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Review

Review of Smart Grid and Nascent Energy Policies: Pakistan as a Case Study

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Abstract: Smart grid plays a vital role in energy management systems. It helps to mitigate the demand side management of electricity by managing the microgrid. In the modern era, the concept of hybrid microgrids emerged which helps the smart grid management of electricity. Additionally, the Internet of Things (IoT) technology is used to integrate the hybrid microgrid. Thus, various policies and topologies are employed to perform the task meticulously. Pakistan being an energy deficient country has recently introduced some new policies such as Energy Wheeling Policy (EWP), Energy Import Policy (EIP), and Net Metering/Distributed Generation Policy (NMP) to manage the electricity demand effectively. In addition, the Energy Efficiency and Conservation Act (EECA) has also been introduced. In this paper, we present the overview and impact of these policies in the context of the local energy market and modern information and communication mechanisms proposed for smart grids. These new policies primarily focus on energy demand–supply for various types of consumers such as the demand for bulk energy for industrial ventures and the distributed production by consumers. The EWP deals with obtaining power from remote areas within the country to ease the energy situation in populated load centers and the EIP highlights energy import guidelines from foreign countries. The NMP deals with the integration of renewable energy resources and EECA is more focused on the measures and standardization for energy efficiency and conservation. The benefits and challenges related to EWP, NMP, and EIP have also been discussed concerning the present energy crisis in Pakistan. The generalized lessons learned and comparison of a few aspects of these policies with some other countries are also presented.

Keywords: energy wheeling policy; energy import policy; energy efficiency; hybrid microgrid; net metering policy; smart grid and conservation

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1. Introduction

Energy management has been a crucial task ever since. It is a significant and fundamental research focus because of its associated environmental and sustainability concerns [1,2]. Energy management is an effective way of optimizing the power system assets comprising generation, distribution, and utilization. However, energy demand in the world has drastically increased over the last decade and is expected to peak by 2025, World Energy Council says [3]. The current global trend regarding the energy sector is primarily focused on energy management by introducing new policies and methodologies to maintain and stabilize energy demand and address environmental concerns like global warming and climate change etc. [4,5].

The term "Smart Grid" refers to a phenomenon that has no single description (SG). However, the smart grid may be characterized as a simple automated, intelligent network with the ability to interact, store data, and make decisions [6,7]. Similar requirements for the establishment of the smart grid are mandated under the US Energy Independence and Security Act of 2007. According to this description, the smart grid is an upgrade to the electrical grid that automatically optimizes the grid functioning of linked system components, starting with centralized and distributed generation and continuing through transmission networks up to load centers [8]. It also increases the grid's resistance to outages. The smart grid is also "a contemporary grid that regulates bi-directional flows of energy," according to the US National Institute of Standards and Technologies (NIST), and employs two-way communication and control capabilities to enable a variety of new functions and applications. It continues by stating that smart grids enable a two-way flow of both energy and data, in contrast to the current system, which transports energy from generating to demand centers [9]. Several organizations and academics are mentioned in the text's sources as having provided definitions of the "smart grid." However, they concur conceptually on the term's broad meaning. The smart grid is also "the transition from the current grid where the flow of power is permitted from the central generation to load locations into a grid where there is a peer-to-peer consumer interaction, distributed generation, and control centers," according to the US-based Electric Power Research Institute (EPRI). The UK's Department of Energy and Climate Change claims that a smarter grid makes operators more aware of supply-demand balance data, assisting with intelligent management and shifting demand from peaking instants to off-peak hours [10]. Similar to how EPRI characterizes it, the Australian government refers to the smart grid as a cutting-edge and incredibly intelligent method of supplying power. Energy Australia and Ausgrid introduced the "Smart Grid Smart City" program [11]. To build a two-way, interactive grid, it combines cutting-edge electrical network technology with cutting-edge sensing and metering infrastructure. Reducing grid interruptions and outages is possible thanks to the use of smart sensing technology. Smart metering might also assist customers in efficiently managing their energy use to save bill expenses.

With the aid of the smart grid, the current traditional grid is replaced with a more contemporary, quick-operating grid. Users, generators, and consumers may be intelligently connected to the grid to provide supplies that are effective, secure, and financially feasible. To increase system efficiency, dependability, and sustainability, the SG combines distributed intelligence, bidirectional communications infrastructure, and power flow [12,13]. The smart grid is also a network that incorporates highly automated services and advanced digital processing capabilities to improve the architecture of the current electrical system. The ability of the system to self-heal is enhanced by enabling the changeover to a smart grid [14–16]. Table 1 summarizes the key differences between the conventional power system and the smart grid. SGs require an efficient deployment of information and communication technology to implement this strategy successfully. Converting the conventional electrical grid into an active network with two-way communication capabilities is one of the main problems for smart grids (SGs). Following the variety of the power network, a seamless transition to integrate SG technologies has been made with the necessary category standards.

Pakistan is an energy-deficient and developing country of over 207.774 million people [17,18]. The country has been facing energy scarcity for a long [18,19]. Pakistan has an average peak demand of 22,000 MW with a shortfall of 5000 MW [20]. The annual energy demand growth rate is 10% which shows that the average demand will rise to 45,000 MW by 2030 [20]. The government of Pakistan has taken initiatives and introduced various policies to manage the growing energy demand [21]. First, the government introduced the Power Policy in 1994. The policy was mainly aimed to attract Independent Power Producers (IPPs) with the exemption from all taxes (sales/income/duty taxes). The 1994 policy resulted in a major shift to thermal generation and a reduction of hydel power from 60 to 30 per cent [22,23]. Therefore, Hydropower Policy 1995 was announced for power producers to explore hydel resources along with thermal sources with the same incentives [24]. The amendments of 1998 in the 1994/95 policies have paved the path for competitive bidding by presenting open bid tariffs [25]. The 2002 power generation policy aimed to promote public-private partnerships for the cause of power generation [26]. In addition, the government has put consistent efforts into matching the supply and demand curves. The Power Policy 2006 for renewable energy development [27], Co-generation Policy 2008 [28], National Energy Policy 2010–2012 [29], National Power Policy 2013 [30], Power Generation Policy 2015 [29] are some of the efforts. Even though the country has witnessed a series of policies, the system remained to fail to fulfil the energy demand due to various political and managerial reasons. Therefore, the government is taking dynamic, remedial measures such as Energy Wheeling Policy (EWP), Net Metering Policy (NMP), Energy Import Policy (EIP) and Energy Efficiency and Conservation Act (EECA). The EWP deals with obtaining power from remote areas within the country to ease the energy situation in populated load centers and the EIP highlights the energy import guidelines from foreign countries. The NMP deals with the integration of renewable energy resources and EECA is more focused on the measures and standardization for energy efficiency and conservation [31,32]. Some other examples of such policies include carbon pricing and financial incentives, etc. [33].

Table 1. Comparative study between Conventional Grid and the Smart Grid [34].

Conventional Grid	Smart Grid
Mechanically operated	Digitized
Unilateral	Bi-directional
Centralized power generation	Distributed Generation
Radially connected	Dispersed
A small number of sensors	Many
Less monitoring capabilities	Highly monitored
Manual control	Automated control
Fewer security issues	Vulnerable to security issues
Slow responsive actions	Fast response

The concepts of dynamic energy management and smart grid provide a bidirectional environment to exchange data and power [35,36]. Such an environment will be helpful and user-friendly for the successful and optimized implementation of EW and NM policies. The two-way communication and flow of data ease the practical application of these policies on real grounds. The smart grid promises to make the electrical system proactive with many qualities like self-healing, resilience against cyberattacks, etc. [37].

The concept of smart metering is a key element in smart grid technology; it provides an opportunity for users to take significant benefit from renewable resources such as solar and wind power when it is feasible in terms of price and intermittency. Consumers may use their renewable generation when grid supply is not available or is insufficient and supply to the grid when they get excessive renewable energy making their smart meters run in the reverse direction. On the other hand, a smart grid is adaptive and intelligent, it does not rely on the operator but rather tends to neutralize and rectify any disturbance and critical predicaments that might happen [38]. One of the main ideas behind the smart grid technology is the conservation of energy which leads to reduced monthly electricity tariffs.

Academia has also shown great concern over the energy policy of Pakistan in the last few years. Several such studies have presented Renewable Energy Sources (RES) as a rational remedy for the energy crisis. In 2010, it has been discussed the exploration of RES in the country suggested that feed-in-tariffs and subsidy transfers could be effective measures for developing energy policy [39,40]. It is considered renewable energy is a supportive solution to the national cause of sustainable development. The authors identified that unawareness of the general masses about the potential of RES is the main reason for its low exploration. According to research, inefficient generation mix, less reliability, and inefficiency of power regulatory bodies and the absence of an effectively competitive market are factors that resulted in the widening supply–demand gap of the country [41]. The study proposed that distributed generation, privatization of the distribution sector and inter-regional cooperation could uplift the power sector [42]. The future energy security has been analyzed using LEAP. The study used four different situations as "business-as-usual, green Pakistan, nuclear and optimization" to evaluate the legitimacy of the energy proposals and concluded that green Pakistan along with RES is the optimal choice for future energy security. It emerged as critics of government leniency toward electricity generation by thermal power and characterized it as a hurdle toward clean and green Pakistan, a policy initiated in 2006 [43]. In a study of the existing power sector in the country, another research [44], proposed an integrated framework based on the "Performance Enhancement Plan, Government Support Plan and Organization-al Plan" to strengthen the power sector. Many researchers [45] have quantified the implementation of a wind/solar integrated system in the country. They have proposed a system with an installed capacity of 882 MW solar PV and 10.4 GW wind that can overcome the energy shortage of 38.36 TWh. It has reviewed the power sector of Pakistan and categorized the presence of natural RERs as a strength of the country [46], bad governance as its weakness, and the application of distributed generation and smart grid as an opportunity with overuse of thermal sources for electricity generation as a threat to the country. The significance of the energy rebound effect on the country's energy consumption is highlighted in [47]. The energy rebound effect caused an increase in consumption despite improvements in energy efficiency. The study has concluded that the rebound effect has 42.9% magnitude in the short run and 69.5% magnitude in the long run policies, respectively [47].

Pakistan being a developing country is experiencing many challenges to implement these smart energy policies fully. Among these challenges, these are some major limitations that can hinder to implement these policies.

- Lack of initial capital amount to construct new renewable distributed generation plants at governmental level.
- Lack of proper subsidy plan for consumers to construct distributed generation at their end as the per capita average income of citizens of Pakistan is considerable low.
- Lack of proper infrastructure for energy wheeling to long distances.
- Energy theft and circular debt in electric power department, NEPRA hinder it to initiate it in a large scale.
- Lack of awareness among the public about the importance of these policies about their economic gain.

The limitations regarding these policies are thoroughly discussed above; however, in light of the above discussion, this paper contributes to electrical system of developing countries like Pakistan are as following:

- An overview and impact of EWP, EIP, NMP, and EECA in Pakistan for demand side management of energy.
- Dynamic energy management via hybrid microgrid management and smart grid to control the energy wastage considerable [48].
- To encourage public towards distributed generation by introducing Net Metering policy.
- The EIP enabled the government to import the necessary energy from neighboring states, i.e., Central Asia South Asia energy import agreement (CASA-1) has become possible due to this policy [49].

The paper has further covered to provide an insight into the environment necessary for the successful implementation of these policies. The rest of the paper is organized as follows. Section 2 is dedicated to the discussion of the above-mentioned policies. Section 3 presents the comparison of a few aspects of the policies with some other countries. Finally, the paper is concluding in Section 4.

2. Current Energy Scenario and New Energy Policies

This section elaborates on the current energy scenario, hybrid microgrid management and new energy policies including EWP, EIP, NMP, and EECA as follows.

2.1. Current Energy Highlights of Pakistan

South Asian countries such as Bangladesh, India, and Pakistan are the most diversified areas in sense of geological, geographical, topographical, and meteorological points of view. However, the total energy demand in these areas is very high because of densely populated areas of the world [1]. To understand the relation between existing supply and demand, consider the following statistics which provide an intuitive analysis of Pakistan about the electricity generation during the last few years as depicted in Table 2.

However, the generation demand for electricity in Pakistan in 2015-16 is about 18–23 thousand MW [50] and is achieved mostly by thermal followed by hydel, nuclear, and renewable sources, respectively, which is shown in Figure 1. Although with the growing population and advanced industry, electricity demand has been increasing at a rate of 10% per year, it is necessary to work on new innovative ideas to generate electricity accordingly to meet the demand.

Electricity generation from RES has been quite insignificant in Pakistan; nevertheless, the ice has been broken, and RES is expected to flourish in near future. Figure 2a,b overviews the potential of RES mainly solar and wind energy and various RES projects installed in Pakistan, respectively [51].

Table 2. Yearly Energy Generation of Pakistan 2008-18 [51–53].

Electricity Generation for July–March 2008-18									
	Installed Capacity (MW)	Generation (GWh)	Hydel		Thermal		Nuclear		Imported (GWh)
			Installed Capacity (MW)	Generation (GWh)	Installed Capacity (MW)	Generation (GWh)	Installed Capacity (MW)	Generation (GWh)	
July–March									
2008-09	19,575	60,793	6481	20,526	12,632	39,154	462	918	195
2009-10	19,650	63,178	6481	21,671	12,707	39,342	462	2521	185
2010-11	20,729	68,970	6481	23,817	13,785	42,664	462	2260	229
2011-12	22,578	66,130	6557	22,044	15,234	39,940	787	4146	...
2012-13	22,851	66,962	6650	20,536	15,414	43,125	787	3301	...
2013-14	23,048	73,435	6858	23,953	15,440	44,847	750	4331	304
2014-15	23,212	71,712	7027	23,478	15,435	43,611	750	4273	350
2015-16	23,101	73,209	7027	24,544	15,324	45,252	750	3078	335
July–February									
2016-17 *	22,600	68,592	7097	21.862	13,514	42,545	1005	3082	315
2017-18	29,573	69,956	7248	18,858	19,816	19,816	1321	5236	322

* Electricity generation from Renewable sources remained at 1102 GWh and 1377 GWh against 984 MW and 1188 MW installed capacity for the periods 2016–17 and 2017–18, respectively.

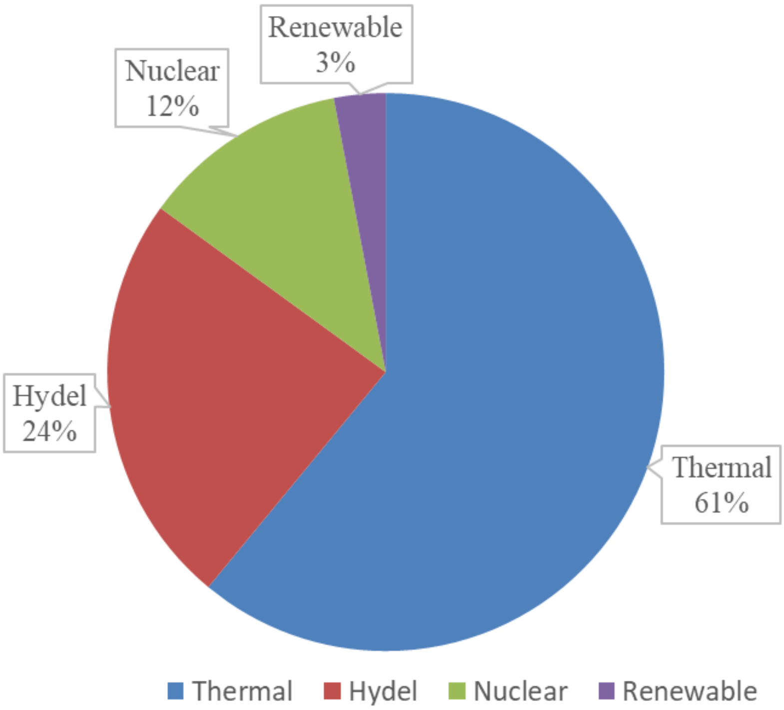

Figure 1. Pakistan's Sources Share in Electricity Generation during 2021–22 [1,54].

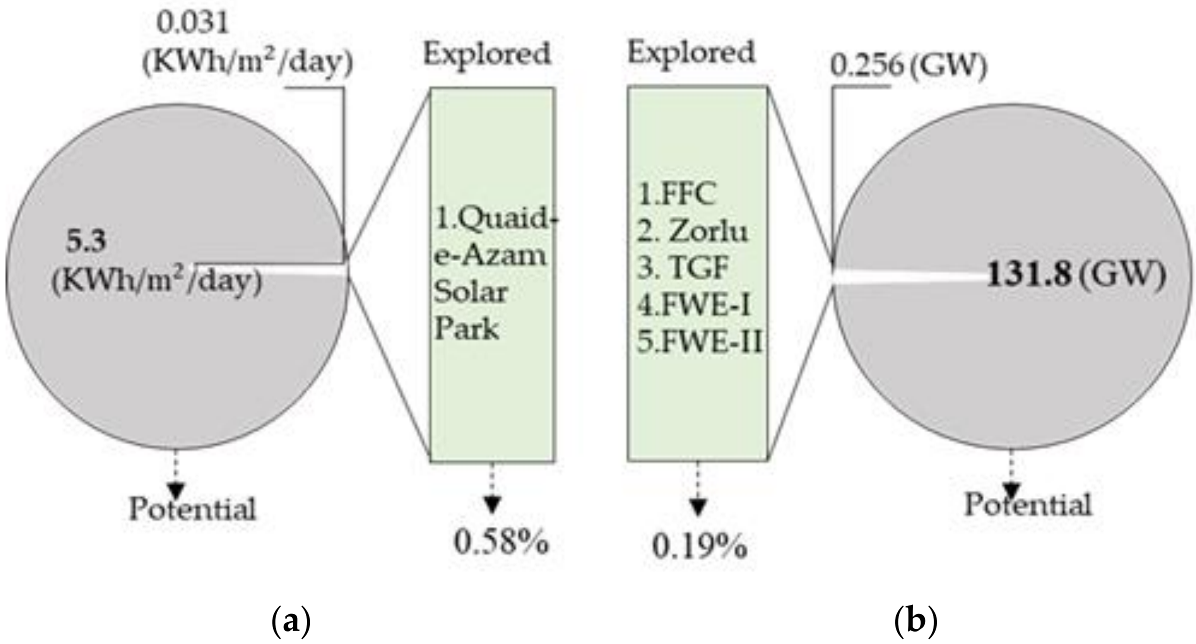

Figure 2. (**a**) Solar Energy in Pakistan [36]. (**b**) Wind Energy in Pakistan [51]. FFC—Fauji Fertilizer Company; TGF—Three Gorges First; FEW—Foundation Wind Energy.

Before discussing the NMP in detail, we need to make a precise analysis of available RES in Pakistan. Biomass, wind, and solar have appeared as the most feasible energy sources in the country.

Pakistan is immensely rich in solar energy around the year with an average of 5.3 kWh/m^2/day [1]. According to a scientific assumption, solar power harvesting is possible if the sun shines approximately 165 days in a year while Pakistan gets twice the sunshine than the threshold [55]. However, wind energy is another feasible and economical source to harness for electricity generation. Pakistan has two large wind corridors, which are the wind corridor in Sindh coastal areas and the wind corridor in Baluchistan coastal areas [56]. These two wind corridors have the potential of 50,000 MW [57] with 131,800 MW overall potential in the country [1]. Pakistan's electricity consumption share is shown in Figure 3, which illustrates that the maximum share is in domestic followed by industrial, agricultural, commercial, street lights, and other government loads, respectively [56].

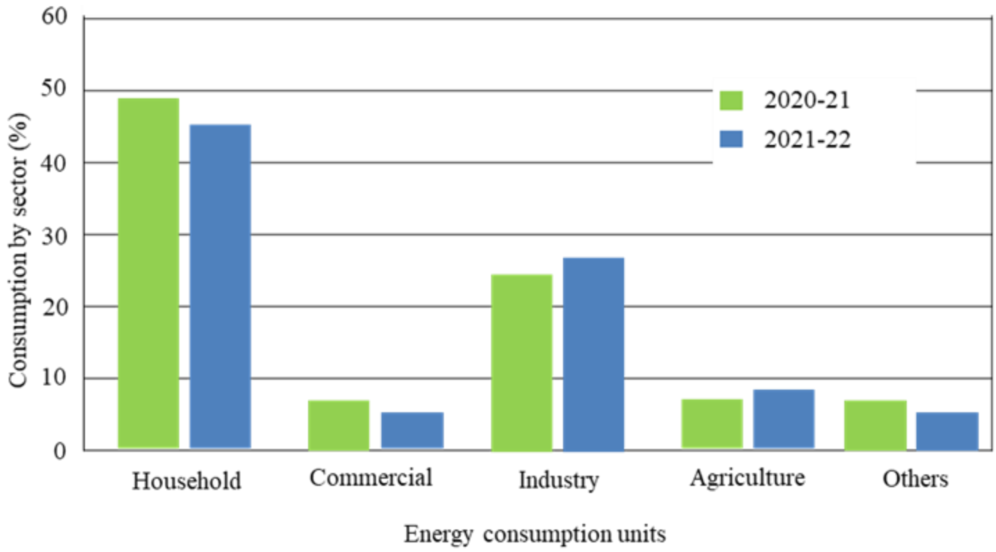

Figure 3. Sector Wise Share of Electricity Consumption in Pakistan, Source: Pakistan Economy survey 2021–22 [58].

The energy consumption share in different sectors in Pakistan shows that maximum electricity is consumed in the domestic followed by industrial and agricultural sectors, respectively. The per capita energy consumption has increased over decades in the manner shown in Figure 4. Also, it shows per capita consumption by 2010 has increased three folds compared to that in the 1970s. This increase in per capita energy is associated with the increase in the country's population and its industrial ventures [59]. Due to these issues, the electricity deficit increased, and the energy crisis rose with time as shown in Figure 5.

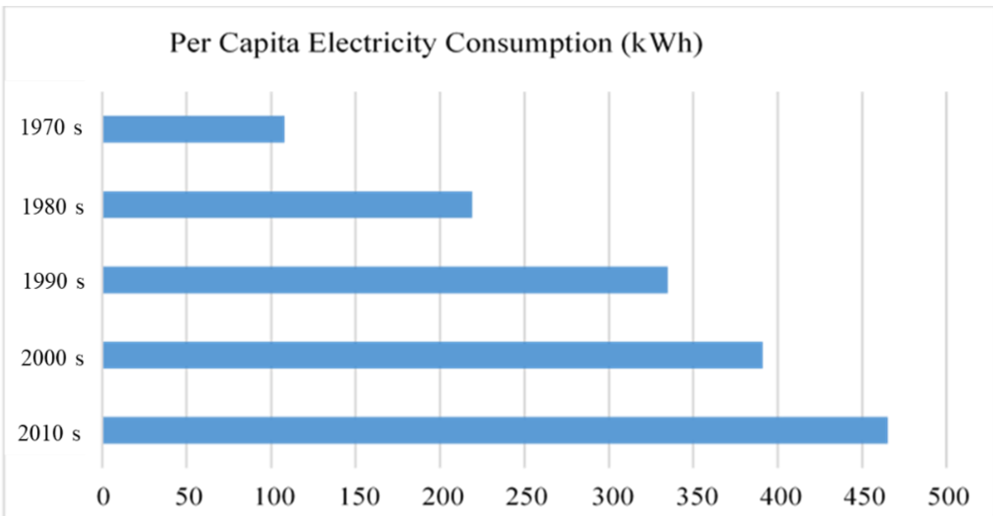

Figure 4. Decade Wise Comparison of Electricity Consumption per Capita (KWh). Data Sources: Pakistan Economic Survey 2009-10 & World Bank.

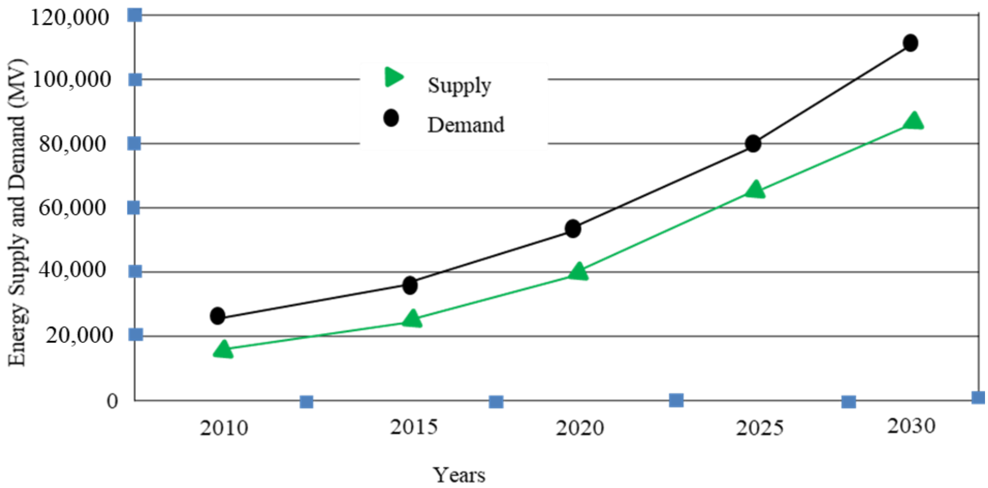

Figure 5. Supply and Demand of Pakistan: 2010–2030 [60].

2.2. Hybrid Microgrid Management

The integration of RES as distributed generation is a desirable response to the reliance on fossil fuels, the steadily rising energy demand, and the inferior energy quality delivered by an old and inefficient power network (DG) [61]. Numerous analyses have been conducted that examine various facets of these networks, including control methods, global test locations, plans for optimization, software tools accessible, security measures, etc. With the use of microgrids, it is possible to integrate RES, ESS, and loads into a single grid. The designs of microgrids can be ac, dc, or hybrid ac/dc; however, in recent years, hybrid systems (Figure 6) have begun to be seen as an appealing choice since they incorporate the most important components of both ac and dc networks. Because most research focuses on ac- or dc-based microgrids individually, a more detailed analysis of the characteristics relevant to hybrid microgrids is required [62,63].

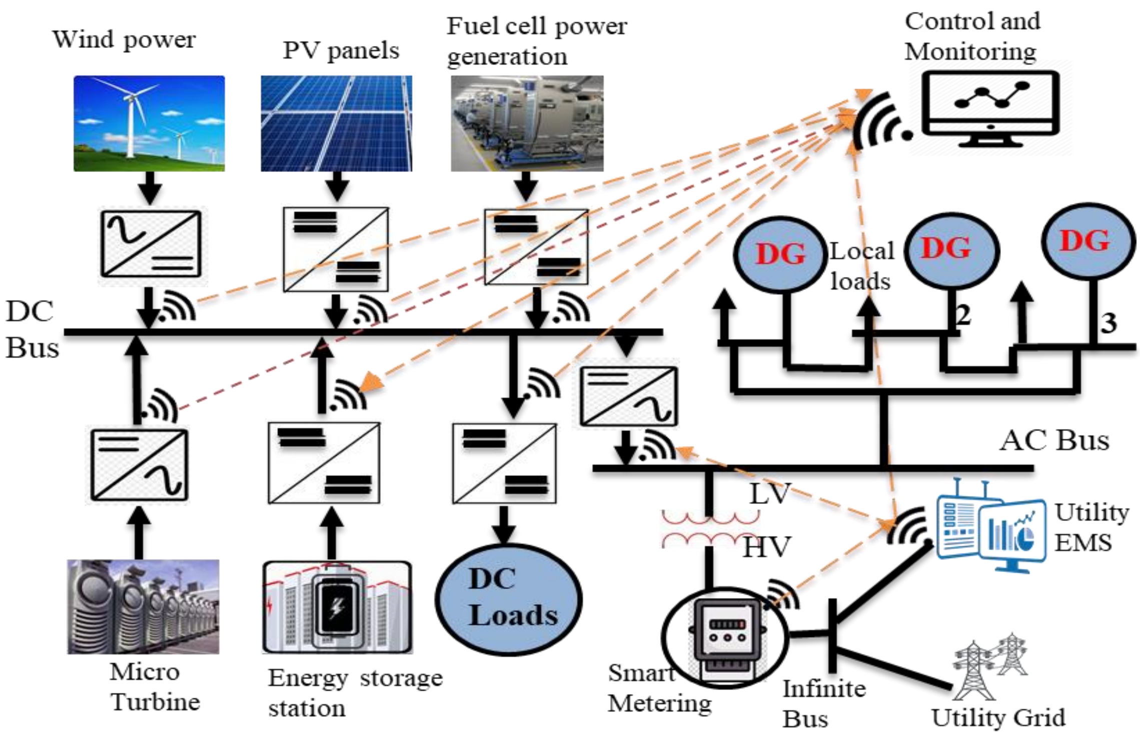

Figure 6. The Topology of Hybrid Microgrid System.

Hybrid microgrids consist of an ac network, a dc network, and an interface that controls the power flow between the networks and the utility grid as depicted in Figure 6 [64,65]. The capacity to connect ac- and dc-based equipment to the grid without using as many interface converters is only one advantage of these configurations. However, their control strategy must incorporate the following elements: Stability of voltage and frequency at grid-tied and islanded modes of operation, adequate power sharing of RES and ESS units, and optimal power exchange between the microgrid and the power network.

Even though there are several control techniques listed in the literature, only a handful of them specifically targets hybrid ac/dc microgrids. Additionally, there have not been many assessments of hybrid microgrid techniques, and the data that is given is a bit contradictory. Therefore, the major goal of this research is to identify and evaluate the most significant control mechanisms that hybrid microgrids may use [66,67]. When modified, several of them might be beneficial for hybrid microgrids as well as standalone ac and dc microgrids. Researchers and developers will be helped in choosing the best management strategy based on the needs of their company by the classification and analysis of the key aspects of the control strategy.

The Hybrid microgrid systems management has a great importance owing to manage the energy generation and consumption of countries especially in the developing states. In developing states, the governments do not have enough resources to construct new major generation plants. However, the citizens that have capacity of individual generation can contribute to the national grid, which can only be possible by managing the renewable energy such as Solar Hybrid microgrids [68].

Control Strategy Overview of Hybrid Microgrids

The control technique used to manage the network's connected devices is one of the most distinguishing characteristics that set microgrids apart from traditional distribution grids. This approach is essential for the best management since microgrids are distributed [69,70]. To provide a reliable and constant power supply, it is crucial to deploy ESS devices to effectively control the intermittent behavior of DG units. When used in an autonomous mode, the microgrid also has to be properly maintained to guarantee consistent voltage and frequency and provide a smooth transition in operating mode [71–73]. These restrictions make control systems for microgrids a difficult subject that has drawn a lot of research.

In the microgrid context, the following requirements are typically required for a control strategy:

- Stability: it is the control of the microgrid's voltage and frequency while it is operating in a variety of modes. Additionally, it guarantees a stable and dependable power network on both the ac and dc sides of the microgrid [74];
- Protection: it includes managing grid faults, monitoring energy flow, and keeping an eye on vital components;
- Power balancing: optimum load sharing and synchronized DG supply;
- Transition: transitioning without interruption from one microgrid operation mode to another, such as from islanding to grid-tied mode or vice versa;
- Power transmission: it is the process of moving electricity from the utility grid to the microgrid;
- Synchronization: For the best power transmission, the microgrid and the power network must be synchronized;
- Optimization: it is the management of systems based on the microgrid and utility grid circumstances (such as market scenario, power demand/supply, or energy projection), to lower costs, enhance the energy efficiency, etc. [75].

These components need the creation of a more intricate control architecture as compared to the controls included in typical distribution networks. Storage units in a normal electricity grid are not managed by the grid operator unless their scale is typical for the network [60].

The most common control techniques are difficult to classify since they mostly depend on the characteristics of the microgrid. The majority of authors suggest applying hierarchical control strategies to accomplish the aforementioned objectives. This method distinguishes between local/primary control, microgrid/secondary control, and global/tertiary control as the three basic control levels [76,77]. Each level is responsible for the control of the microgrid at a different scale and their main functions are summarized in Figure 7.

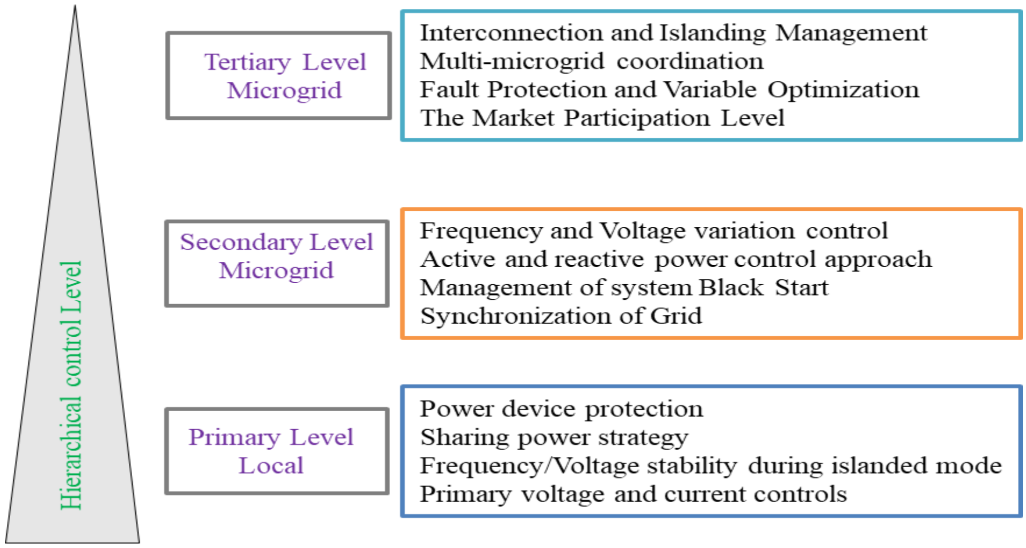

Figure 7. The Key features of control levels of a hierarchical Control strategy.

The classification of the most important hierarchical control level strategies is shown in Figure 8. The categorization was made using the studies mentioned in the literature, and each attribute is discussed in more detail in the sections that follow.

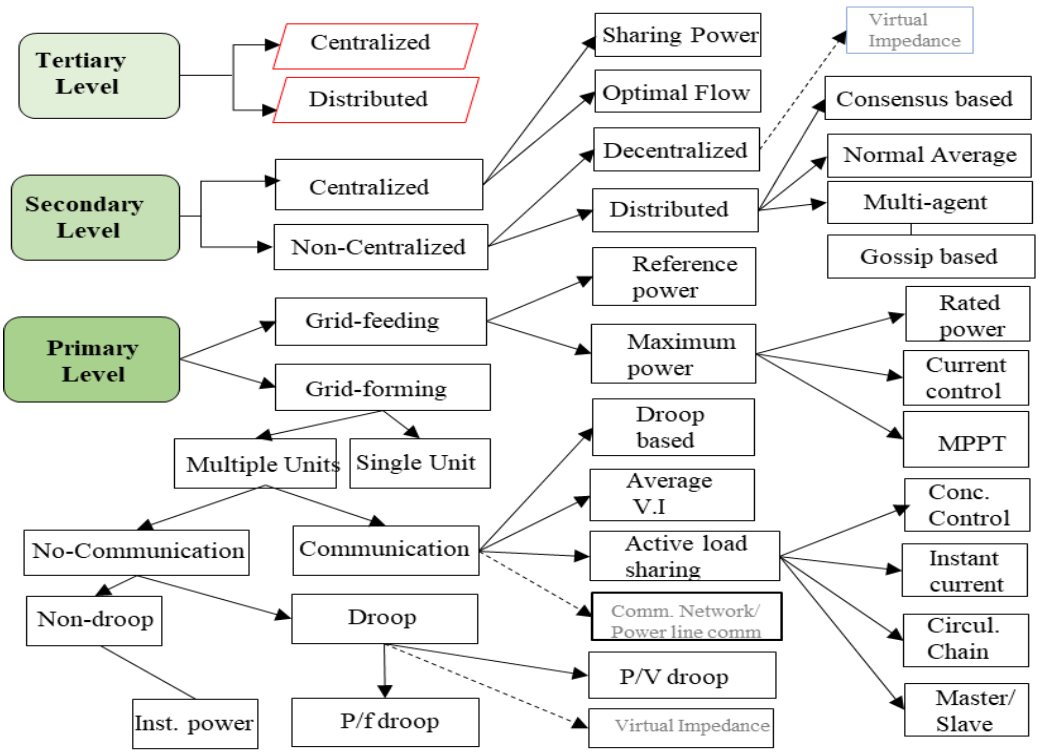

Figure 8. The categorization of primary, secondary and tertiary control levels.

2.3. Introduction of the National Electric Power Regulatory Authority

National Electric Power Regulatory Authority (NEPRA) is an independent organization in Pakistan which primarily regulates electric power issues with the assurance of no extraneous influence. The need for its establishment was first presented in Water and Power Development Authority's (WAPDA) strategic plan in 1992. The strategic plan proposed privatization of the power sector with its success lies in the creation of an autonomous body. In this context, the authority was established in 1995 by a Presidential Ordinance, however, formal notification was made in the Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997 [78]. The primary aim behind its establishment was to provide a conducive environment for investors and to promote private power production in the country. Furthermore, its responsibilities include the issuance of licenses and tariff determination for three pillars of the power sector (Generation, Transmission and Distribution), ensuring high quality and safety of operation and granting financial approvals & power acquisition to utilities. NEPRA has a serious challenge of proving its autonomy and impartiality in the context of strong political influence seen by many government departments. NEPRA is the key authority which constructs these policies for Pakistan for its energy management meticulously and moving one step towards smart grid via these recommended energy policies [78].

2.4. Wheeling of Electric Power, 2016

Wheeling of Electric Power was first devised in 2016 when NEPRA added some new regulations in the Electric Power Act, 1997, officially notified as, "National Electric Power Regulatory Authority (Wheeling of Electric Power) Regulations, 2016". These regulations apply to Transmission Licensees/Distribution Companies (DISCOs) and the applicants who desire to acquire wheeling services. These regulations encourage the applicants by ensuring "non-discriminatory open access" to all services offered by the service providers. The regulations also allow Generation Company (GENCO) to construct its own dedicated Transmission/Distribution facility at its expense. However, the expenses incurred in this set-up could be recovered through the wheeling charges. Once constructed, the operation, maintenance and ownership of this dedicated system would be to the relevant Distribution Company. Details of the application process, requirements of the wheeling meter, banked energy, shortfall, overdrawing, and liquidated damages are also given in these regulations as shown in Figure 9 [78,79].

The EWP and NMP policies are the benchmark and milestones toward the advancement of the national grid. Mostly the major Bulk Power Consumers (BPCs) are situated in areas like Karachi, Faisalabad, Lahore and Multan, where the electricity is generated from thermal resources. As the BPCs require power in bulk amounts, it makes the electricity more expensive and prone to interrupts because of the load on the national grid at peak hours. As the Generation Companies near BPCs use thermal generation sources, the price per unit is higher as compared to hydel sources. Therefore, it is necessary to import electric power from the other GENCOs which have relatively inexpensive sources of generation such as far-apart hydel sources. For this purpose, the NEPRA introduced the EW policy [31] in 2016 under Pakistan's Legislation.

This policy allows the BPCs to get the energy from any GENCO and opens the doors for a competitive environment for power purchase in the country. Transmission for this purpose is almost impossible for any individual BPC because of the large distances involved from GENCOs, particularly from the north of Pakistan which produce electric power from hydroelectric sources which are relatively inexpensive. To overcome this difficulty, BPCs can be benefitted from the current network of National Transmission and Dispatch Company (NTDC) and DISCOs for power transmission and distribution accepting the terms and conditions for this facility [80].

Under this policy, the BPC and the GENCO agree on a specific amount of energy. The subsidiary agreement between BPC and the DISCO/NTDC permits BPCs to use the existing transmission and distribution network. According to this agreement, the specific grid code is assigned for a specific grid path from GENCO to BPC through NTDC and DISCO under the consent of higher authority, i.e., NEPRA (2016) [81].

The wheeling meters are installed at the entrance and exit points of NTDC and DISCO for the calculation of the amount of in and out flow of electrical power. The transmission at 500 KV and 220 KV levels are handled by the NTDC [80] while the distribution at 132 KV and 11 KV levels are carried out by the respective DISCOs [82]. There are four GENCOs and nine DISCOs in Pakistan.

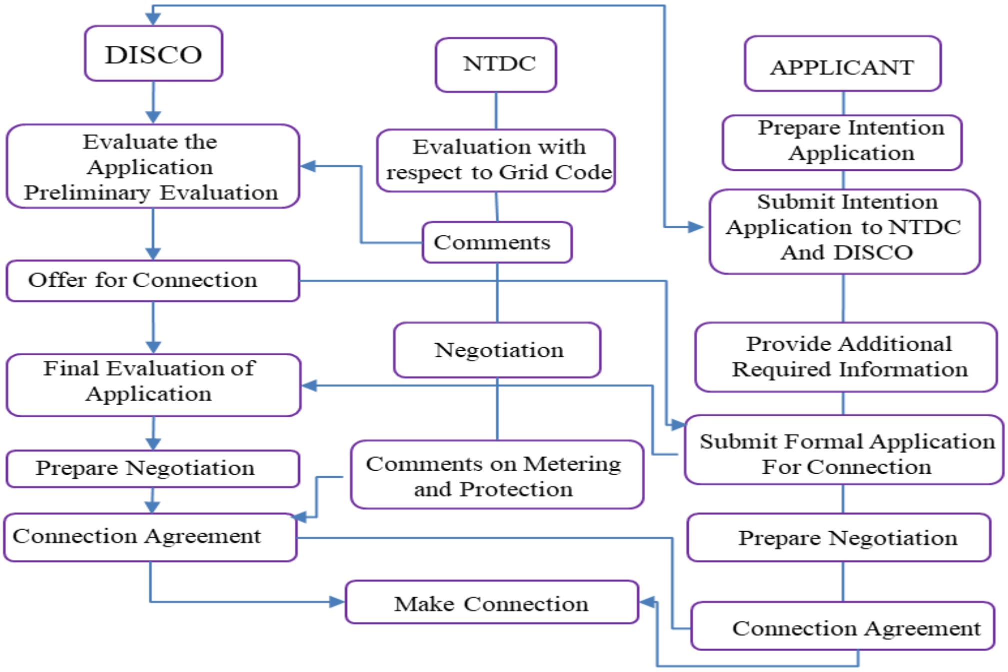

Figure 9. The Connection Agreement, Connection Agreement NEPRA Energy Wheeling Agreement (Schedule II) [83].

The BPC will be responsible to pay the generation cost (running cost) and the wheeling cost. The wheeling policy establishes mutual coordination link between DISCO and BPCs ensuring no load on a specific grid code by DISCO without prior consultation with the BPC otherwise strict action could be taken by BPC under the law. The Wheeling meters are sealed in presence of the representatives of both parties. In the case of maintenance, the representatives of both parties are present on site [84]. The BPC will be responsible to pay the generation cost and the wheeling cost. Due to the EW policy, the uninterrupted power supply is provided to the BPC which is essential for business activities. The EW policy ensures the provision of inexpensive energy to the BPCs. By introducing these types of new policies, the firms are encouraged to invest in businesses available in their area.

Applications and Challenges Associated with EW Policy

As for as, the concern of the economy of a country, the industry is considered its backbone. Energy is the primary mover for industrialization in the country. So, the country should have an adequate amount of energy generation capacity so that its industrial wheel would move smoothly. EW policy enables to ensure the uninterrupted supply of energy to the industrial sector. Pakistan is already investing a huge amount in the form of subsidies to provide cheap and uninterrupted energy to the industrial sector. It would result in sustainability in industrial growth by providing cheap energy wheeled through remote areas to BPCs. This is directly associated with the economic sustainability of the country.

Many issues and problems arise due to EW policy. These involve legislation, maintenance, tariff charges and power quality challenges. The power quality is mainly affected by losses in long-distance transmission. According to the policy, the power is to transmit over long distances through transmission and distribution networks, therefore, transmission losses such as copper losses etc. are expected to be increased. To prevent these losses the transmission and distribution companies should adopt modern techniques [85]. The transmission and distribution companies have assigned the predetermined tolerance value of power; in case of violation, a code of conduct applies to the stakeholders. The other power quality issues are harmonics due to switching and natural disasters. These harmonics can be controlled using modern digital meters [86].

2.5. Distributed Generation/Net Metering Policy, 2015

To increase energy in the national grid, new power plants must be constructed, and new energy conservation and management policies must be defined; one of these policies is NMP. NEPRA introduced distributed generation and net metering rules in 2015 as shown in Figure 10, called "National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015". In addition to some general rules such as registration & application process, it also describes the mechanism of interconnection between DGs and DISCOs, facility design and protection requirements along with details of financial responsibilities. It also specifies permissible variation of ±1% and ±5% to the nominal frequency and voltage, respectively. According to these rules, a single meter or two separate meters should be installed to accomplish the net metering operation. However, the condition of accurate measurement is imposed in either case. Distributed Generators are also responsible to ensure all safety requirements to assure reliable operation of the system. The flow of billing follows the "as much produced as much earned" policy. If Distributed Generator consumes more kWh and supplies less to DISCO, then it would be charged by the DISCO and vice versa. Importantly DISCOs would pay off-peak rates of kWh for excess supply from distributed generators. They would also enjoy exemption from fuel price adjustment, fixed & peak time charges and duties/levies. Minor amendments to these regulations have been introduced in net metering amendments 2017.

This policy enables the users to become prosumers (power producers and consumers) and supplies the two-way flow of energy between the DISCOs and the consumers [85,87]. Prosumerism can only be achieved by distributed generation, i.e., generating own energy through RES and luckily Pakistan is rich in these resources as stated earlier [88]. The most important aspect of the connection between DISCOs and the national grid is the points where the energy consumed by the consumers from the national grid and the energy given to the national grid by consumers are monitored and compensated utilizing advanced smart meters [89]. At the end of the month, the tariff is finally calculated and formulated accordingly [90]. Furthermore, Net Metering can be implemented in different typologies including Net Metering, Aggregate Net Metering, and Virtual Net Metering [91]. However, when a community collectively generates energy from renewable resources and supplies it to the national grid through net metering is known as Community Net Metering and when any private firm or any other organization generates energy from renewables in aggregate form and supplies it to the national grid by mean of net metering is known as Aggregate Net Metering while if it produced virtually from any resource, like the parallel connection of the car batteries for time being, is known as Virtual Net Metering [92].

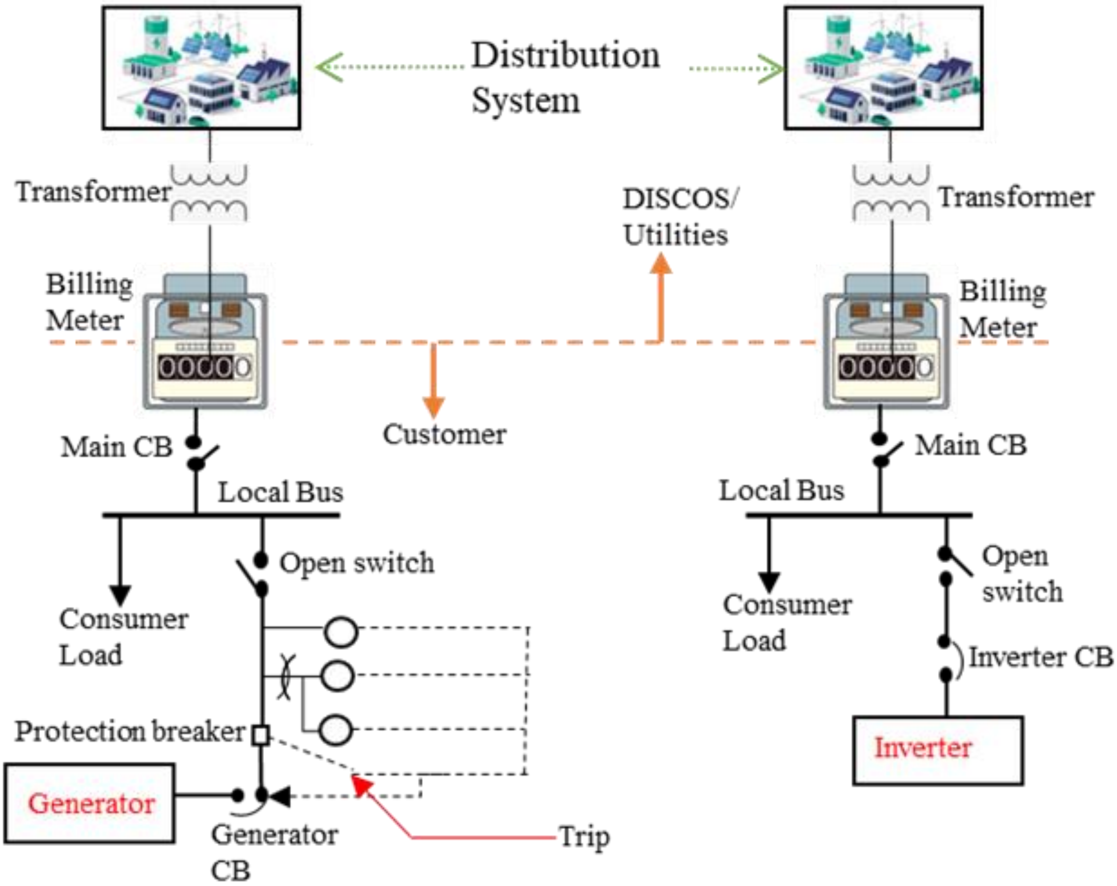

Figure 10. The Topology of distribution systems and Net Metering Concept draft [90].

NMP Issues and Recommendations

Despite the inception of NMP in 2015 by the NEPRA, it is still struggling for its effective implementation in the country due to some associated issues. The main issue is the synchronization of the power provided by consumers with the national grid. The distributed generation and the DISCOs have different frequencies, voltage levels, phase differences, phase angles and reactive power [93]. To attain synchronization, all characteristics should be the same; the quality of power and voltage level can be improved by providing reactive power to the system by adding capacitor banks as condensers. Among other issues, the most discouraging factor is the initial processing time consumed in the application approval. Standards defined by NEPRA in Net Metering Regulation 2015 for equipment compatibility are impractical and ambiguous especially since the provision of “other international standards” in the regulation has worsened the situation. The regulation also impedes the single-phase consumers from this opportunity, limited to the three-phase consumers only. The undefined interconnection charges, unskilled workers, lack of proper forum to facilitate the customers, safety issues, high initial installation cost, and efficiency and power quality issues of renewable energy generating equipment are some other aspects which are restricting the applicability of net metering. Application processing time based on the capacity of the system can trigger fast processing as 15, 45 and 60 days for capacity up to 20 kWp, 100 kWp and 1 MWp, respectively. Defining clear standard operating practices and standards equivalent to UL 1741, extension in agreement term from 03 to 10 years, specification of interconnection charges, trained staff, list of approved manufacturers for inverters, incentives for bidirectional meter manufacturers and exemption from daytime load shedding for feeders connected with net metering are some recommendations to promote NMP implementation in the country.

2.6. Energy Import Policy 2017

NEPRA has added some regulations in the Electric Power Act, of 1997 to define its energy import policy, 2017. These regulations are officially known as the "National Electric Power Regulatory Authority (Import of Electric Power) Regulations, 2017". Initially, the policy puts a bound on the seller to have a generation facility in the regions of Gilgit Baltistan, Azad Jammu and Kashmir, a territory where the Act is not applicable and/or in a foreign country. However, this restriction was limited to only a territory where the Act is not applicable following the corrigendum issued by NEPRA a month later. The buyer, which would be a distribution company or a market operator, is obliged to sign a Power Purchase Agreement (PPA) with the seller by declaring some definite aspects such as duration of purchase, starting date of operation, energy demand to be met, and, most importantly, any modification required in the existing infrastructure etc. NEPRA has also applied strict limits on any change in the tariff rates and terms & conditions once the PPA is signed between the parties. Moreover, the agreed rates and terms & conditions after getting approval from the authority would be forwarded to the Federal Government to notify the official Gazette [94].

2.7. Internet of Things (IoT) Integration in Hybrid Microgrid

IoT smart energy management intends to significantly improve energy efficiency through energy information gathering, energy distribution management, and energy sharing/trading by developing IoT-based smart energy platform technology. To this end, IoT smart energy management services provide services for increasing energy efficiency as well as for sharing and selling energy through the connection and integration of energy supply–transfer–utilization energy systems using the Internet of Things technology. Several smart devices efficiently linked to a power grid, including next-generation meters, also known as smart meters. These devices collect information from the electrical grid and connect to other hardware and distant software entities through the Internet by utilizing IoT features. The resulting Advanced Metering Infrastructure offers several characteristics that any energy market player can select from (AMI).

For example, Distribution System Operators (DSOs) may use smart meters to increase the efficacy, capacity, and dependability of the distribution network. Smart meters can help retailers anticipate changes in network load and create the right demand–response strategies. Consumers may use smart meters to manage their energy usage and production, which is extremely variable owing to the intermittent nature of renewable energy sources and to lower the price of their power bill.

2.8. Energy Efficiency and Conservation Act, 2016

Energy management and conservation have remained a key consideration during the last few years. The Government of Pakistan has also passed an act in this regard, officially called as "National Energy Efficiency and Conservation Act, 2016". The act defines a mechanism to carry out efficient energy use and its effective conservation. It also legalizes the establishment of new institutions/organizations following rules and regulations which address the energy issues. Pakistan Energy Efficiency and Conservation Board and the national Energy Efficiency and Conservation Authority are two such bodies proposed to be established under this act. The board supervises and manages the initiatives taken by the authority. It also approves the policy direction specified by the authority for the purpose. The board has the power of establishing suborganizations for carrying out various associated functions such as project management, certification of energy-efficient products, technology development etc. The authority serves as a building block to implementing and coordinating energy conservation initiatives all over the country. Enforcement of the provisions of the Act, upgradation/recommendations in energy policy, initiatives for research and development in support of the purpose, defining procedures to monitor, inspect and audit any irregularities seen in the efficient use of energy and recommendation of appropriate measures are some responsibilities of the authority. The

Act has also made the Federal Government responsible to define standards for equipment manufacturing, processing, and energy consumption to avoid unnecessary waste of energy. It also bans the manufacture or import of appliances violating the defined standards. The Act appreciates and encourages the consumers who have adopted energy-saving measurements by awarding certificates issued by the Federal Government. National Energy Conservation Centre initially working as an independent organization is given the status of National Energy Efficiency and Conservation Authority under this act. Various other topics such as the power of provincial governments, power to inspect & exempt, mechanism of investigation, inquiry and energy audit, imposition of fine and energy conservation tribunals are also described in detail in the Act [95].

3. Energy Policies in Other Countries

This section elaborates on a few comparative aspects of some energy policies of other countries. Electrical energy demand in the world's most populated and the biggest energy-consuming country, China, is primarily met by coal and natural gas before the introduction of RE policies in the country. To meet energy poverty, especially in rural areas, the country introduced its first RE policy in 1980 incentivized by a 50% subsidy on all RE projects in the coming years. The country aims to achieve a benchmark success to lower coal consumption (from 58% to 32%) and increase RE utilization (from 35% to 57%) for the period, 2016–2040 [96]. NMP, in China, has been implemented since 2011 under the umbrella of Feed-in-Tariff schemes developed to strengthen renewable energy development in the country. With the considerable gain in the initially targeted sustainable energy development in 2014, China signed 'Renewable Energy Technology Transfer (RETT)' with different countries of Africa suffering energy scarcity and unstable power supply [97].

South Africa (SA) heavily relies on fossil fuels for its electricity generation and recently the country has adopted semi decentralized distribution system. SA faced an increasing electricity demand–supply gap in 2007, consequently, the country decided to move towards NMP and installed its first system in 2013. Later, this policy has been successfully implemented by 34 out of 164 distribution companies by the end of 2017.

India, being the third largest producer and the fourth largest consumer of electricity in the world, relies primarily on thermal sources for its electricity generation. By 2006, India has introduced National Tariff Policy with a special focus to increase RE share in its energy mix. As a result, the country has achieved a 20% of the total generation by the end of 2018 [98]. The country motivated its inhabitants towards NMP with zero electricity duty charges. The excess generation is utilized by DISCO and after one year the consumers are incentivized according to the preset tariff defined by State Electricity Regulation Commission.

The Philippines, being a progressive nation with an ambitious target of adopting sustainable energy, has introduced NMP since 2013. The Government of the Philippines made it obligatory for each distribution company to add a minimum 1% share of renewable energy by 2019. The prosumers in the country are paid for excess generation based on the average generation. Readers are encouraged to see [1] for detailed insight into the energy sector situation of developing countries.

Important to note that when NMP is being implemented almost all over the world from high-income countries such as the USA, Canada, Australia and many others as given in [99] to low middle and low-income countries such as the Philippines, Pakistan and Senegal, it was unacceptable for Benin and Burkina Faso in Western Africa. These African countries are facing an energy situation similar to Pakistan, i.e., increasing supply and demand gap, reliance on petroleum products and import of electricity from neighboring countries. The introduction and implementation of NMP and EW in Pakistan could inspire these countries and others with similar energy scenarios to adopt the technology and get benefitted once the distributed generation adds additional kWh in the system with net profit to the prosumers. In addition, Pakistan is emerging as a fast-developing nation in South Asia after signing CPEC with China, the steps taken by Pakistan to improve its energy sector could attract and drive policymakers, energy managers and researchers from under-developed nations to look at and take the similar initiatives for their betterment.

Comparative Study of Innovative Smart Grid Policies around the World

To provide a thorough review of the Smart Energy scenario, this study primarily addresses four key areas: technical development, community activities, regulatory rules, and the economic situation/business perspective of the country. For each of the four categories under examination, this work basically gathers and perform a comprehensive analysis of the relevant data. The countries that are considered are Australia, Brazil, China, and Sweden. These countries were selected to provide a global view on the advancement of smart energy, taking into consideration developed (Australia and Sweden), emerging (China and Brazil), and other countries from across the world (Europe, Asia, Latin America and Oceania). The goal of gathering this data is to understand how developed the Smart Energy industry is in these four countries and any possible effects on business expansion.

Analyzing the technical development element will take into account two distinct factors:

(a) Introducing smart meters concerning the energy sectors in country Pakistan
(b) The proportion of smart meters deployed in different areas

The following list includes five kinds of relevant pilot projects regarding smart grid implement in different countries:

- The smart metering pilot project consists of projects that are specifically focused on the implementation of smart meters.
- Pilot projects involving integrated systems. Focuses on the fusion of several Smart Grid applications and technologies, including smart metering and substation automation initiatives.
- Home application pilot projects are programmers' that concentrate on cutting-edge home applications or directly engage users.
- Pilot programmers for automation in transmission and distribution. Refer to projects concerned with improving the automation of the electrical grid at the transmission and distribution levels.
- Lead projects for others. Describe projects that are not specifically focused on the Smart Grid but that test one or more capabilities connected to Smart Grid technology or services. Examples of this kind of project include those involving smart cities, renewable energy, or electric automobiles.

The framework that was first designed by the EU-US Council and the Virginia Tech Clearing House serves as the foundation for classifying applicable smart grid pilot projects. The US Department of Energy and the JRC (Joint Research Center- European Commission) are collaborating to provide standard evaluation procedures for smart grids as part of this program. Table 3 mainly only includes activities that are connected to the Smart Grid and are featured in the "Smart Grid 2013 Global Impact Report." [100,101].

Table 3. A comparative study of country-wise implemented Smart Grid Innovation.

Smart Grid Innovation	Australia	Sweden	Brazil	China
Installed smart Meter	23%	100%	75%	27%
Na Pilot Projects	12	5	12	11
Pilots Projects on Smart Meter	2	0	6	3
Pilots Project on Integrated systems	2	4	6	2
Pilots project on home application	1	0	0	0
Pilot project on transmission and distribution automation	0	0	0	4
Pilot project in other areas	7	1	0	2

Australia: Victoria State has fully installed smart meters, although the rest of the nation has only embraced them to a 23% penetration level. The successful completion of pilot programs demonstrates the growth of smart meters as well as interest in initiatives involving renewable energy, particularly solar electricity [102].

Sweden: despite being one of the early adopters of the Smart Grid, the nation wishes to maintain its status as a pioneer in the sector. The energy market in Sweden is developed, and the country's citizens care about the environment and the use of renewable energy sources. In Sweden, smart meters are already in use, and a second generation is under consideration. The completed pilot projects demonstrate how the nation is emphasizing testing integrated systems rather than only individual Smart Grid components [103].

Brazil: Only 7.5% of residences were expected to get smart meters by the end of 2014, and only 75.3% of homes will have them by the year 2030. This shows the enormous potential of Brazil, the work that still has to be done in the future, and the country's limited adoption of Smart Grid technology. Brazil is focusing on smart metering in particular for its pilot projects since one of the objectives is to stop fraud in the electrical grid. The finished pilot projects show that Brazil's smart grid is still under development and has a substantial commercial potential [104].

China: SGCC (State Grid Cooperation of China) is now deploying smart meters in large quantities throughout China, with a current deployment rate of 27% (Siemens). The issues China has while using its power grid are reflected in the pilot projects' unique activity and leadership in the field of transmission and distribution automation. Improving Transmission and Distribution efficiency and control is a clear priority for China's Power Grid since it is experiencing difficulties expanding at the same rate as the sector.

4. Conclusions and Policy Implications

The economic stability of any country is dependent on reliable energy supplies. In this paper, we have presented the EWP, EIP, NMP and EECA policies of Pakistan in the context of dynamic energy management. We have also compared a few energy policy aspects with some other countries. The EWP and NMP have been introduced much later as compared to the advanced countries; however, these policies could prove beneficial for meeting energy demand and facilitating the industrial sector with cheaper supplies. The EWP provides opportunities for industrial users to wheel the cheaper electricity to the load centers, however, the enhancement of the transmission network is necessary to accommodate the EWP users. As the existing transmission network is overloaded; consists of outdated infrastructure and causes many faults and outages in the system. It could only be possible when the policies are being followed so that uninterrupted and relatively inexpensive energy could be supplied to the consumers. The NMP enables the system more dynamic and resilient toward the consumption and production of energy. The NMP will help in the transformation of the mono-policy market into a competitive market. In addition, it will encourage microgeneration and promote renewables. It might mitigate the energy demand by adding the distributed generations to the national grid. EIP defines the rules for energy import guidelines from foreign countries. Energy import will be helpful as a short-term solution to the energy crisis. EECA provides the necessary guidelines for standardization and measures for energy efficiency and conservation.

There are the following recommendations regarding these nascent energy policies for developing countries like Pakistan for meticulous demand side management and smart grid management,

- The application of EW and NMP requires a robust control system to ensure quick decisions for energy transfer. It encourages technology advancement in terms of batteries for DGs in particular and sophisticated protection devices in general. Therefore, the implication of EW and NMP in Pakistan opens doors for international competitors.
- Further, the primary advantage of energy security and saving of EW and NMP invites the international community to opt for the policy especially the South Asian Countries where continuous energy supply is still a dream.

- In addition, energy wheeling technique provides investor certainty linked with the cost of transferring power using the existing transmission network which attracts international investors ultimately.
- Lastly, the geographical location of Pakistan strengthened by the development of the China-Pakistan Economic Corridor and The Persian Gulf and Pars Gas Field along with the practice of EW and NMP makes it the best choice for foreign investors to install and promote DGs [105,106].
- The general lessons learned from these policies in Pakistan are: (a) Value of excess energy: Excess energy fed to the DISCOs is compensated for each kWh. (b) Impact on consumer: the consumer receives compensation for each kWh injected into the system based on the off-peak tariff defined by NEPRA. Payback time varies from 5–8 years to 7–10 years depending on the nature of consumers. (c) Impact on distributor: DISCOs are benefitted in paying consumers for energy exported at reduced rates, i.e., off-peak rates irrespective of the fact energy is fed to the DISCOs at peak or off-peak hours.

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