategies	Voltage management solutions for distribution grids	State estimation solutions for distribution grids	Current limiter devices	Harmonic filters	Modifications to large VRE generators	New or modified large conventional generators	Centralized storage	Centralized demand response	VRE forecasting technology	Transmission grid reinforcement / expansion	HVDC transmission systems	Power flow controller	Reactive power controller	Inertia or short-circuit power providers	Central feed-in monitoring & control			
Quality	Increasing flicker	●																					1	
	Increasing harmonic distortions	●								●													2	
	Unreliable shut-down during blackouts	●					●																2	
	Increasing local voltage excursions	●				●	●																3	
Flow	Increasing regional voltage excursions	●	●	●	●	●	●	●										●			●		10	
	Missing distribution grid capacity	●	●	●	●	●		●													●		7	
	Increasingly volatile flow patterns from lower grid levels	●	●	●	●	●			●						●	●						●	9	
	Inadequate protection design						●		●														3	
	Increasing short-circuit currents	●				●	●			●													4	
	Missing controllability of VRE generation			●	●				●													●	4	
	Missing visibility of VRE generation	●				●			●						●	●							5	
	Narrow voltage trip limits	●	●					●				●											4	
	Missing transmission grid capacity		●	●									●	●		●	●	●					7	
	Increasing transmission distances															●	●						2	
Stability	Insufficient reactive power provision	●	●								●		●			●		●	●				7	
	Decreasing level of short-circuit power										●	●	●							●			4	
	Decreasing level of inertia										●		●		●					●			4	
	Inadequate coordination of frequency trip limits	●	●	●	●						●	●	●	●						●	●		10	
	Inadequate coordination of voltage trip limits	●	●								●		●						●	●			6	
	Decreasing frequency control reserves	●	●	●	●						●	●	●	●										8
	Increasing control interactions										●							●					2	
Balance	Insufficient short-term generation adequacy	●	●	●	●						●	●	●	●	●								9	
	Insufficient long-term generation adequacy		●	●								●	●										4	
	Insufficient firmness of VRE generators	●	●	●	●						●	●	●	●	●								9	
	Insufficient forecasting of VRE generators		●	●	●						●	●	●	●	●								8	
	Restricted dispatchability of VRE generators	●	●	●	●						●	●	●	●	●	●							9	
		17	14	12	10	6	5	3	5	2	1	12	8	12	7	6	5	3	2	3	5	5		

Solution Potential

6. Future Prospects

The correlation matrix can serve as a guide for businesses and policy makers to identify groups of solution technologies that help mitigate prevalent problems in any framework of operations (centralized grids or Micro/Mini grids), and devise strategies and policy measures to support the deployment of such technologies. Also, prioritizing mitigation technologies based on their solution potential would render flexibility technologies as most suitable for solving problems of RES integration. Consequently, the future perspective of RES integration based on the current status in Nigeria indicates the following:

1. Since problems of RES integration affect all major performance characteristics of power systems, a step change approach is required to develop indigenous mitigation solution at the same pace with the increasing RES penetration.
2. While a given mitigation technology can address a significant number of problems, flexibility technologies generally have a higher solution potential in comparison to grid technologies. Hence, the development of flexibility technologies and the corresponding policy regulation focusing on hybrid standalone RES integration is an important prospect in the Nigerian power market.
3. Since the analysis provides a means of identifying mitigation technologies for centralized versus distributed mitigation technologies, and because distributed solution technologies mostly aid in solving problems related to local power flow, more attention is needed to develop the centralized mitigation technologies to help in tackling the burden of existing stability problems in anticipation of the centralized framework of RES integration in Nigeria.
4. **Agrovoltaic:** Electricity generation can be improved by upgrading APV plants with wind turbines to combine wind and solar energy production. Hence the ZeFarms concept becomes largely realizable in in medium and small scale.

7. Conclusions

This paper identified the various problems associated with increased penetration of RES toward the decarbonization drive and the available mitigation technologies. The classifications and categorization of various mitigation technologies can provide guidance to firms and policy makers and regulators for developing adequate business strategies and policies. The correlation matrix can serve as guidance to different stake holders in decision making and for drafting/amending national RES integration technology roadmaps or proposals which seek to contribute to Nigerian power sector decarbonization. Future prospects will provide useful information for policymakers, innovators, project developers, investors, industries, associated stakeholders and departments, researchers, and scientists.

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