TECHNO-ECONOMIC ANALYSIS OF WIDESPREAD MICROGRID/MINIGRID (MG) DEPLOYMENT IN PAKISTAN'S ELECTRICAL POWER SECTOR

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ABSTRACT

The Government of Pakistan has taken appreciable initiatives in the Electrical Power Sector which is undergoing an extensive reform and restructuring process, especially in the fields of de-carbonization and deregulation. However, a significant percentage of population is yet to be electrified in Pakistan though the country has been bestowed with huge natural energy resources. Due to various reasons such as limited financial resources, scattered population, etc., expansion of centralized grid is not economically viable in most of the remote unelectrified locations. In this regard, Micro/Mini Grids deployment offer an excellent opportunity to address this problem and to improve the life quality of people of Pakistan and complement the economy thereof. The study is based on simulation and analysis based research methods, wherein the techno-economic evaluation is performed for the potential regions of Pakistan modelled with their associated characteristics.

As per the study findings, Renewable Energy dominated Micro/Mini Grids presents much more financial viability as compared to fossil-fuel based Micro/Mini Grids, which will also help in reducing detrimental effects on the environment. At the same time, they offer a lucrative investment opportunity for the investors. Although Micro/Mini Grids present a very cost-effective solution for remote unelectrified areas of Pakistan, however, they may face technical issues if not properly designed. Direct Current Micro/Mini Grids and the application of Micro/Mini Grids for irrigation purposes present interesting cases, reducing the overall cost of energy. Some of the important factors to be considered to evaluate the feasibility of Micro/Mini Grids are electricity demand pattern, supply reliability requirement, discount rate and the project lifetime.

There is an urgent need of dedicated and comprehensive policy and regulatory framework, since the existing one is insufficient to effectively upscale Micro/Mini Grids deployment in Pakistan. While assessing electricity provision options for remote unelectrified areas of Pakistan, it is imperative for the electricity planners to consider and evaluate Micro/Mini Grids before proposing huge investments for transmission and distribution infrastructure. One of the important considerations is to align the design of Micro/Mini Grids with the affordability of the customers in the specific geographical area, to create a win-win situation for all the stakeholders.

PREFACE

The study has been performed under Pakistan Institute of Development Economics (PIDE) initiative i.e., 'Research for Social Transformation and Advancement' (RASTA) which encompasses policy-oriented research program in Pakistan under the Public Sector Development Program (PSDP) of the Ministry of Planning, Development and Special Initiatives, the Government of Pakistan. RASTA's mission is to develop high-quality, evidence-based policy research to inform Pakistan's public policy process. The study is mandated to make recommendations to sensitize the decision makers about the policy initiatives meant to attract the investors and other stakeholders aiming at widespread deployment of Micro/Mini Grids in Pakistan which will pave the way for enhancing the electricity access to the people of Pakistan mostly without burdening the national grid and thus launching development activities particularly in the remote areas through local coordination. This study facilitates a win-win situation for the federal as well as provincial/territorial governments since it is likely to offset the demand on the national grid and at the same time trigger widespread development of micro/mini grids under the geographical domain of provincial/territorial governments.

The final report consists of several sections that discuss various aspects for techno-economic analysis of MGs in Pakistan. In the first chapter, the current situation of the power sector of Pakistan has been discussed along with an explanation of the rationale for deploymentof Micro/Mini Grids. The second chapter throws light on the research methodology followed. Techno-economic and technical analyses have been presented in Chapter 3 and 4 respectively. Similarly, policy and regulatory framework and business models are investigated in Chapter 5 and 6 respectively. Last but not the least, the conclusion and recommendations are presented in Chapter 7.

During the whole study, the study team faced a lot of challenges for carrying it out especially for the data collection activity. We would like to thank RASTA CGP for providing this opportunity and supporting the research project throughout the course of the study. We are also grateful to our mentors, their support and guidance helped a lot to successfully complete this work. We extend gratitude to our colleagues and friends as well for their suggestions, time and valuable input. We hope this work will serve as an initial step towards the destination of providing affordable, sustainable and reliable power supply to every citizen of our country.

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LIST OF ABBREVIATIONS

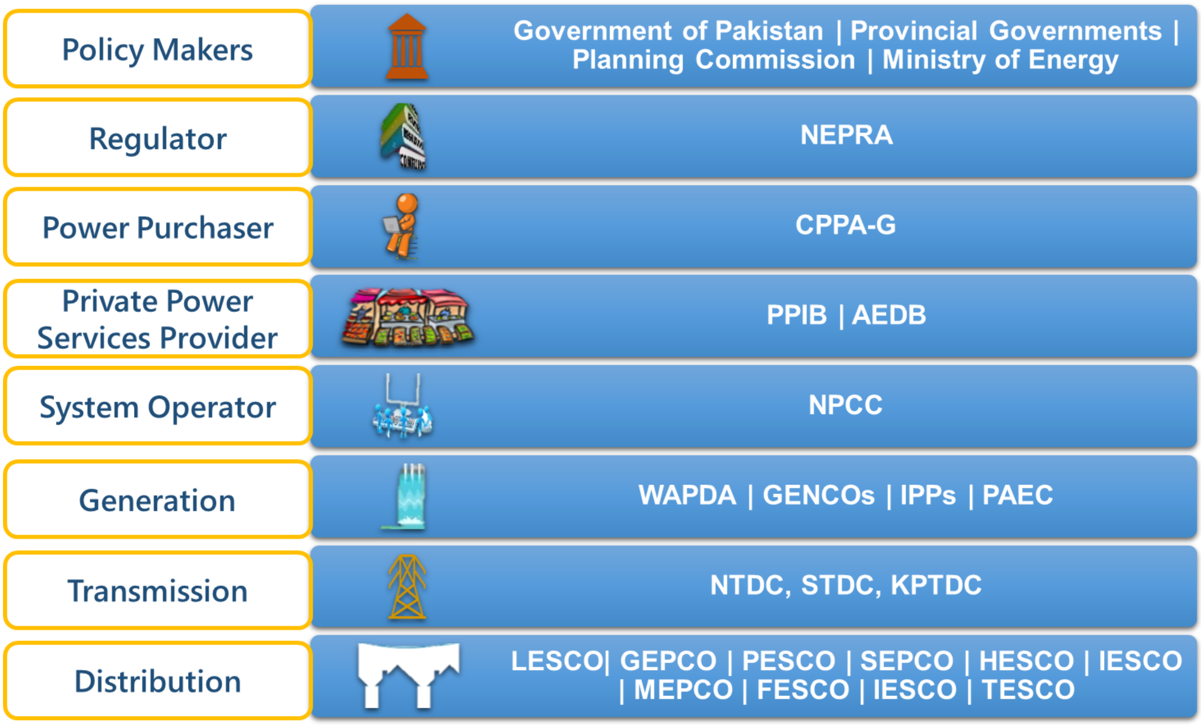
AC	Alternating Current
AEDB	Alternative Energy Development Board
ARE	Alternative and Renewable Energy
CAPEC	Capital Expenses
CBO	Community Based Organizations
CL	Current Limiters
CoE	Cost of Energy
CPPA	Central Power Purchasing Agency
CTBCM	Competitive Trading Bilateral Contract Market
DC	Direct Current
DER	Distributed Energy Resources
DISCO	Distribution Company
ESCO	Energy Supply Companies
GoP	Government of Pakistan
IFI	International Financial Institutions
IPP	Independent Power Plants/Producers
kV	Kilo Volt
kWh	Kilo Watt Hour
LCoE	Levelized Cost of Energy
MG	Micro/Mini Grids
MW	Mega Watt
NPC	Net Present Cost
NEPRA	National Electric Power Regulatory Authority
OPEX	Operating Expenses
NTDC	National Transmission & Despatch Company
PPPA	Power Purchase Agreement
PKR	Pakistani Rupees
NPCC	National Power Control Center
RE	Renewable Energy
WAPDA	Water and Power Development Authority

INTRODUCTION TO POWER SECTOR OF PAKISTAN

1.1 Introduction

The present power structure comprises of the top-down regulated structure with the policy makers i.e., Ministry of Energy, Power Division at the top, however, being intricate and having the ramifications across other sectors of the economy as well, the decision-making process involves other Ministries along with highest forums of the Government. Complete structure of the power sector is shown in the Figure 1.

Figure 1: Existing Structure of Power Sector



An independent regulator, National Electric Power Regulatory Authority (NEPRA) is functioning since late nineties to ensure that the rights of investors, public companies and consumers are protected. The existing power sector operates on a single buyer model i.e. electric power is procured from the Generation companies for the Distribution companies through a single entity which is the Central Power Purchase Agency (CPPA-G), the Power Purchaser of the sector.

Prior to procurement of electric power from the Generation companies, there is a comprehensive process for entry into the electricity market of Pakistan along with development of a power project. This requires support to private companies who are prospective participants for the regulated market. These services are provided by Private Power Infrastructure Board (PPIB) for the conventional thermal and hydro projects and Alternative Energy Development Board (AEDB) for the renewable projects.

Electric power is generated from generation facilities of WAPDA, Thermal Generation Companies

(GENCOs), Pakistan Atomic Energy Commission (PAEC) and Independent Power Producers (IPPs). This power is transmitted through high voltage transmission network of National Transmission and Despatch Company (NTDC) and it is distributed among the Consumers through the distribution network of Distribution Companies (DISCOs). The system operations of the power sector are managed at the National Power Control Center (NPCC) by NTDC.

Among the power sector stakeholders, K-Electric is a vertically integrated utility which performs functions of generation, transmission, distribution, regional system operator and private power services provider in Karachi region.

Future Electricity Market

The regulated structure is coming to an end since NEPRA has recently approved the Competitive Trading Bilateral Contract Market (CTBCM) model and plan to deregulate the power sector. CTBCM is set to introduce a de-regulated framework in Pakistan power sector enabling wholesale purchases of electricity through bilateral contracts.

Electricity is a commodity capable of being bought, sold and traded. In a mature electricity market, bids and offers use supply and demand principles to set the price. Additionally, there may exist long-term contracts similar to power purchase agreements as well as bilateral transactions between generators and bulk power consumers.

First phase of the CTBCM is envisaged to begin wholesale trade of electricity through bilateral contracts between generators and wholesale electricity consumers either directly or through traders.

With such radical transition set to place in a couple of months, the purpose of competitive market of electricity in Pakistan is to achieve the following:

1. Optimize basket price of electricity
2. Create the conditions to attract investments
3. Introduce competition to enhance efficiency in the power system
4. Ensure accountability, transparency and open access to information
5. Maximize the economic benefits of available resources and promote efficiency Implementation of the action items as per approved CTBCM model and plan is in full swing. Commercial Operation Date of CTBCM is 1st May 2022.

The New Age

In pursuit of energy access and low cost of sustainable energy, the new age of the power sector of Pakistan demands salvation from the integrated grid due to its inefficient and unsustainable nature – yielding high cost of electricity to the consumers – CTBCM is the beginning of the decentralization of power sector in Pakistan. However, Micro Grids/Mini Grids (MGs) fit in the jigsaw of decentralized power sector with respect to sustainable, low cost, energy access to the consumers of electricity promising more value for money. MGs are gradually taking the center stage in the future outlook of power sector, both in Pakistan and globally.

1.2 Rationale for MG Development

MG is a small network of electricity users with local energy resources (mostly renewables or hybrid) of generation along with storage that can function independently as well as in connection with the grid. Globally, the size of MGs ranges from 1 kW to 10 MW.

Significant percentage of population is yet to be electrified in Pakistan whereas the country has been bestowed with huge natural energy resources geographically spread throughout the land. Due to various reasons such as limited financial resources, scattered population/electricity demand (particularly in Baluchistan), expansion of national/DISCO grid is not economically viable in most of the so far unelectrified locations. MGs offer huge opportunities with respect to improving the life quality of people of Pakistan and complementing the economy thereof. Fortunately, unstructured efforts have already been started in the country and globally MGs have become a mainstream solution for achieving energy access for all. It is, therefore, inevitable to upscale the setting up of MGs throughout the country, where required and of course potentially possible. Following are some of the important drivers to upscale MGs for providing energy access at low cost to the people of Pakistan:

1. Sharp sustained increasing trend of end-consumer tariff
2. Large number of unelectrified areas in Pakistan not expected to be electrified in near future
3. Decreasing cost trend of MGs deployment due to significant reduction in individual component cost of MGs like converters, solar PV panels, wind turbines, etc.
4. Availability of huge potential of renewable energy resources like solar, wind, hydro, etc.
5. Substantial number of areas in Pakistan having difficult terrain making grid access difficult
6. Detrimental environment impacts being faced by Pakistan in recent years due to extensive share of conventional fuels for electricity generation, usage of other inefficient fuels due tolack of generation adequacy
7. Hampering of economic development due to lack of electricity access in remote areas
8. Prevailing supply unreliability for remote areas

The Government of Pakistan (GoP) has promulgated the National Electricity Policy in 2021 which stresses out clearly the sustainability of electrical power sector in Pakistan. It means GoP has decided to pass electricity prices in full to end-consumers by withdrawing subsidies, contrary to other developing nations of the world. The policy direction for sustainability in Pakistan's electricity sector will have considerable implications on the people of Pakistan who are already paying very high per unit tariff for electricity consumption.

Considering the internal report of one of the credible institutions of Pakistan's power sector (it is an internal working report and is expected to be publicized soon), the existing average tariff i.e. Rs.14.85/kWh is forecasted to be Rs.24.28/kWh in the year 2030 excluding taxes. This forecast is based on certain optimistic assumptions of factors as listed below; variation in these factors may significantly increase the forecasted end-user tariff.

1. Rising trend of inefficiencies in the integrated electrical grid
2. Continuing trend of incurring Sunk Cost of committed power projects

3. Introduction of CTBCM and great probability of increase in end-user tariff due to market power, inexperience, increase in Stranded Costs, etc.
4. Sharp currency devaluation
5. Increase in Fuel Prices, etc.

Considering above mentioned factors and GoP target of sustainability in the electricity power sector, people of Pakistan, who can afford substantial investment, have already started opting for stand-alone roof-top solar PV with and without net-metering provision. Major drawback of standalone PV is the unavailability of solar power during the late evening/night time as well as supply reliability during rain or bad weather. MGs thus provide a more complete solution to cater the issues of higher costs and supply reliability.

Off-grid MG deployment for remote rural areas is a globally accepted solution. Feasibility of MG deployment for various scenarios have been analyzed in detail for this study. However, it is important to mention here that there are certain challenges with respect to MG design, development and implementation which need to be addressed for the successful implementation of MG in Pakistan. These challenges are discussed in this study along with the proposed remedial measures.

After the 18^{th} amendment in the Constitution of Pakistan, provincial governments can take decisions regarding generation, transmission and distribution of electricity in their respective service territories. Instead of following a strenuous and long process which includes red-taped project approval at centralized level and building extensive generation, transmission and distribution infrastructure, MG deployment is, nevertheless, a sustainable solution for the provincial/territorial governments in Pakistan.

The communities living in many far-flung areas have no electricity for approximately 16 hours a day, due to multiple reasons including theft, distribution system unreliability, etc. Reliability of supply, in regard to MGs development, is another important aspect which is technically explored through this study.

It is important to mention here that this study does not recommend deployment of MGs everywhere in Pakistan, rather, it indicates certain favorable factors, scenarios and applications where MG deployment stands far more promising as compared to other potential options. Few of the possible scenarios are:

1. Remote rural areas
2. Difficult terrain areas where grid access is difficult
3. Communities having rich mini/micro hydro potential
4. Areas having flexible load demand profiles (or can be easily adjusted)
5. Hospitals and military installations which cannot afford unreliability of supply
6. Housing Societies/Commercial Centres having Net metering provision
7. Communities/Areas where provincial/territorial governments want viable solution for provision of electricity other than national integrated grid

Since the study is mandated to analyze unconventional solutions for electricity related issues in Pakistan, hence it requires simulation-based techno-economic evaluation. Techno-economic evaluation is the key to finding most feasible solution to electrical energy related issues. For this purpose, HOMER (Hybrid Optimization of Multiple Energy Resources) Pro software has been used to present reliable results and findings. The study benchmarks and standardizes the analysis procedures to evaluate MG deployment.

One of the key motives to perform this analysis is to present the case for democratization of power sector in Pakistan. Every citizen of Pakistan has the right to receive electrical energy from the seller or opt for electrical energy related services of his choice, i.e., a utility, service provider, independent MG system, own means, etc. The study explores initiatives to start the journey, as a nation, towards the democratization of power sector. It may be highlighted that recent decision for incentivizing the ordinary customer by allowing Net-metering up to 25 kW without any formal license is an initial step towards democratization of power sector in Pakistan. One of the benefits of providing consumers with a choice for opting MG solution will be promotion of competition in the electricity market in Pakistan.

1.3 Research Questions

Following research questions have been derived for the purpose of this study:

1. Can MG be a possible solution to resolve the issues of unelectrified areas and expensive electricity rates? What are the possible application scenarios for MG development in Pakistan?
2. How to evaluate the feasibility of MG development in a particular area in Pakistan? What are the general technicalities involved in MG development in Pakistan?
3. What are the possible advantages/disadvantages of MGs in the context of Pakistan electricalpower sector? How can the policy and regulatory framework be utilized for successful widespread deployment of MGs in Pakistan?
4. What are the possible business models, in broader terms, for MGs deployment in Pakistan?What are the recommendations to decision makers to promote MGs in Pakistan?

1.4 Objectives of the Study

The objective of the study is to present a comprehensive analysis for the widespread deployment of MG systems in Pakistan. The study is carried out keeping in view the techno-economic and policy perspectives; its results will facilitate the policy makers in taking necessary initiatives for MGs development in Pakistan. Identification of business attractive models for MGs are also a part of this research work which will encourage various stakeholders in utilizing this cutting-edge technology to overcome the current challenges of Pakistan's power sector i.e., sustainability, affordability and reliability.

Power sector of Pakistan is already following the path of major restructuring in line with the globally well-established 3D reforms, i.e., Decarbonize, Decentralize and Democratize. The current reforms related to 'Decarbonize' and 'Decentralize' include the important steps of electrical vehicle policy, implementation of CTBCM and Alternative and Renewable Energy (ARE)

Policy 2019. This research work will pave the way for the very next step, which is 'Democratization' of power sector through deployment of MGs in the electrical power network of Pakistan.

For this purpose, potential application scenarios as well as locations are identified across Pakistan and their technical, economic and policy implications are analyzed. The significance as well as potential benefits of MGs in Pakistan's future energy policies are investigated. In addition to policy recommendations, technical solutions for issues associated with the interconnection/operation of on-grid and off-grid MGs, such as frequency control, voltage control, harmonics, stability issues, etc., are proposed specifically in the context of a weak electrical power network in rural/remote areas. Moreover, possible business models for MGs deployment in Pakistan are chalked out. The envisioned scope and output of the study makes it a win-win situation for the federal as well as provincial/territorial governments since it is likely to offset the demand on the national grid and trigger development of widespread MGs under the geographical domain of provincial/territorial governments.

METHODOLOGY

The study was carried out in a linear fashion, answering each research question and then moving forward to the next one. While answering each research question different research methodologies were employed.

Literature review and textual/content analysis were conducted to understand how MG has made a significant impact especially in the regions of South Asia and Africa. On the basis of these qualitative analyses, three possible scenarios were developed to understand the technical and commercial interactions of the MG with the power grid of Pakistan and prospective customers of MGs.

Data was collected to simulate three scenarios to evaluate the feasibility of MG development, and was validated using multiple sources. Data collection was conducted through survey questionnaire, interviews and site visits. In order to determine the feasibility and business viability of MGs for particular scenarios, techno-economic was carried out on HOMER-Pro, a dedicated optimization tool for MG analysis.

The study is predominately based on simulation and analysis based research methods. It means that the answers to the research problems have been found out through a mathematical model that represents the structure and dynamics of technical and economic processes of the subject under study which is MG in this case. The HOMER-Pro mathematical model is designed to handle complexities of building cost effective and reliable MG systems that may include elements like conventional generators, renewable energy resources, storage, load management, etc. Similarly, wide ranging data has been analyzed in this study to draw out conclusions. The analysis based research method allows to stay open and remain unbiased towards unexpected patterns, expressions, and results since the data used comprises of both qualitative and quantitative in nature.

Textual and content analysis of ARE Policy 2019, National Electricity Policy 2021, NEPRA (Microgrid) Regulations 2021 (draft) were carried out. Moreover, existing business models, being implemented in Pakistan were also considered. Interviews were conducted with concerned personnel from PEDO and PPDB, the executing agencies for MG in the provinces of KPK and Punjab respectively, and with the authors of the draft MG regulation from NEPRA. On the basis of results from the techno-economic analyses of three scenarios and interviews performed with the officers from the regulator and public-sector executing agencies, business models were proposed in this study.

The research processes, tools and techniques used during the study are briefly described below:

2.1 Data Collection

Numeric data was collected for the requisite analyses i.e., techno-economic analysis for this study. Depending upon the nature and necessity of data, various sources were selected for data collection i.e., relevant international /national publications, journals and reports. In addition to numeric data, qualitative data is used and also reported in this document.

Literature Review

To carry out techno-economic analysis, research papers pertaining to techno-economic analysis, energy modelling, renewable energy resources, grid resiliency, system stability and protection issues, etc. were studied. In addition to research papers, important policy documents were also studied i.e. ARE Policy 2019, National Electricity Policy 2021, IGCEP 2021 and NEPRA (Microgrid) Regulations 2021.

Survey

Data collection was performed through survey along with site visits (Site Visit report attached as Annexure-III). Questionnaire was distributed to the concerned provincial entities to obtain the specific/customized data particularly pertaining to our study (Questionnaire is presented in Annexure-I of this report).

Interviews

One to one correspondence was carried out with concerned persons/experts in relevant offices of PEDO, PPDB and NEPRA.

2.2 Techno-Economic Analysis

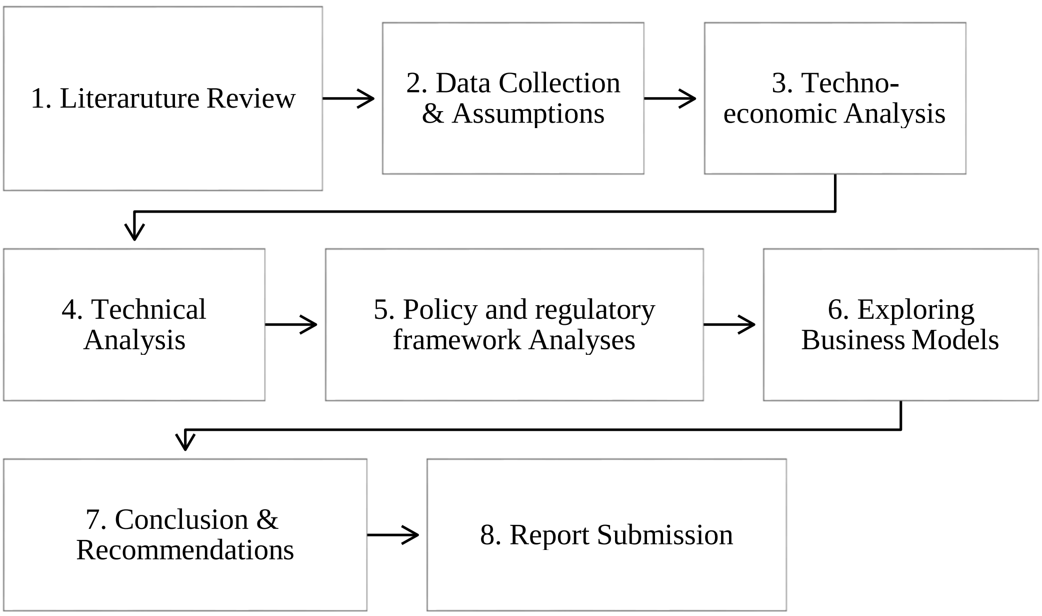
The techno-economic analysis was performed on HOMER-Pro hybrid optimization model. The three scenarios were analyzed on HOMER-Pro to find out the techno-commercial feasibility of the scenarios.

2.3 Textual Analysis

The case studies, policy instruments and regulatory documents were prudently analyzed to find coherence in their objectives, identify gaps and pointing out missing links while comparing them with international best practices.

The flowchart shown in Figure 2 describes in totality the research methodology followed during the study.

Figure 2: Research Methodology for the Study



MODELLING ANALYSIS, SIMULATION AND RESULTS

3.1 Introduction

This section explains the modelling of MG, its analysis and the findings of the simulations carried out for the purpose of this study. Techno-economic feasibility has been performed for both off-grid and the grid-connected applications of MGs. Homer-Pro modelling and simulation tool has been used to draw out the findings pertaining to the objectives of this study. Advance study comprising sensitivity analysis has been performed to further deliberate the discussed scenarios of applications. Special applications of MGs like Deferrable Load and Direct Current (DC) MGs are also analysed.

3.2 Techno-Economic Analysis

In this section, techno-economic modelling and simulations using HOMER-Pro Software tool is discussed; here the work is presented on how to evaluate the feasibility of MG development in a particular area of Pakistan.

Homer-Pro

The HOMER-Pro is a software used for optimizing MG design in various applications, from remote far-flung villages to grid-connected communities and campuses. It simplifies the task of evaluating designs for both off-grid and grid-connected power systems from both feasibility and design perspectives. For designing of a MG power system, following critical decision parameters about the configuration of the system arise:

1. Choosing the best combination of components/elements for the system
2. Selecting the required optimal number of each component/element along with most feasible size/rating of it.

A large number of technology options, variation in costs and availability of energy resources make these decisions quite complex. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate many possible system configurations and selecting the best option for a particular application/scenario/site (Homer Energy, 2021).

Considered Application Scenarios

Out of various possible options for widespread MGs deployment in Pakistan, following three most probable and feasible scenarios are designed for the pre-feasibility analysis under this study:

3. Off-grid MGs application for rural villages/areas having solar PV and wind potential
4. Off-grid MGs application for rural villages/areas having solar PV and micro-hydro potential
5. Grid-connected MGs application for housing societies or commercial centres in urban areashaving utility electricity access

Each scenario is discussed in the following section along with results/findings obtained usingHOMER-Pro software tool.

Basic assumptions for the whole study are tabulated in Tables 1 and 2.

Table 1: Basic Assumptions for Analysis

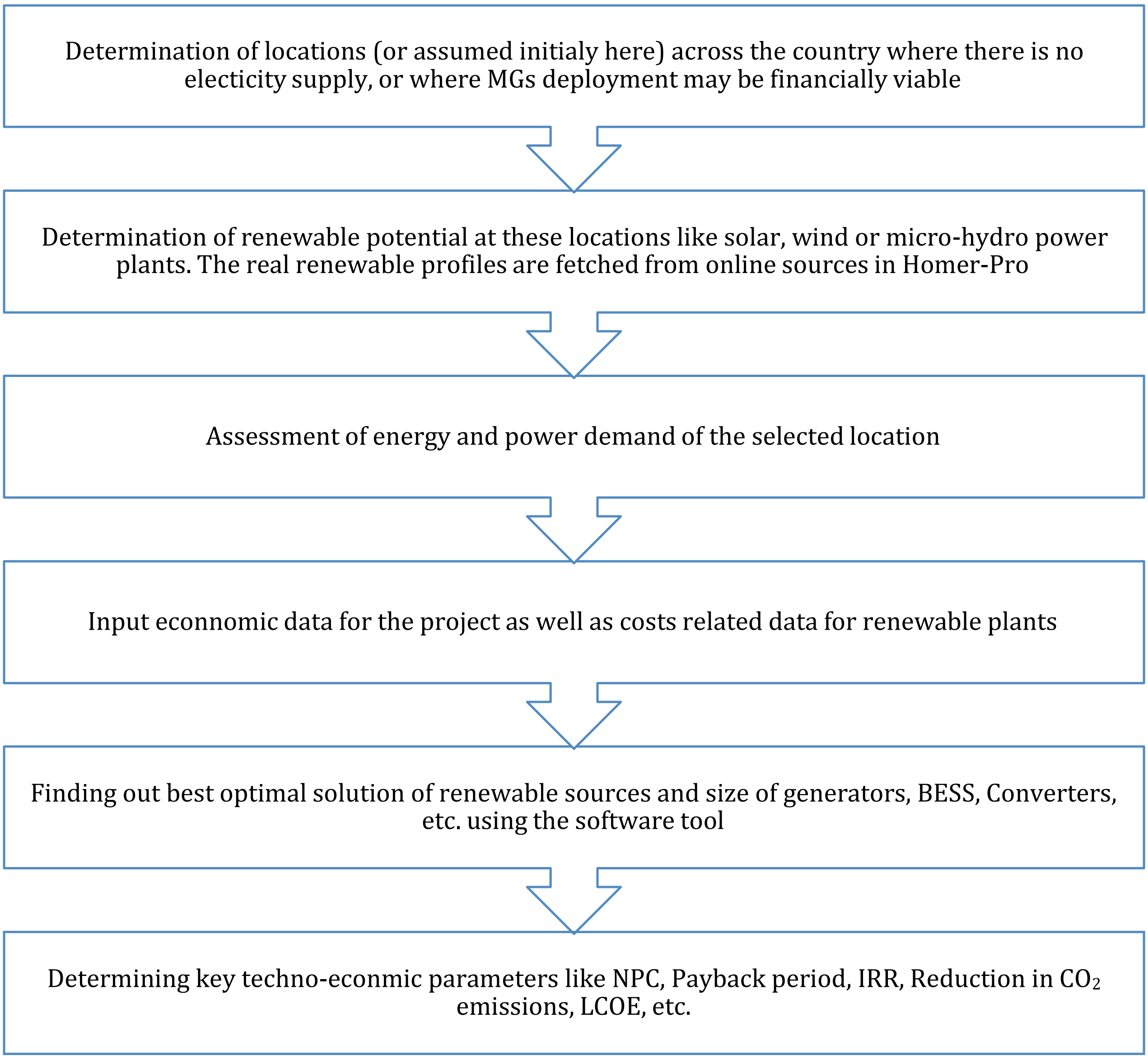
S.#	Parameters	Units	Values
1	Project Lifetime	years	30
2	Discount Rate	%	10
3	Inflation Rate for project Life	%	8
4	Fuel Price for Generator	$/litre	0.8
5	Operating reserve as percentage of hourly load	%	5
6	Operating reserve as percentage of peak load	%	0
7	Operating reserve as percentage of solar poweroutput	%	10
8	Operating reserve as percentage of wind poweroutput	%	10
9	Grid sale tariff	$/kWh	0.15

Table 2: Cost Assumptions for Analysis

S.#	Component	Initial Capital Cost ($/kW)	Replacemen tCost ($/kW)	O&M Cost ($/kW)	Lifetime (Years)
1	Solar PV	496	496	18.3	30
2	Wind Turbine	1,473	1,178	44.5	35
3	Battery Storage	350	280	20	10
4	Converter	600	300	3	15
5	Diesel Generator	500	500	0.03 ($/operating hour)	15,000 operatinghours
6	Micro-Hydro	2000	1000	80 ($/year)	40

It is important to mention here that considerations like the cost of distribution infrastructure, cost of land, profit margins, etc. are not considered for the scope of this study, which need to be taken care of while evaluating the feasibility of a particular project, as it may vary significantly from one case to another.

Figure 3: Approach Used for Techno-Economic Analysis

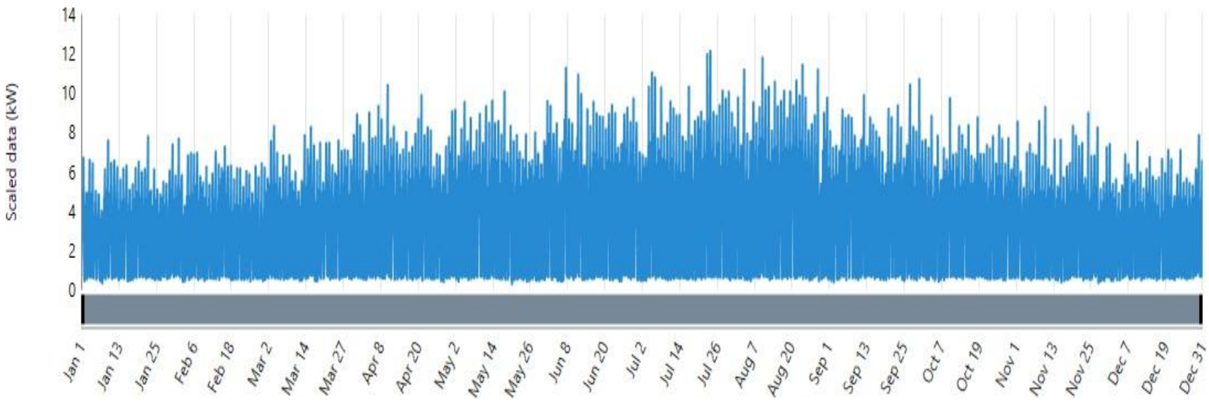


Following approach has been used to for the above-mentioned study:

Scenario 1: Off-Grid MGs Application for Rural Villages/Areas Having Solar PV and Wind Potential

This scenario is particularly important to analyze feasibility for remote rural populations havingsignificant distance from the utility grid connection. This situation is quite relevant in the scenario for Baluchistan, wherein large number of areas are still unelectrified and providing grid access tothose areas is difficult and does not hold financial viability. A village near Panjgur with geographical coordinates of 26°58.2'N, 64°5.3'E is considered. Following load profile is considered with peak load of 12.13 kW and annual average energy of 72 kWh/day.

Figure 4: Load Profile for Scenario 1



In order to meet this demand profile of electricity, the schematic as shown in Figure 5 has been modelled in the software with the option to optimize the selection and size of most feasible option considering the real solar and wind profiles from NASA database.

Figure 5: Schematic Diagram for Scenario 1

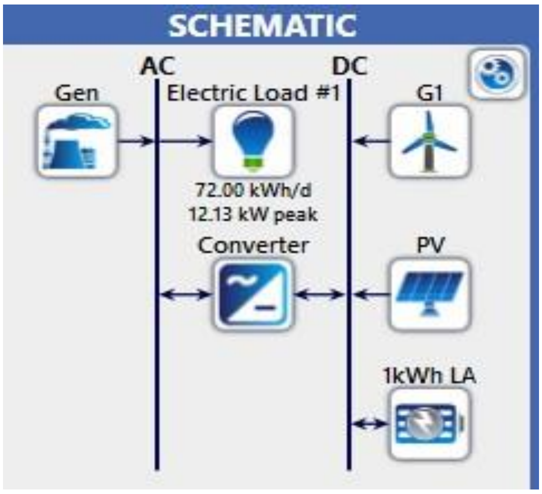


Figure 6: Wind Speed Data for Scenario 1

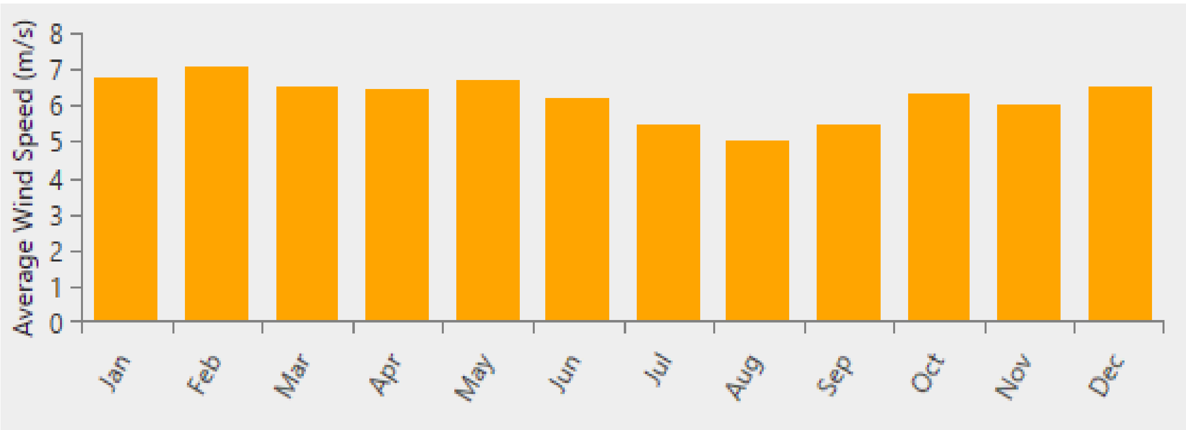
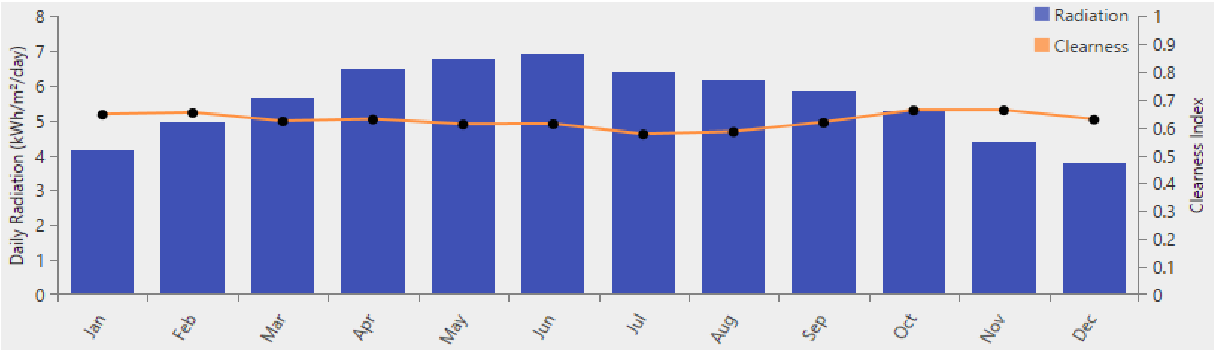


Figure 7: Wind Speed Data for Scenario 1



Different technology options are considered to determine the most feasible one for the MG, as listed in the Table 3 below:

Table 3: Considered Combinations for Scenario 1

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	**PV + Wind + Storage**
8	PV + Wind + Storage + Diesel Generator
9	PV + Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator

From the above different combinations, option # 7 is determined to be the most feasible one; the optimized size/rating for each component is provided in the Table 4:

Table 4: Optimized System Size for Scenario 1

Component	Type	Size	Unit
PV	Generic flat plate PV	21.1	kW
Storage	Generic 1kWh Lead Acid	19	Strings
Wind turbine	Generic 1 kW	4	kW
System converter	System Converter	8.04	kW

Net present costs for each category of the selected components are summarized in Table 5 below:

Table 5: NPC for Scenario 1

Component	Net Present Cost (US$)				
	Capital	Operating	Replacement	Salvage	Total
Generic 1 kW Wind Turbine	$5,892	$4,069	$0.00	-$388.19	$9,573
Generic 1kWh Lead AcidBattery	$6,650	$8,687	$15,407	-$2,703	$28,041
Generic flat plate solar PV	$10,469	$8,830	$0.00	$0.00	$19,299
System Converter	$4,824	$551.40	$1,832	$0.00	$7,207
Total System	**$27,836**	**$22,137**	**$17,238**	**-$3,091**	**$64,120**

Technical results related to load, storage and generation from various resources are summarized in Table 6:

Table 6: Technical Results for Scenario 1

Parameter	Value	Unit
AC Primary Load	25,233	kWh/year
Solar PV Production	46,840	kWh/year
Hours of Operation	4,388	Hours/year
Levelized Cost	0.0180	$/kWh
Wind Production	9,857	kWh/year
Hours of Operation	7,460	Hours/year
Levelized Cost	0.0425	$/kWh
Energy Input to the BatteryStorage	4,660	kWh/year
Annual Throughput	4,174	kWh/year
Autonomy	5.07	Hour
Energy Input to the Converter	25,488	kWh/year
Hours of Operation	8,715	Hours/year

Comparing Base System (Option # 1) with the proposed optimized system, the IRR of the proposed system will be 79.5% while discounted payback period and simple payback periods are found to be 1.34 years and 1.32 years respectively. A brief comparison of the Base System and the proposed system is given in the Table 7:

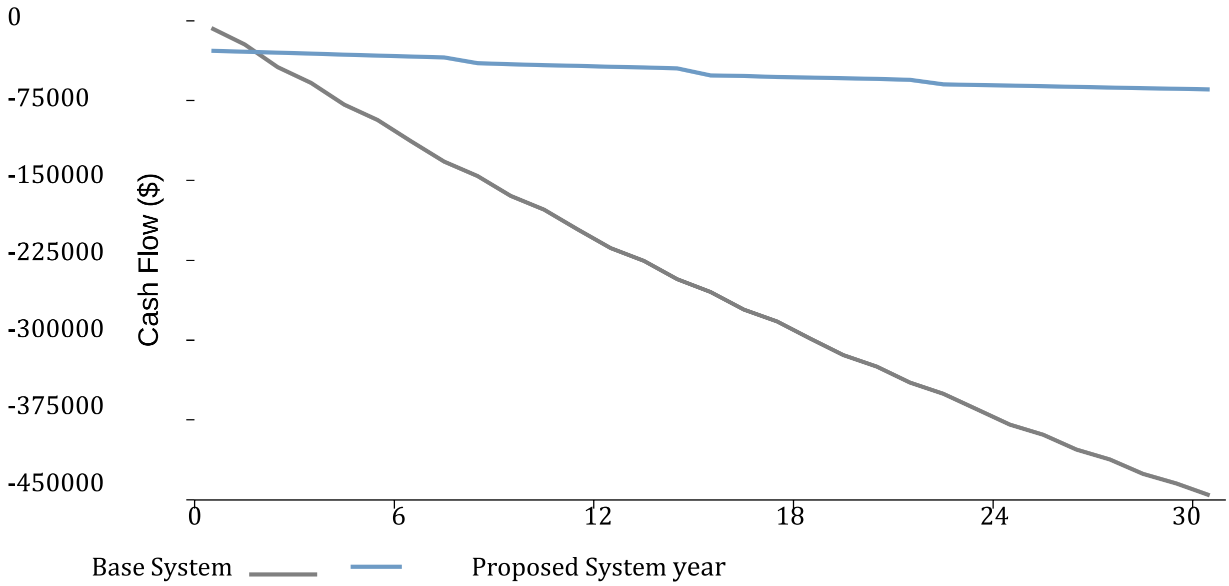
Table 7: Comparison with Diesel Generator Option for Scenario 1

Parameter	Base System	Proposed System
Net Present Cost	$445,342	$64,120
CAPEX	$6,500	$27,836
OPEX	$19,197	$1,587
LCOE (per kWh)	$0.741	$0.111
CO_2 Emitted (kg/year)	39,831	0
Fuel Consumption (Litre/year)	15,216	0

Levelized Cost of energy (LCOE) comes out to be $0.111/kWh which is quite reasonable.

Graphical comparison of the Base and the proposed system in terms of cash flows for project lifetime is shown in the Figure 8:

Figure 8: Cash Flows Comparison for Scenario 1

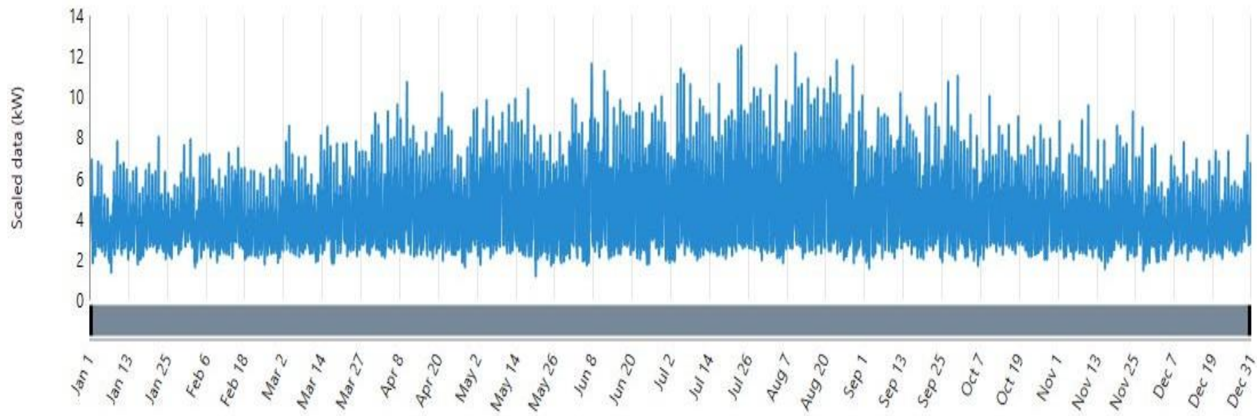


Scenario 2: Off-Grid MGs Application for Rural Villages/Areas Having Solar PV and Micro-Hydro Potential

This scenario is particularly important to analyze feasibility for remote rural populations having significant distance from the utility grid connection. This situation is especially relevant for Gilgit Baltistan, AJK and Northern areas of KPK, wherein large number of areas are unelectrified and providing grid access to those areas is difficult and does not hold financial viability. These areas possess large hydro power potential and most of them are blessed with natural scenic beauty, rendering them attractive for tourists. Pakistan was declared as one of the top 10 tourist destinations in the world, while recently GoP with the collaboration of provincial governments have announced initiatives to promote tourism industry in Pakistan; lack of reliable electricity access especially in the context of clean heating in these areas is a dire need. Moreover, burning woods to meet the heating demand in these areas will not only affect the environment, but it also affects GoP target of promoting tourism in these areas. Hence, off-grid MGs deployment in these areas will be a feasible option. A sample feasibility of off-grid MG deployment is discussed in the following section.

A village near Chitral, named Kiyar is considered with geographical coordinates of 36°5.9'N, 71°51.0'E. Following load profile is considered with peak load of 12.51 kW and annual average energy of 100 kWh/day.

Figure 9: Load Profile for Scenario 2



In order to meet this demand profile of electricity, the schematic as shown in the Figure 10 has been modelled in the software with the option to optimize the selection and size of most feasible option considering the real solar and wind profiles from NASA database.

Figure 10: Schematic Diagram for Scenario 2

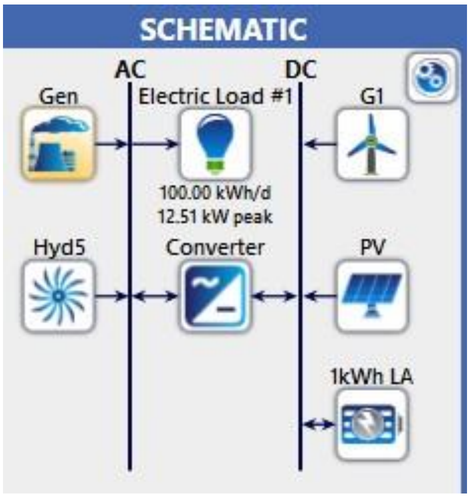


Figure 11: Wind Speed Data for Scenario 2

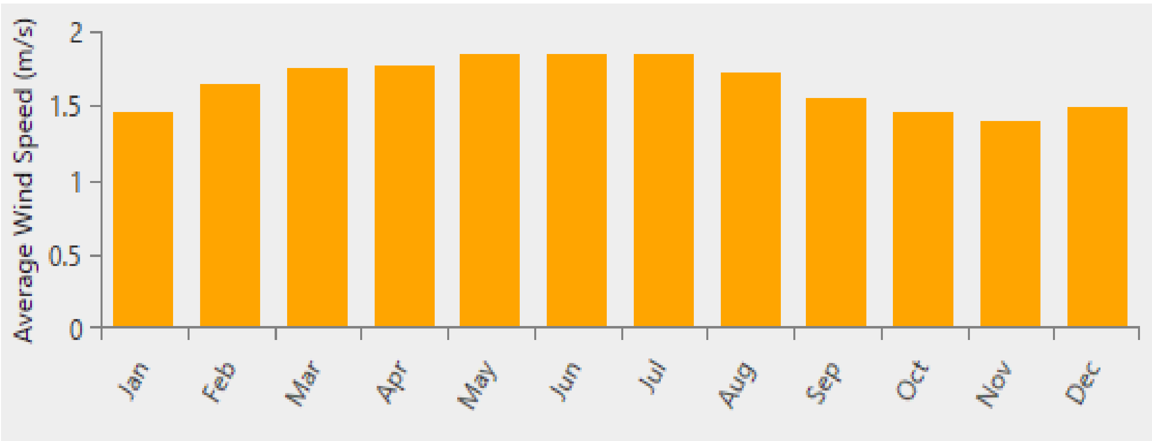
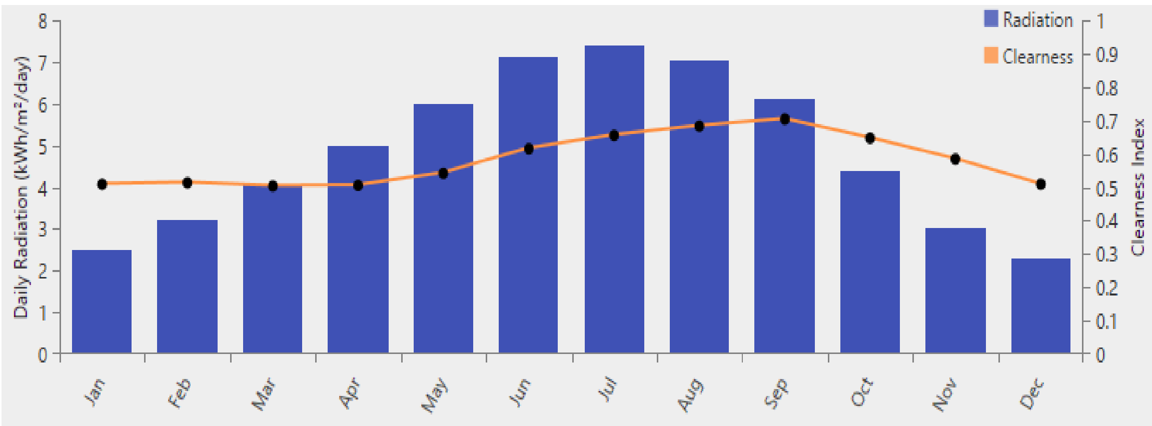
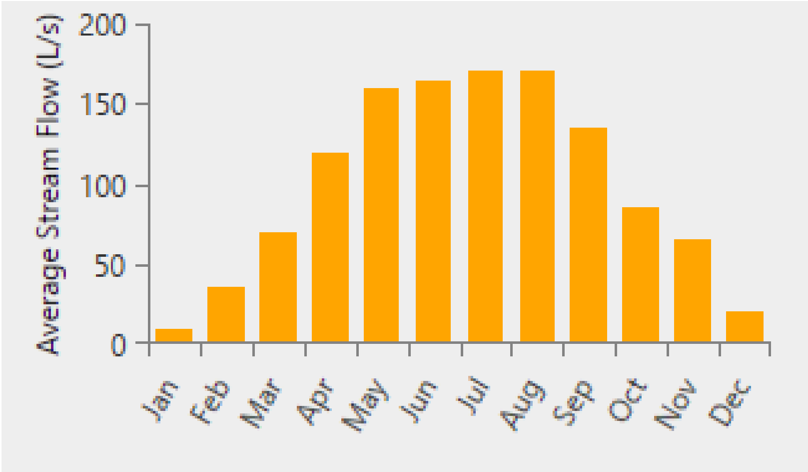


Figure 12: Solar Irradiance Data for Scenario 2



The stream flows assumed for the micro-hydro plant are as shown in Figure 13. Available head of 7 m and pipe head loss of 10% are also assumed.

Figure 13: Hydro Flow Data for Scenario 2



Different options are considered to determine the most feasible one for the MG, summarized in Table 8:

Table 8: Considered Combinations for Scenario 2

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	PV + Wind + Storage
8	PV + Wind + Storage + Diesel Generator
9	PV+ Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator
13	Micro-hydro Only
14	PV + Wind + Storage + Micro-Hydro + Diesel Generator
15	PV + Wind + Storage + Micro-Hydro
16	PV + Micro-Hydro
17	Wind + Micro-Hydro
18	Storage + Micro-Hydro
19	Micro-Hydro + Diesel Generator
20	Storage + Micro-Hydro
21	PV + Wind + Micro-Hydro
22	PV + Storage + Micro-Hydro
23	Wind + Storage + Micro-Hydro
24	Storage + Micro-Hydro + Diesel Generator
25	PV + Micro-Hydro + Diesel Generator
26	Wind + Micro-Hydro + Diesel Generator

From the above combinations, Option #22 is determined to be the most feasible one; the optimized size/rating for each component is as given in the Table 9 below:

Table 9: Optimized System Size for Scenario 2

Component	**Type**	**Size**	**Unit**
PV	Generic flat plate PV	30	kW
Storage	Generic 1kWh Lead Acid	32	Strings
Micro-Hydro	5kW Generic	5.84	kW
System converter	System Converter	5.26	kW

Net present costs for each category of the selected components are summarized in Table 10:

Table 10: *Table 10: NPC for Scenario 2*

Component	Net Present Cost ($)				
	Capital	Operating	Replacement	Salvage	Total
5kW Generic Micro-Hydro	$5,000	$1,829	$0.00	$360.42	$6,468
Generic 1kWh Lead Acid Battery	$11,200	$14,630	$13,666	$0.00	$39,496
Generic flat plate solarPV	$14,860	$12,533	$0.00	$0.00	$27,393
System Converter	$3,153	$360.40	$1,197	$0.00	$4,711
Total System	$34,213	$29,352	$14,863	$360.42	$78,068

Technical results related to load, storage and generation from various resources are summarizedin table below:

Table 11: Technical Results of Scenario 2

Component	Value	Unit
AC Primary Load	34,808	kWh/Year
Solar PV Production	59,750	kWh/Year
Hours of Operation	4,383	Hours/year
Levelized Cost	0.0201	$/kWh
Hydro Production	38,174	kWh/Year
Hours of Operation	8,016	Hours/Year
Levelized Cost	0.00741	$/kWh
Energy Input to the Battery Storage	2,846	kWh/Year
Annual Throughput	2,572	kWh/Year
Autonomy	6.15	Hour
Energy Input to the Converter	6,595	kWh/Year
Hours of Operation	3,851	Hours/Year

It is important to mention here that although per unit cost for micro-hydro is far less than PV and wind resource, yet the software is guiding to choose only 5kW (39%) from hydro resource. This is because of the reason that hydro flow is almost negligible during winter months, hence, other resources like solar PV would be needed to meet the load demand ensuring supply reliability to the consumers.

Another important aspect to consider is excess electricity generation as compared to load demand. Here again, the reason is intrinsic intermittency and uncontrollability of electricity generation from renewable energy resources, however, it must be highlighted that this excess electricity is the minimum excess electricity generated keeping in view the factors of load variability, renewables intermittency and supply reliability of consumers. If not properly sized or designed, the excess electricity will be increased which results in increasing LCOE. The issues related to unwanted power flows and voltage control will be managed by a system controller of the MG system.

Now, comparing Base System (Option # 1) with the proposed optimized system, the IRR of the proposed system will be 66.1% while discounted payback period and simple payback periods are found to be 1.57 years and 1.53 years respectively. A brief comparison of base system and the proposed system is given in the Table 12.

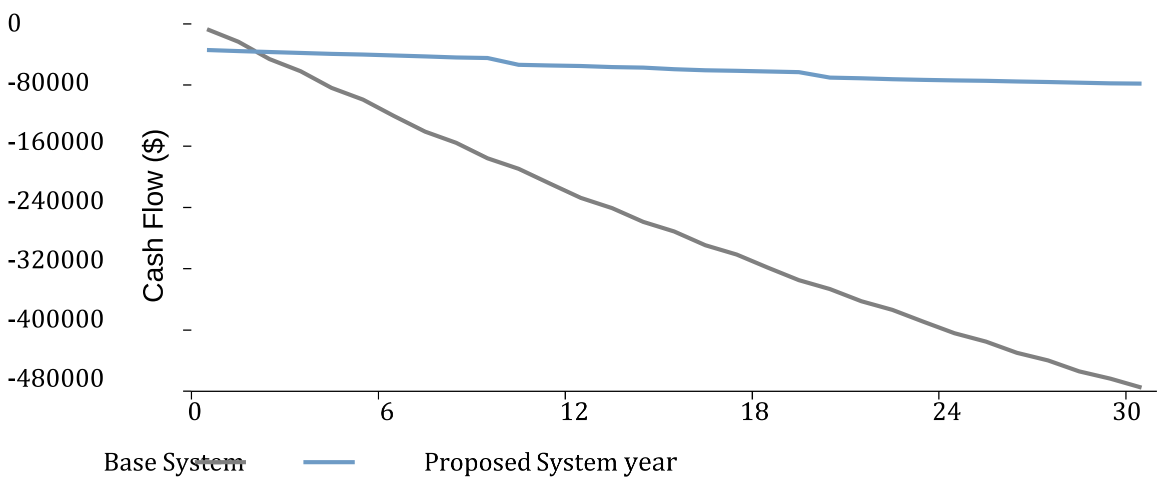
Table 12:Comparison with Diesel Generator Option for Scenario 2

Component	**Base System**	**Proposed System**
Net Present Cost	$475,276	$78,068
CAPEX	$7,000	$34,213
OPEX	$20,485	$1,918
LCOE (per kWh)	$0.570	$0.0981
CO_2 Emitted (kg/year)	42,276	0
Fuel Consumption (Liter/year)	16,151	0

Levelized Cost of energy (LCOE) comes out to be **$0.0981/kWh** which is quite reasonable.

Graphical comparison of the Base and the proposed system in terms of cash flows for project lifetime is shown in the Figure 14:

Figure 14: Cash Flows Comparison for Scenario 2

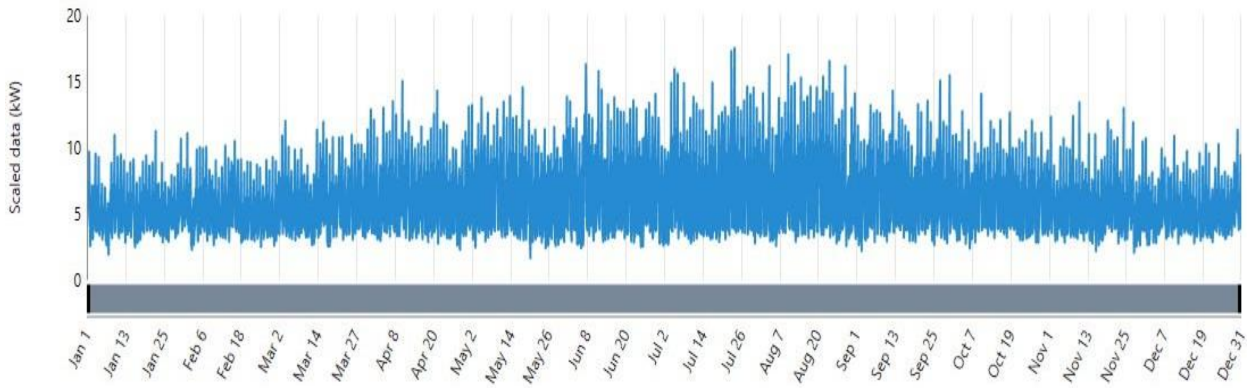


Scenario 3: Grid-Connected MGs Application for Housing Societies or CommercialCentres in Urban Areas having Utility Electricity Access

This scenario is particularly important to analyze feasibility for housing societies or commercial centres situated in the urban areas having utility electricity connection. This situation is relevant for large cities in Punjab, KPK and Sindh, wherein a lot of private housing societies and large commercial centres already exist or will be developed in the near future. The rationale of considering this MG feasibility here is its ability to create a win-win situation for both the government as well as private sector. This aspect will be discussed later in this section.

A small housing society in Lahore near Sunder Raiwind is considered with geographical coordinates of 31°14.7'N, 74°12.8'E. Following load profile is considered with peak load of 17.51 kW and annual average energy of 140 kWh/day.

Figure 15: Load Profile for Scenario 3



In order to meet this demand profile of electricity, the schematic as shown in Figure 16 has been modelled in the software with the option to optimize the selection and size of most feasible option considering the real solar and wind profiles from NASA database.

Figure 16: Schematic Diagram for Scenario 3

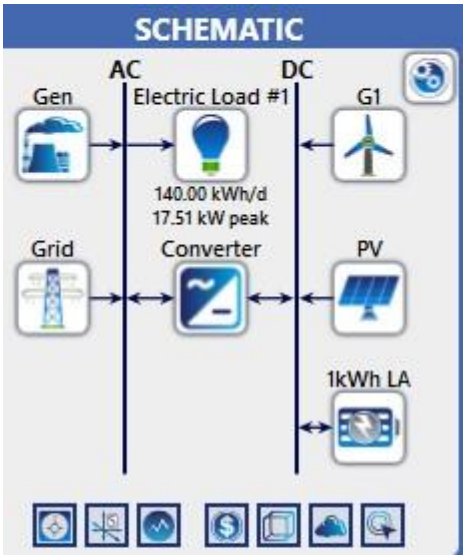


Figure 17: Wind Speed Data for Scenario 3

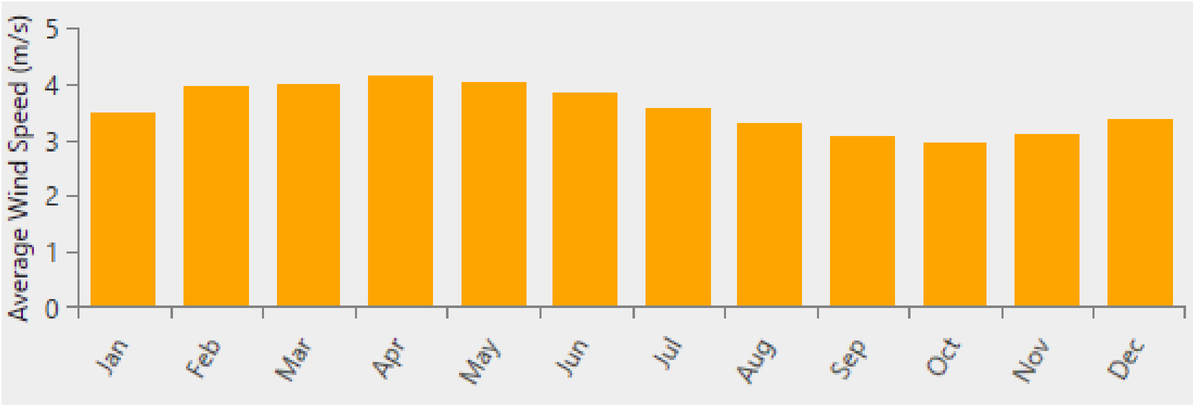
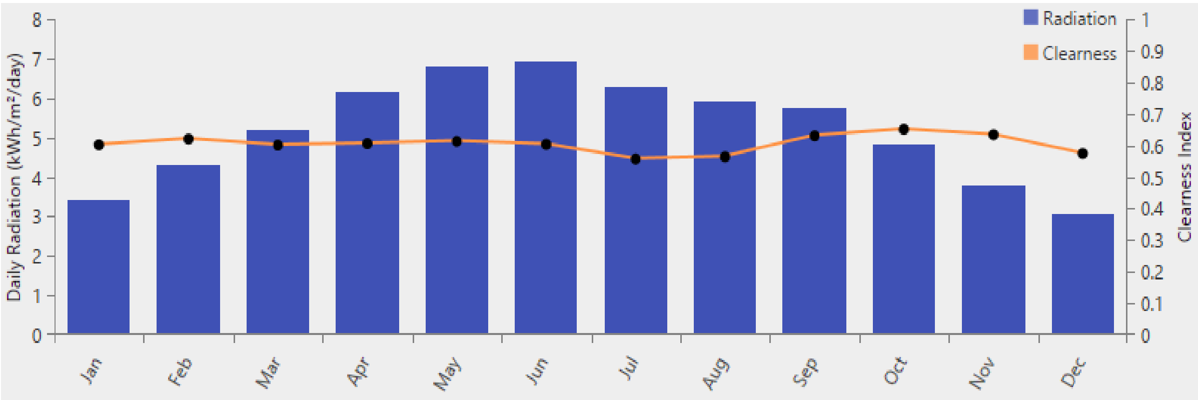


Figure 18: Solar Irradiance Data for Scenario 3



Different options are considered to determine the most feasible one for the MG, summarized in Table 13:

Table 13: Considered Combinations for Scenario 3

Option No.	Combination
1	Diesel Generator Only
2	Solar PV Only
3	Wind Only
4	PV + Wind
5	PV + Storage
6	Wind + Storage
7	PV + Wind + Storage
8	PV + Wind + Storage + Diesel Generator

Option No.	Combination
9	PV + Diesel Generator
10	Wind + Diesel Generator
11	PV + Storage + Diesel Generator
12	Wind + Storage + Diesel Generator
13	Grid Only
14	PV + Wind + Storage + Grid + Diesel Generator
15	PV + Wind + Storage + Grid
16	PV + Grid
17	Wind + Grid
18	Storage + Grid
19	Grid + Diesel Generator
20	Storage + Grid
21	PV + Wind + Grid
22	PV + Storage + Grid
23	Wind + Storage + Grid
24	Storage + Grid + Diesel Generator
25	PV + Grid + Diesel Generator
26	Wind + Grid + Diesel Generator

From the above different combinations, Option #16 is determined to be the most feasible one and the optimized size/rating for each component is as given in the Table 14:

Table 14: Optimized System Size for Scenario 3

Component	Type	Size	Unit
PV	Generic flat plate PV	21.3	kW
Grid	Grid	-	kW
System converter	System Converter	9.14	kW

Net present costs for each category of the selected components are summarized in Table 15:

Table 15: NPC for Scenario 3

Name	Net Present Cost ($)				
	Capital	Operating	Replacement	Salvage	Total
Generic flat plate PV	$10,563	$8,909	$0.00	$0.00	$19,472
Grid	$0.00	$91,237	$0.00	$0.00	$91,237
System Converter	$5,484	$626.85	$2,082	$0.00	$8,194
Total System	**$16,048**	**$100,773**	**$2,082**	**$0.00**	**$118,903**

Technical results related to load, converter and generation from various resources are summarized in the Table 16:

Table 16: Optimized System Size for Scenario 3

Component	Value	Unit
AC Primary Load	51,100	kWh/Year
Solar PV Production	45,205	kWh/Year
Hours of Operation	4,383	Hours/Year
Levelized Cost	0.0188	$/kWh
Grid Purchase	26,608	kWh/Year
Levelized Cost	0.15	$/kWh
Energy Input to the Converter	29,680	kWh/Year
Hours of Operation	4,383	Hours/Year

Now, comparing Base System (Option #1) with the proposed optimized system, the IRR of the proposed system will be 20% while discounted payback period and simple payback periods are found to be 5.22 years and 4.93 years respectively. A brief comparison of Base System and the proposed system is given in the Table 17:

Table 17: NPC for Scenario

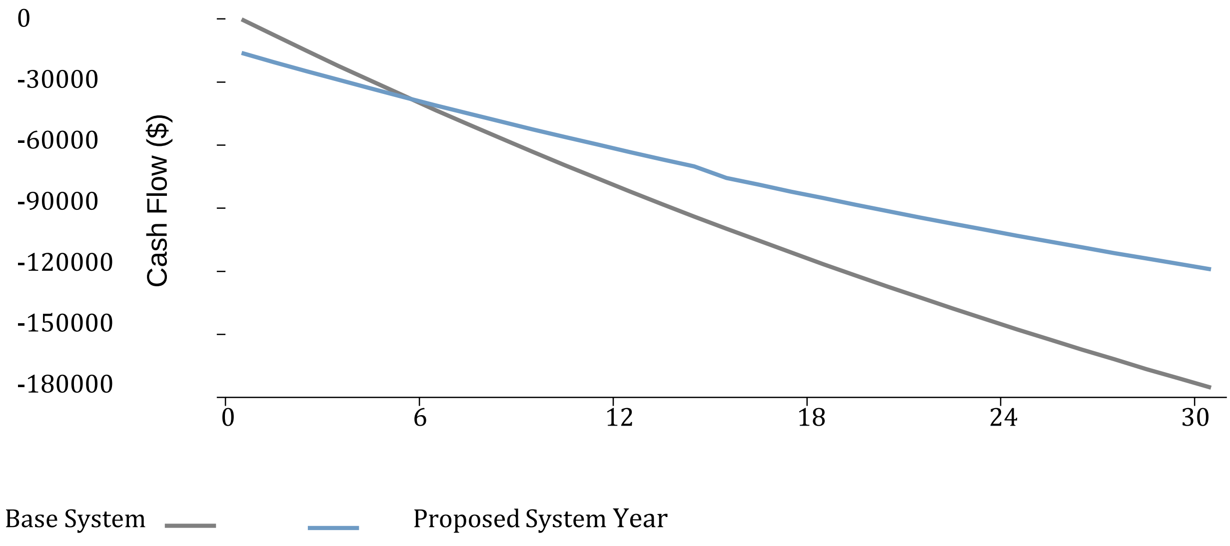
Component	Base System	Proposed System
Net Present Cost	$175,218	$118,903
CAPEX	$0.00	$16,048
OPEX	$7,665	$4,499
LCOE (per kWh)	$0.150	$0.0929
CO_2 Emitted (kg/Year)	32,295	16,816
Fuel Consumption (Liter/year)	0	0

Levelized Cost of energy (LCOE) comes out to be **$0.0929/kWh** which is significantly lower than the existing grid provided electricity tariff rate.

Explaining win-win situation for both government and private sector, it is evident from the above that the LCOE which the end-consumer have to bear having only grid connection (0.15/kWh), now drops to $ 0.0929 $/kWh. Hence, it holds substantial financial viability for end-consumer living in urban centres/housing societies.

Now, considering it from the perspective of government, need of investment planning for lesser energy/power, environment friendly electricity generation, improving energy efficiency targets, job creation in private sector, etc. are its advantages. It also supports democratization objective of electricity/energy sector aligned with globally accepted '3D' targets of Decarbonize, Decentralize and Democratize. Graphical comparison of base and proposed system in terms of cash flows for project lifetime is shown in the Figure 19.

Figure 19: Cash Flows Comparison for Scenario 3



3.3 Further Insights into Modelling, Analysis, Simulation and Results

In this section, further insights are provided for the scenarios presented above with respect to modelling, analysis, simulation and results of MGs deployment in Pakistan. Advance study comprising sensitivity analysis and multiyear analysis are performed to further validate and deliberate the discussed scenarios of applications. A special application of MGs in Pakistan's rural areas with respect to irrigation is discussed named Deferrable Load Analysis. Moreover, considering the rapid advancement in technology, application of DC MGs is also analyzed as compared to conventional Alternating Current (AC) MGs.

It is important to highlight that main purpose of the above-mentioned analyses is to present further insights and methodologies, hence performed for only a few of the selected cases and applications. The need of performing these analyses or even more advanced ones depends upon the exact application and model of a specific project; result may vary from one project to another.

Sensitivity Analysis

Sensitivity analysis also known as 'What-if analysis' is required to assess the impacts of changes in various input parameters on the results of the analysis. Most important input parameters for performing sensitivity analysis are:

- Permitted Capacity Shortage (%)
- Project lifetime (Years)
- Discount rate (%)

These parameters are varied for a range of values and resulting impact on LCOE is observed.

Table 18: Sensitivity Range for the Input Parameters

S.#.	Permitted Capacity Shortage (%)	Project lifetime (Years)	Discountrate (%)
1	0	5	1
2	0.5	10	2
3	1	15	3
4	1.5	20	4
5	2	25	5
6	2.5	30	6
7	3		7
8	3.5		8
9	4		9
10	4.5		10
11	5		
12	10		
Total	12	6	10

Based on the range of input parameters as highlighted in the Table 1, total number of 720 (12*6*10) scenarios/sensitivities are simulated through Homer-Pro for Case 1. Out of these 720 sensitivities, let us compare the following as an example:

- Sensitivity A (Discount rate = 10, Project lifetime = 5 years, Capacity Shortage = 0%)
- Sensitivity B (Discount rate = 5, Project lifetime = 30 years, Capacity Shortage = 10%)

Table 19: Sensitivity A vs Sensitivity B

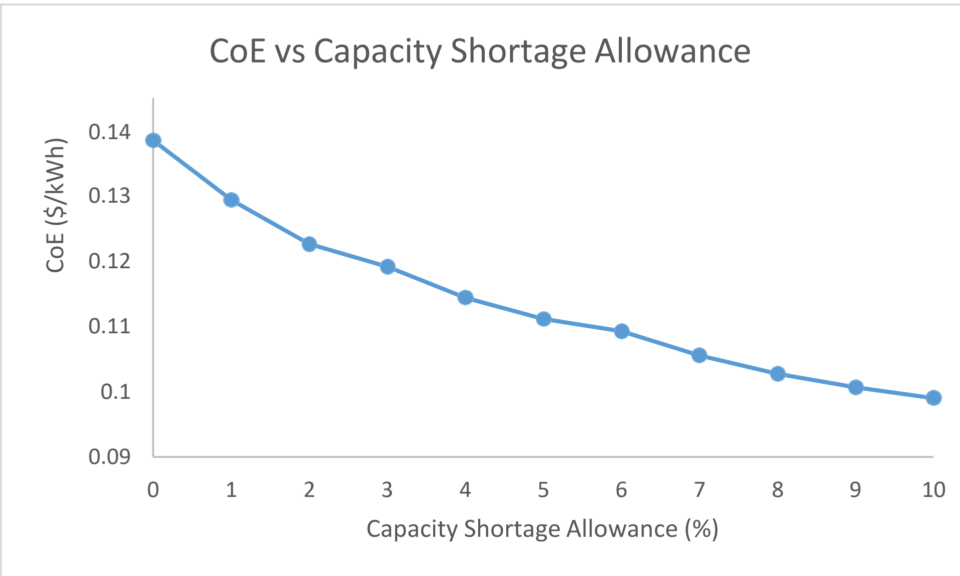
Component	Sensitivity A	Sensitivity B
Net Present Cost	$22,079	$83,957
CAPEX	$33,984	$25,841
LCOE (per kWh)	$0.177	$0.0729

It has been observed that the LCOE decreases either by increasing the project lifetime and allowed capacity shortage or by decreasing the discount rate.

These sensitivities along with other similar sensitivities may be simulated for a specific project during the feasibility studies to identify the optimal solution as per the requirements. It is interesting to note that MGs feasibility analysis is a multi-dimensional optimization task where the project owner has to decide which energy mix will be installed to meet the electricity requirements of the consumers.

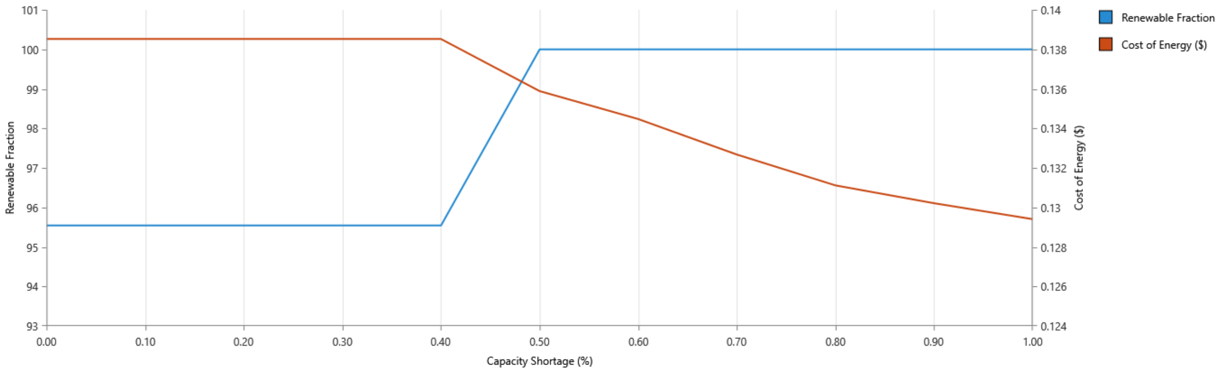
For example, let us consider the sensitivity of Cost of Energy (CoE) with the capacity shortage allowance as shown in Figure 20. It is evident that the CoE decreases exponentially with the increase in the allowed capacity shortage.

Figure 20: CoE vs Capacity Shortage Allowance



An interesting behavior is observed with respect to the renewable fraction in the energy mix for the MG. For capacity shortage allowance upto 0.4 %, it is essential to include conventional generator to determine the optimal resources for the MG, as shown in Figure 21. The corresponding graph for the Cost of Energy is also plotted with it.

Figure 21: CoE and Renewable Fraction vs Capacity Shortage Allowance



Similarly, the relationship of CoE with Discount rate and Project lifetime can be easily observed as increasing linear and decreasing exponential respectively, as shown in Figures 22 and 23.

Figure 22: CoE Vs Discount Rate

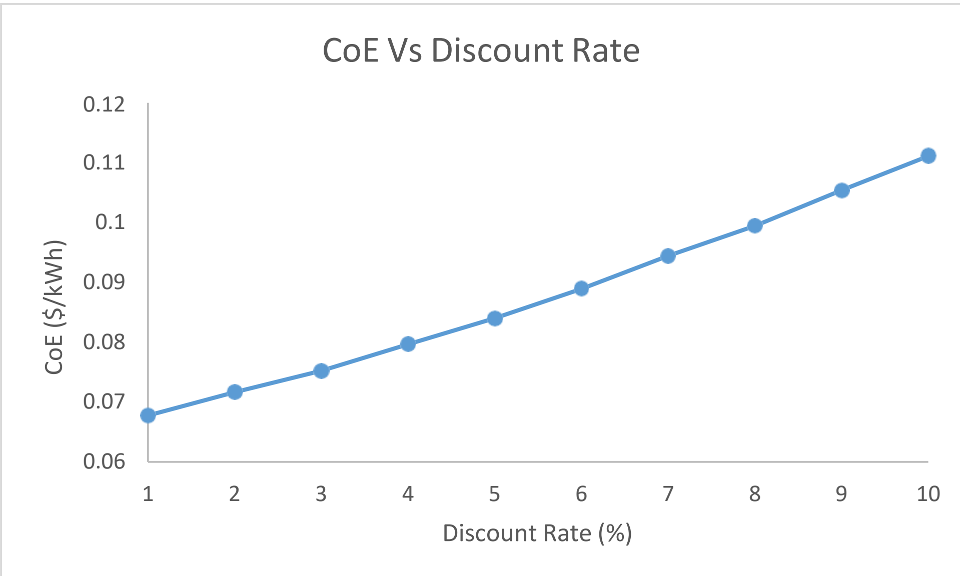
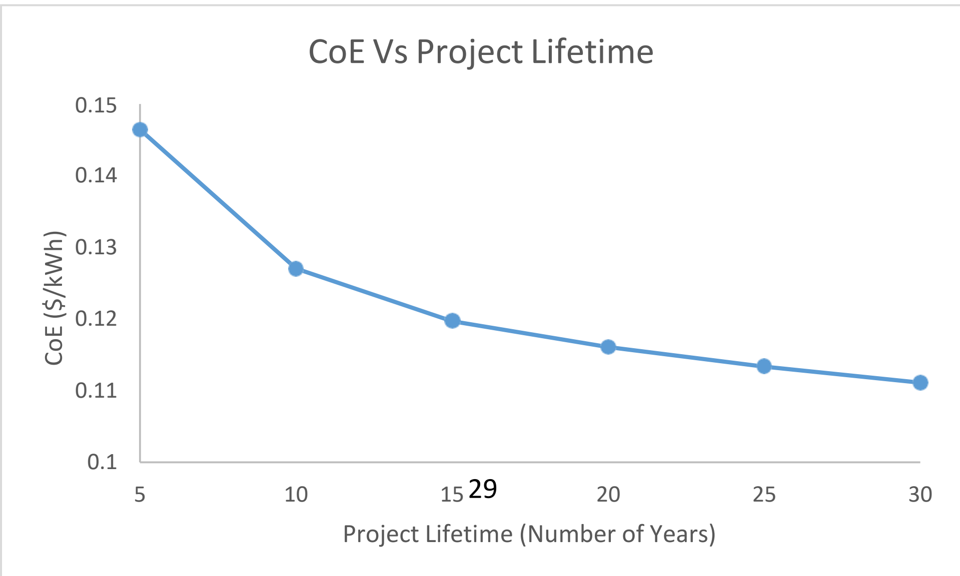


Figure 23: CoE Vs Project Lifetime



It presents an important insight for the policy makers to look into the impact of these critical factors. For example, if the customers want the provision of supply 100% of the time, the price of per unit electricity may increase 200% as compared to the customers who want 95% of the supply reliability. Again, this must be correlated with the consumer affordability index which varies significantly across the country. In line with the regulator's intent of deregulating this sector completely, it can be anticipated that it is the project-owner who will conduct this sort of preliminary analysis to safeguard the investment, which would be depicted in the bilateral contracts between the project-owner and the customers.

Multiyear Analysis

Multiyear analysis is performed by inputting future costs projections of solar PV and wind to provide a more realistic insight for the future. Following are the cost projections for solar PV and wind energy in $/kW taken from IGCEP 2021:

Table 20: *Table 20: Sensitivity A vs Sensitivity B*

Year	**ar PV Cost($/kW)**	**Wind Cost ($/kW)**
2021	511	1274
2022	494	1261
2023	476	1249
2024	460	1236
2025	444	1224
2026	428	1212
2027	413	1200
2028	399	1188
2029	385	1176
2030	371	1164

Due to the Homer-Pro's license restrictions, the multiyear analysis could not be performed for this study. It is important to highlight here that the results summarized in the previous modelling section will obviously get improved i.e. LCOE will get further decreased by incorporating multiyear analysis.

Deferrable Load Analysis

Deferrable Load analysis is performed in order to analyse a very practical application of irrigation in Pakistan's rural areas. Without going into details of irrigation system, let us analyse the application of MGs in the agriculture sector of Pakistan, aligning the terminologies used in our analysis with that of the rural applications of agriculture.

Deferrable load is the load for which the exact timing for the electricity provision does not matter, however it requires certain amount of energy in a specific time period. Loads are normally categorized as deferrable when they are linked with the availability of storage. Water pumping is a common example of deferrable load in rural areas of Pakistan; hence this special case will be analysed here with respect to MGs widespread deployment in the country.

An example of an agricultural area is considered where there is water requirement of 50 m^3 for irrigation. Suppose there is a water storage provision of 175 m^3. The rated capacity of the water pump is 5 kW and it pumps approximately 25 m^3 per hour. Following parameters are inputted into the model to analyse the situation:

- Peak load = 5 kW
- Storage capacity = (175/25) hours x 5 kW = 35 kWh
- Average deferrable load = (50/25) hours per day x 5 kW = 10 kWh/day

Since Deferrable load provides extra flexibility for the modelling of the MGs, it is easily anticipated that LCOE for this case (considering deferrable loads of agricultural sector) will be lesser than that of normal rural loads. The simulations' comparison of both the cases are provided through Table 25.

Table 21: Comparison: Normal Load vs Deferrable Load

Cost	Deferrable Load	Normal Load
Net Present Cost	$64,059	$78,095
CAPEX	$28,999	$33,289
OPEX	$1,534	$1,960
LCOE (per kWh)	$0.0976	$0.119

It is evident from the above comparison that MGs application for irrigation is feasible case and has more economic viability.

DC MG Analysis

DC MGs have become a reality in most recent years. Let us compare the already presented Scenario 1 with that by replacing it with DC MG. Here the AC Load will be converted to DC Load, which will result in avoiding the requirement of AC Bus and the converter. Main parameters and results of the two scenarios are tabulated below for the comparison:

The optimized size/rating for each component for the two scenarios is as shown in Table 26.

Table 22: *Table 22: Comparison: Optimized System Size for Scenario 1 vs DC MG*

Component	Type	Unit	Scenario 1	cenario 1(DC MG)
PV	Generic flat plate PV	kW	21.1	17.3
Storage	Generic 1kWh Lead Acid	Strings	19	20
Wind turbine	Generic 1 kW	kW	4	5
System Converter	System Converter	kW	8.04	0

Net present costs for each category of the selected components are summarized in Table 27:

Table 23: Comparison: NPC for Scenario 1 vs DC MG

Component	**Net Present Cost ($)**	
	Scenario 1	**Scenario 1 (DC MG)**
Generic 1 kW Wind Turbine	$9,573	$11,966
Generic 1kWh Lead AcidBattery	$28,041	$28,788
Generic flat plate solar PV	$19,299	$15,824
System Converter	$7,207	$0
Total System	**$64,120**	**$56,579**

Technical results related to load, storage and generation from various resources are summarized through Table 28.

Table 24: Comparison: Technical Results for Scenario 1 vs DC MG

Component	Unit	Scenario 1	Scenario 1 (DC MG)
Primary Load	kWh/Year	25,233	25,233
Solar PV Production	kWh/Year	46,840	38,407
Hours of Operation	Hours/Year	4,388	4,388
Levelized Cost	$/kWh	0.0180	0.018
Wind Production	kWh/Year	9,857	12,321
Hours of Operation	Hours/Year	7,460	7,460
Levelized Cost	$/kWh	0.0425	0.0425
Energy Input to the Battery Storage	kWh/Year	4,660	4,708
Annual Throughput	kWh/Year	4,174	4,216
Autonomy	Hour	5.07	5.34
Energy Input to the Converter	kWh/Year	25,488	0
Hours of Operation	Hours/Year	8,715	0

A brief comparison of the two is given in the Table 29.

Table 25: Comparison: Scenario 1 vs DC MG

Cost	Scenario 1	Scenario 1 (DC MG)
Net Present Cost	$64,120	$56,579
CAPEX	$27,836	$22,949
OPEX	$1,587	$1,471
LCOE (per kWh)	$0.111	$0.098

Levelized Cost of energy (LCOE) comes out to be **$0.098/kWh** for the case of DC MGs as compared to that of **$0.111/kWh**.

MGs with Day-Only Load

The load profile significantly affects Levelized Cost of energy (LCOE), for example when the load profile is changed to day-only load, LCOE comes out to be **$0.0677/kWh** as compared to that of

$0.111/kWh (in Scenario 1).

TECHNICAL CHALLENGES AND SOLUTIONS

4.1 Introduction

MGs are predominantly composed of Distributed Energy Resources (DERs), which refers to a variety of small-scale electricity generation units and storage devices that are generally connected to an islanded electricity grid. In this chapter, most relevant technical issues for MGs deployment in Pakistan and their possible solutions are discussed. It is important to highlight that the issues and their solutions are elaborated qualitatively since they may vary significantly from case-to-case basis.

Stability of MGs

In order to analyze the stability phenomenon in MGs, it is important to understand the fundamental modes of operations of various types of MGs described as follows:

Utility MG

A utility MG is connected to the main grid at one or more points, known as Point of Common Coupling (PCC). It can be operated in either grid connected mode or islanded mode, based on its application. In grid connected mode, the voltage and frequency of the MG is synchronized with the main grid, while in islanded mode, the MG is not connected to the grid.

Facility MG

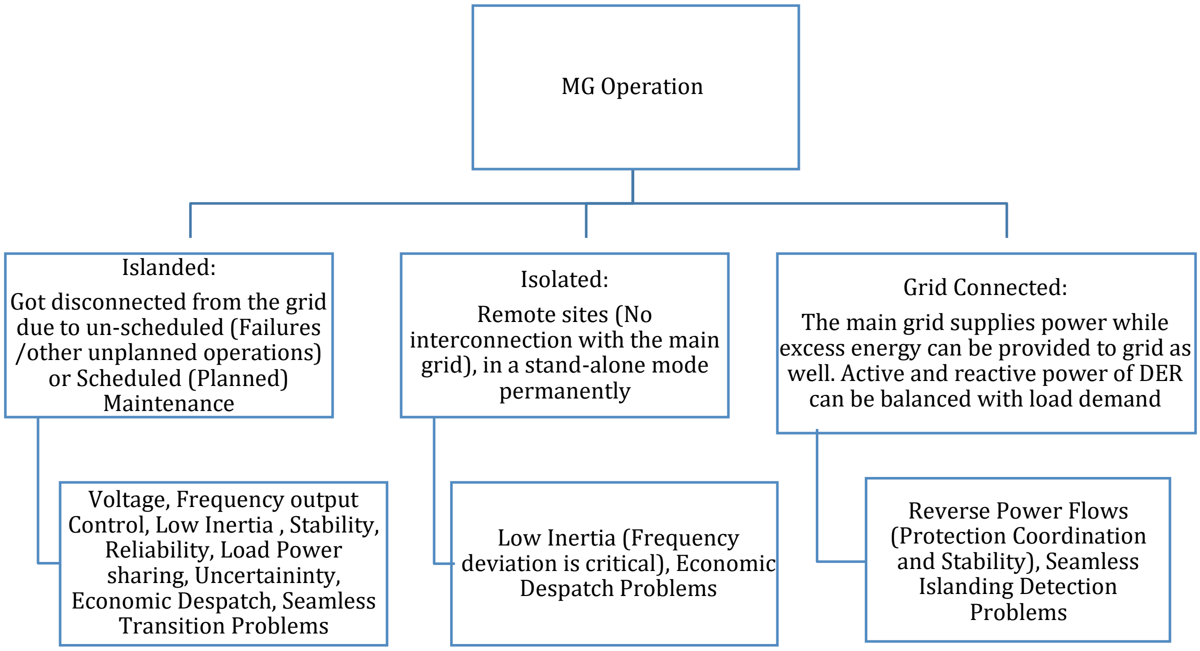
An MG can also be designed to provide dedicated power supply to a single business-entity i.e., institutional or industrial facility. This type of grid is known as facility MG and it can also be operated either as grid connected or islanded mode.

Isolated or Remote MG

There is also another type of MG which is classified as isolated or remote MG. It is not linked with main grid or a utility and decentralized control techniques are used for its operation.

Major issues associated with different modes of operation of MGs are summarized in the Figure 24.

Figure 24: Major Issues in Various MG Operational Modes:Stability Challenges



In a conventional power system, synchronous generators are usually high in number and inertia of these rotating generators help it withstands transitions. However, typically MG systems do not have such large number of synchronous generators and hence the rotating mass and inertia of the system is low. Consequently, MGs cannot handle transients in the same way as conventional power systems. Low-inertia is an important concern for MGs. In addition to that, existence of power electronics devices makes MGs unique and different in comparison to the conventional power system, which necessitates effective and efficient control techniques for MGs. It is important to recall that there exists inverse relationship between frequency deviation and inertia of the system. Moreover, Voltage Source Converters (VSC), used for Renewable Energy generators, do not provide inertia, and also have limitations on switches current ratings and droop control characteristics. Therefore, MGs intrinsically have instability problems in terms of frequency and voltage regulation. In literature, control techniques based on virtual inertia have been presented with objective to enhance the ability of system to withstand large deviation in frequency during major faults and disturbances (Abdel & Oboskalov, 2020). Undesired load shedding can also be reduced in isolated MGs using these techniques.

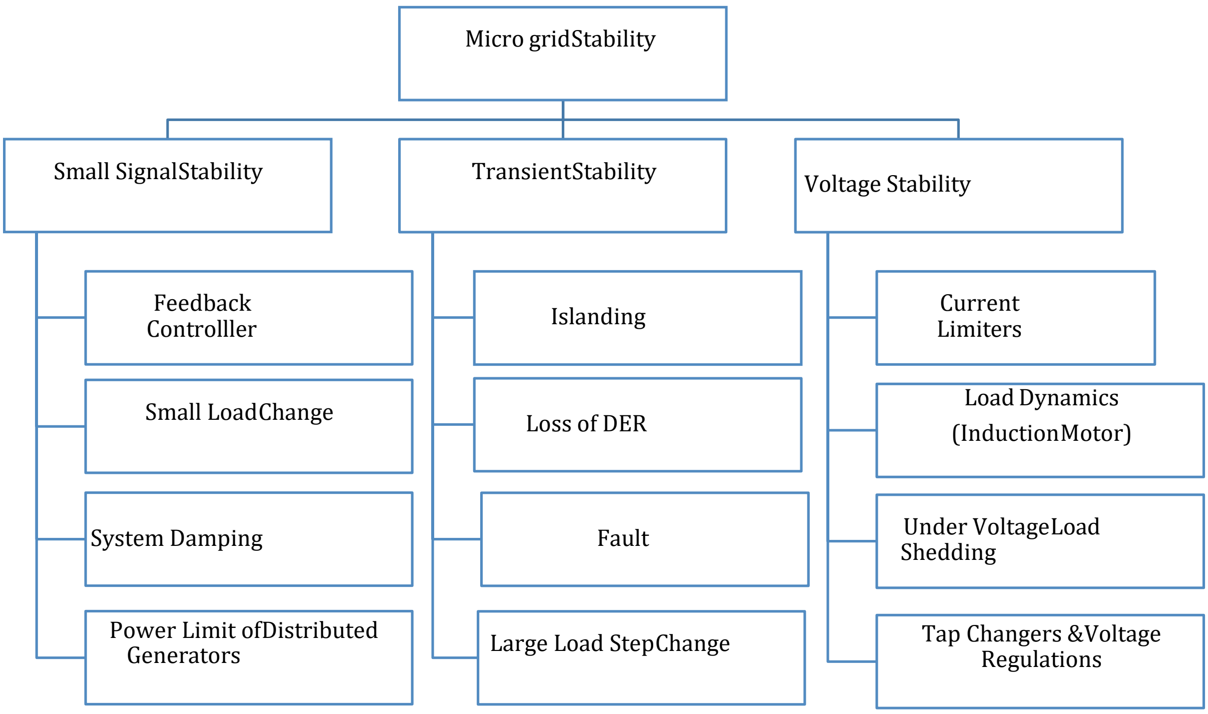
In case of grid connected MGs, bidirectional flow (to and from MG – to and from main grid) of active and reactive power is possible and excess energy produced by generators of MGs can be sold to the main grid. One of the advantages is that the main grid also provides voltage and frequency references. The load can be served by power from main grid as well as from the generators of MGs. In case of disconnection from grid, the transition from grid connected mode to the islanded mode should be smooth and seamless. In this scenario, either demand may be reduced or generation be increased to tackle the demand supply gap. This transition can bring instability to the MG if not properly handled through adequate frequency/voltage control techniques, accurate and fast islanding detection schemes or provision of enough supply of power through back up generation sources.

In isolated mode, the MG is installed at a remote location and it is not connected to the grid. The issues with isolated mode are similar to that of islanded mode MGs. In islanded mode of operation, if output of solar power is reduced due to clouds, the power from other sources cannot be added to the system promptly to overcome the supply demand gap at the same rate as that of generation reduction. Therefore, an energy storage system shall be the integral part of the islanded and isolated MGs so that the energy balance may be achieved without endangering system reliability.

Stability issues are divided into three groups here, i.e., small signal stability, transient stability and voltage stability. Figure 25 shows the main reasons behind each class of issue.

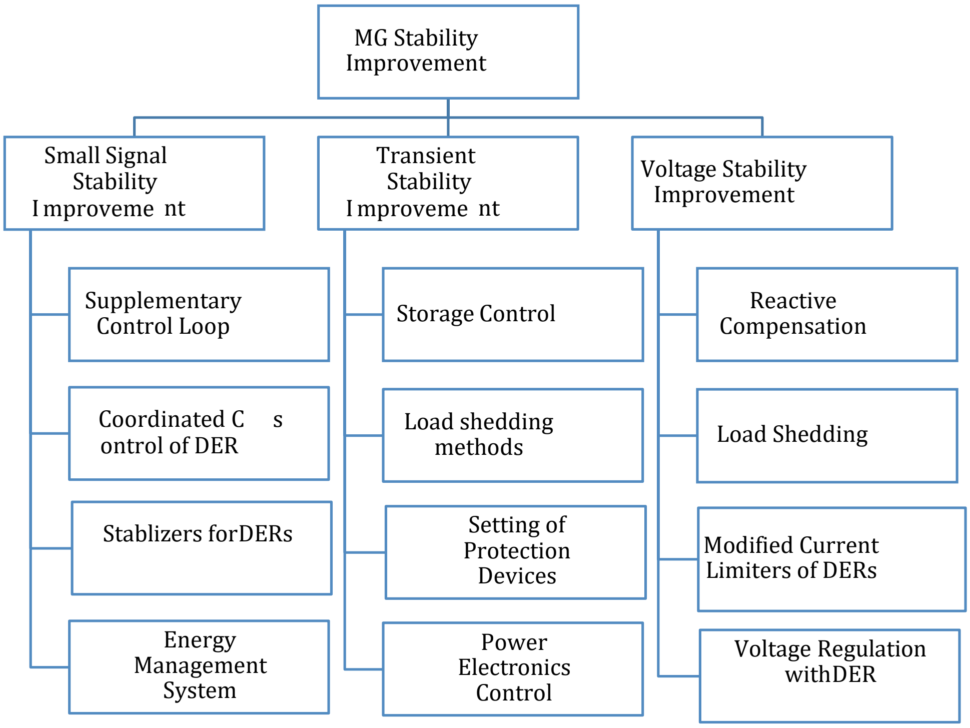
It is pertinent to mention that DER feedback controller with decentralized control techniques and current limiters are the reasons of small signal stability problem in a remote MG and Utility MG respectively. Numerous load switching events within a relatively small area often produce the small signal stability issues in a facility MG (Micallef, 2019). Islanding as result of fault is the most common reason behind stability issues in Utility or Facility MGs. Occurrence of fault and isolation of faulty section produce transient stability problems in Remote MGs too. As far as voltage stability issues in MGs are concerned, lack of reactive power compensation is the main cause.

Figure 25: Main Reasons for Stability issues in MGs



Stability Improvement Methods in Microgrids

Figure 26: Methods of Stability Improvement shows various methods of stability improvements, a few of these are discussed below:



Stabilizer

In order to improve small signal stability, stabilizers may be used with the Voltage- source Converter (VSC) of DERs. The stabilizer can be introduced in any of the control loop. Herethe energy output, frequency and voltage magnitude are inputs of control system of stabilizers.

Reactive Compensation with DSTATCOM

In order to keep the voltage within prescribed limits, reactive power compensation in an MG is essential. Remote and Utility MGs face most of the voltage regulation issues which can be of the following two types:

a. Voltage regulation issue occurring at the load side of the feeder in grid connected mode.
b. Deviation of voltages below prescribed limit anywhere in islanded mode.

Distribution Static Compensator (DSTATCOM) is connected near to the critical load to make sure the desired power quality. DSTATCOM injects reactive power whenever required by the system.

Energy Storage System: Flywheel

Stability improvement is provided by Energy Storage System in MG by injecting active power (sometimes also reactive power) during power outage, tripping, islanding, DER dynamics and fault ride through till the backup diesel generators come online. There are many energy storage devices, however, the flywheel is the most effective one particularly for MG applications. With a fly wheel system, power with value range of MW can be injected within one-fourth of a cycle. The flywheel system is connected with MG with back to back power converters. The first converter works as flywheel drive and keeps the DC side voltage at the desired level. The second converter is at grid side and injects reactive and real power based on the measured voltage and frequency.

Load Shedding for Stability Improvement

The role of load shedding becomes critical in MG stability during islanding. Power imbalance is created due to sudden disconnection of the grid. The load shedding can be carried out with various techniques as mentioned below:

a. Breaker interlock
b. Under Frequency Relay
c. PLC Based Load Shed
d. Advanced Methods of load shedding using optimization process.

4.2 Protection System of MGs

In order to ensure safe and reliable operation of the power system, adequate protective equipment with fast operation, better selectivity, simplicity and with versatile setting arrangements has to be selected. The conventional protection schemes in distribution network cannot operate well in an MG because of variation in fault current, intermittent nature and dynamic characteristics of the DERs, and bidirectional power flows from MGs. In this section, potential challenges and solutions thereof are discussed from the perspective of MG's protection system.

Challenges in MG protection systems

Major challenges encountered in MG protection are:

a. Dynamics in fault current magnitude
b. Loss of connection from utility
c. Blinding of protection

Variation in Fault Current Magnitude

The fault current levels vary significantly for MGs. In grid connected mode, the fault current will be very high due to the presence of both the utility connection and the MG system.

The value of fault current is lower during islanded mode, since the only source in the MG is low capacity DERs. In addition to having low capacity, the maximum fault current contribution is also very low for DERs, i.e., 1.5 times and 5 times the rated current for DER and synchronous generator respectively.

Since the values of fault current have wide range of variability and depend on the operational modes, number and type of DER, and output generated by DERs, therefore, prediction or estimation of fault current remains challenging in MG system.

Loss of Connection from Utility

Loss of connection from utility refers to the partial or complete disconnection of MG from the main grid. The reasons are as follows:

a. Problem in circuit breaker connecting MG with grid

b. Fault in grid

In the case of partial disconnection, the unintentional islanding is dangerous for the personnel attending the fault because a section of the network is still energized where the islanding has not been detected. Generators in islanded system may face uncontrolled frequency and voltage as well as unsynchronized reclosures of circuit breakers, which can damage measuring devices and customer equipment.

Blinding of protection

When fault occurs in MG at the far end of the feeder, contribution of fault current is from both the utility and the DERs. Additional impedance is introduced due to presence of DERs in comparison to a traditional grid, hence, value of Thevenin's impedance at the fault point is also increased. Consequently, there is a probability that short circuit current may become lower than the pick-up current of relay, hence fault may remain undetected resulting into the failure of protection system.

Solution to Protection Challenges

In order to isolate the least portion of the network after the occurrence of fault and to ensure the reliable operation, there is a need to design adequate protection scheme for the MG. This can be accomplished by combining backup and primary protections. The induction of DERs increase the complexity of system. Certain standard solutions are briefly discussed below:

Current limiter

The Fault Current Limiters (FCL) are installed near the PCC to limit the fault current contributed by DER in MG towards grid and to reduce the fault current contribution by the grid to MG.

Protection based on variables

MG protection can also be carried out based on several parameters i.e., voltage and current sampling, angles, Total Harmonic Distortion (THD), Wavelet Packet Transform (WPT) and traveling wave (Micallef, 2019).

Directional relaying

Whenever there is a bidirectional power flow or reverse power flow, malfunctioning of main relays of feeders can occur, which are being fed from the grid. This problem can be solved by the use of directional over current relays.

POLICY OVERVIEW AND REGULATORY FRAMEWORK

5.1 Introduction

Setting up and upscaling of MGs in different geographical and administrative areas of Pakistan would certainly contribute to improve the life-quality of a common man especially for the marginalized class through electricity access. The widespread deployment of MGs entails a well-deliberated and prudent policy framework. For the purpose of this study, prevailing policies i.e., ARE Policy 2019, National Electricity Policy 2021, have been studied and analyzed. The case studies of other regions/countries are also studied where the economic, social conditions, scenarios and issues are similar with that of Pakistan. This chapter also describes the challenges, barriers, pre-requisites and other implications that may be faced while MG deployment in Pakistan within the policy perspective. The best practices followed by other regions for resolution of various issues along with their outcomes, are analyzed. Based on the existing policies, gap analysis carried out and lessons learnt from the international experience of MGs deployment, certain policy insights are presented. Finally, recent developments on MGs regulatory framework are discussed along with mentioning of this study's contribution towards improvement of the framework.

5.2 Analysis of Existing Relevant Policies

ARE Policy 2019

As per ARE Policy 2019, MGs are included in the targets i.e. at least 20% on-grid RE generation by capacity by the year 2025 and at least 30% by 2030. However, all MG projects, under ARE Policy 2019 developing through public sector funding, will come through competitive bidding – this is, of course, not applied on the projects not based on public sector funding. ARE Policy 2019 mandates AEDB to be the focal entity with respect to developing and operating MGs in Pakistan; for this purpose, AEDB is responsible for the following:

1. Monitor the MG projects to ensure adherence to appropriate safety standards for all the MGprojects
2. Maintain enhanced coordination, information creation and sharing, regulatory interventionand contracting support functions
3. Initiate the process for a simpler licensing and regulatory framework to be approved byNEPRA within six months.

National Electricity Policy 2021

The policy, approved in June 2021, is aimed to reform the power sector. However, it broadly undertakes to promote electricity access to areas where grid expansion is financially unviable, through exploring off-grid and micro-grid solutions. The policy further includes provision of integrated planning for rural electrification and provision of electricity to unserved areas of the country.

5.2 Gap Analysis

ARE Policy 2019 is aimed to create a conducive environment for the sustainable growth of ARE sector in Pakistan and is not exclusively meant to focus on encouraging and pushing the MG development in Pakistan. In order to target substantial upscaling of MG, Pakistan certainly requires dedicated policy intervention due to its distinctive nature and associated benefits as well as challenges.

On the other hand, pursuant to the ARE Policy 2019, AEDB needs to accelerate its efforts pertaining to implementation on three major responsibilities i.e. monitoring with respect to adherence to safety standards; support and coordination for the MG developers and other stakeholders; and initiating licensing and regulatory framework (which is currently under approval by NEPRA).

In order to promote and secure upscaling of MGs in the country, Government of Pakistan (GoP) is certainly required to address the policy gaps described in this section; further AEDB is required to proactively pursue its mandate in this regard.

Inclusion of exploring MG solutions in the National Electricity Policy 2021 in a highly broad manner does not really reflect the strong commitment and serious undertaking, on the part of GoP, for the MGs development in Pakistan. It is, therefore, expected that GoP will manage a comprehensive and realistic coverage of MGs in the National Electricity Plan which is expected to be launched for implementation of the National Electricity Policy 2021, covering the aspects, which are not limited to the following:

1. What will be the roles and responsibilities of different stakeholders? e.g. who will build, operate and maintain distribution infrastructure? What is the role of NTDC and DISCOs withrespect to MG interconnections, and that of provincial/territorial government, if any, in thecontext of 18th amendment with respect to autonomy in electricity generation? What will be the role of donors and IFIs for MG deployment in Pakistan?
2. Will the tariff of MG be regulated or not? If yes, what would be the ceiling of non-regulated tariff assuming that very small MG will not be regulated?
3. Will grid-connected MG projects be allowed to become a distributor of electricity purchasedfrom the centralized grid?
4. How simple regulatory framework would be? Will license be required to become an MG operator? If yes, for all or only for above certain kW capacity?
5. What will be the legal and regulatory framework, and mechanism for acquisition and utilization of public sector land for the purpose of MGs development and operation.
6. Will the MG sector be subsidized or not e.g. through allocation of 100% free or partly subsidized public sector land?
7. Will the private housing societies be allowed to have their own MG setup? Will they be allowed Net metering or not? If yes, then upto what capacity? Will licensing be required ornot?

5.3 Existing MGs Experience Pertaining to Pakistan

It is important to mention here that MGs development has already been initiated in a few geographical areas of Pakistan. In order to facilitate new MG projects, there is a need of showcasing the MGs feasibilities, projects, technologies, ready-made business plans, financing options, etc. Moreover, an integrated study may also be performed for the whole country with respect to potential and opportunities related to MGs. Master database may be prepared and shared widely (data of all the existing micro grids, potential for new such options, investment opportunities, funding opportunities, etc.) among the potential sponsors and other stakeholders.

Status of MG Projects under Government of Khyber Pakhtunkhwa (GoKP)

GoKP has done exemplary work in the area of MG development without any structured policy orregulatory framework/guidelines. Currently, it is developing 13 numbers of MG projects based on solar PV.

Pakistan Poverty Alliance Fund (PPAF)

PPAF is implementing 68 numbers of state-of-the-art solar energy MG projects in remote and off-grid locations of Lakki Marwat, Swabi and Karak districts of Khyber Pakhtunkhwa. These MG systems will provide basic lighting requirements as well as support to village level businesses and local enterprises; an estimated 515 tons of CO_2 emissions will be avoided annually through these projects.

5.4 International Experience OF MGs Deployment

Introduction

Democratization of power sector is indispensable for sustainability and enhanced access to clean energy. MG may be explored as an option to provide optimal value of money to the investor and consumer as well as to enhance supply reliability, optimize operational costs and protect environment. However, it poses a difficult and unique set of challenges in terms of design, development and implementation. This section takes into account various dimensions of MG deployment barriers, that are needed to be overcome in order to achieve success in MG deployment endeavor; and what are the pre-requisites and other implications that may be faced with respect to MG deployment in Pakistan. These dimensions have been analyzed by studying various case studies of MGs deployment mainly in Asian and African regions having demographics and economic conditions similar to that of Pakistan.

With respect to MGs development, three tiers have been identified to deconstruct the challenges:

(1) Decision or policy makers, (2) Investors and (3) Consumers. Each of these tiers has its own set of barriers/constraints which are required to be overcome.

Decision or Policy Makers

This is the most critical tier with respect to upscaling of MGs in Pakistan. Policy makers, which includes the regulatory institutions for the purpose of this section of the document, must design and provide a conducive environment for investors and consumers of MGs. One of the key considerations shall be that the tailor-made, bottom-up expectations of the customer should meet the top-down decisions of the policy makers (Bijker et al.,1987).

Two fundamental questions are expected to arise while designing this policy: (1) how do the different tiers interact in the perspective of upcoming MG solutions? (2) how do different stakes associated with MGs, manage by the local community and other stakeholders? (Bijker et al.,1987 and Williams & Edge (1996). This may require the policy makers to prescribe institutional changes meant to facilitate the ease of business opportunities (Motjoadi et al., 2020).

In addition to considering consumer side of the scenario, the policy makers must address the investor side as well. They need to decide the level of participation from both public-sector and private sector. (Motjoadi et al., 2020). One of the key issues regarding non-involvement of private sector is the lack of specified policies and regulations for MGs. The policy considerations regarding investors must include (1) long-term certainty on the market development; (2) addressing risks associated with presence of centralized grid; (3) meeting various regulatory requirements; and (4) providing sustainable operation and cost-recovery through tariff regulations and financial support schemes (Williams & Edge, 1996).

It is learnt from international experience that it is important to have dedicated policies for MG deployment and the inclusion of MGs in national electricity policy and plan may escalate the MG market. For example, Sierra Leone and Rwanda have dedicated policies for MGs Deployment. Nigeria, Peru and Tanzania, have all included MGs solutions in their plans. Furthermore, Rwanda's National Electrification Plan, published by its national utility, has demarcated areas for MGs expansion. (IRENA, 2018).

Another critical policy level issue is the MGs replacing over conventional grid in their application areas and the strategies to deal with stranded cost of transmission and distribution assets (Motjoadi et al., 2020). The policy makers of Indonesia, Nigeria, Rwanda and Tanzania, for example, have incentivized MGs operators to utilize net-metering provisions with central grid at fixed tariff, and to acquire a distribution license, relocate assets or sell parts of its assets to the utility (IRENA, 2018). Through CTBCM interventions in electricity power sector, GoP have successfully devised a mechanism on dealing with the issue of stranded cost related to transmission and distribution assets. This strategy may be customized and utilized as a benchmark for MGs deployment case.

Investors

Keeping in view a longer project life duration, a huge upfront investment is expected to incur. The financial resources for setting up a MG system is presumably greater than the required investment for a diesel generator. Thus, for the implementation of MG systems, particularly in rural or remote communities, access to the adequate capital is a major barrier.

There are two parts to this argument. Firstly, a sustainable investor-led MGs business requires that fixed and operational cost of the infrastructure and its operations be sufficiently recovered along with decent return on the investment. Typical modes of revenue generation are: connection fees and electricity sales. Secondly, the communities are able to pay the cost of services to the project owners. Evidently, it has been observed that the absence of economic activity in remote rural communities makes returns on investment through insignificantly charging the consumers (IRENA, 2018).

There are number of ways that are being exercised around the globe to ensure smooth flow of capital from consumers to project owners which includes setting the right mechanism and the tariff for cost recovery, facilitation in project preparation, subsidizing MG projects, facilitation in access to finance and involvement of public sector in financing of community development projects.

In certain cases, policy makers allow project sponsors and local community to set tariffs through mutual deliberation, such that the tariffs are sufficient to cover costs but ensure that consumers are willing to pay. Increasingly, policy makers are taking a custom-build approach regarding setting the tariff for MG. For example, Nigeria, Rwanda and Tanzania have allowed deregulated tariffs for MG under an installed capacity ceiling. However, large MG systems are required to use standardized tariff calculation and such tariffs need to be approved by the policy makers. Indonesia and Peru have prepared a methodology for standardizing tariffs to encourage private sector involvement (IRENA, 2018).

Tanzania has allowed project sponsors to share cost for preparation studies for licenses, feasibility studies, environmental impact studies, etc. There are also conditional awards available for the support of pre-investment financing up to 80% of the charges (EUEI 2014). The Rural Electrification Project in Nigeria provides public financing for the project preparation phase including economic and geo-spatial data gathering for pre-selected locations (IRENA, 2018).

The upscaling of MG systems includes a key element focusing on a line of credit and direct financing for off-grid electrification. Such initiatives provide lines of credit to financial institutions on a local level for on-lending to micro, small and medium enterprises, households as well as direct loans to private organizations. For example, in Tanzania, a USD 23 million credit line by the World Bank has been agreed to be provided to local commercial banks to refinance up to 85% of loans on low-interest debt to projects under 10 MW (IRENA, 2018).

The countries examined for this study show a varying degrees of both public and private sectors participation in MG development depending on the context. In Indonesia, the government has provided financial support in developing MG through subsidies and grants. The ownership remains with public sector, while operation and maintenance is transferred to the community. In India, MG project sponsors are provided a choice to opt a pre-determined subsidy in exchange of other requirements including tariff restrictions, service quality, safety and security standards. In Nigeria, the subsidy is allocated through a bidding process for pre-selected MGs locations from private sector developers and operators. Split-assets investments approach is another alternative to encourage public-private partnerships wherein the development of the distribution network is financed by the public utility, while construction, operation and maintenance of the generation assets are taken care through private sector finances (IRENA, 2018).

Investors are, furthermore, feared that presence of centralized grid may take business opportunity of MGs due to its superiority of ensuring continuous supply of electricity. The details of this critical issue along with its potential mitigation strategies are discussed in Chapter 4 of this document.

Consumers

There is an increasing urge for clean, continuous, and economical energy generation, which is causing to search for alternate energy solutions. This is, however, subject to many underlying factors and realities that are either hidden or not adequately evaluated prior to project development. From the consumer perspective, the need for energy may be of any type of end-use, like for lighting, cooking, cooling, heating, irrigating, charging, etc. and that need is to be decided by the consumer, which will eventually drive the type of MG solution.

With respect to MGs design and development, customer spread is assumed to be uniform within a particular MG, whereas the distinct differences of communities and their electricity requirements among the population are discounted. This also refers to the fundamental questions discussed in designing of the policy of MGs. For the successful implementation of the MG systems, public-in-particular framework should employ in which the communities have an identifiable stake, particularly, an issue, controversy or internal difference can be solved or mitigated through technological endeavors. (Michael. 1998).

The consumer, irrespective of the energy being clean, ultimately requires uninterruptible supply of electricity. The case study of Bihar, India clearly indicates that the hunger for more energy exists in the consumer, and they make an intended effort to go beyond the contracted energy needs. Such increasing appetite for energy then drives consumers towards centralized grid or in many cases the consumer may eventually claim their entitlement, enfranchisement of public, to the centralized grid (Sharma, 2020).

5.5 Policy Insights

Based on the existing policies, gap analysis carried out and lessons learnt from the international experience of MGs design, development and implementation, following are the certain policy insights that may be considered for the successful and large-scale deployment of MGs in Pakistan:

a. Dedicated policy is critical to scale up MGs development addressing long-term certainty onmarket development, financial support schemes and addressing risks associated with presence of the centralized grid.

b. Although MGs deployment has already been initiated in few areas, there is an urgent need of a regulatory framework to address various regulatory requirements, sustainable operation and cost-recovery mechanism.

c. A meticulous identification of requirements becomes imperative in consultation with localcommunity, to elicit the MGs solution. For example, a MGs solution in Baluchistan or areas of Thar, Sindh where there is currently zero access to electricity or any other form of energy, the requirement of energy from MGs systems may, perhaps, be getting water from nearby wells, energy for cooling purposes or getting access to telecommunication services or the internet for significant time of the day. On the other hand, requirement of energy-use in Northern Areas of Pakistan is quite different as energy is required for mostly heating purposes where one cannot rely on hydro resource which becomes simply unavailable or highly unreliable in winters.

d. Extensive stakeholder engagement is vital for moving forward and this may be achieved through engagement of Community Based Organizations (CBOs), technology demonstration and its effective use, and knowledge creation and its institutionalization pertaining to sustainability of MGs solutions.

e. As a recent development in power sector (August 2021), the GoP has approved exemption of generation license for small-scale RE-based systems up to 25 kW for net metering to facilitate the consumers who wish to install small-scale solar systems for their homes and businesses while availing the facility of net metering. With the same spirit, GoP and NEPRApreferably may develop and implement a simple and encouraging regulatory framework for overwhelming development of MGs in Pakistan.

5.6 Regulatory Framework

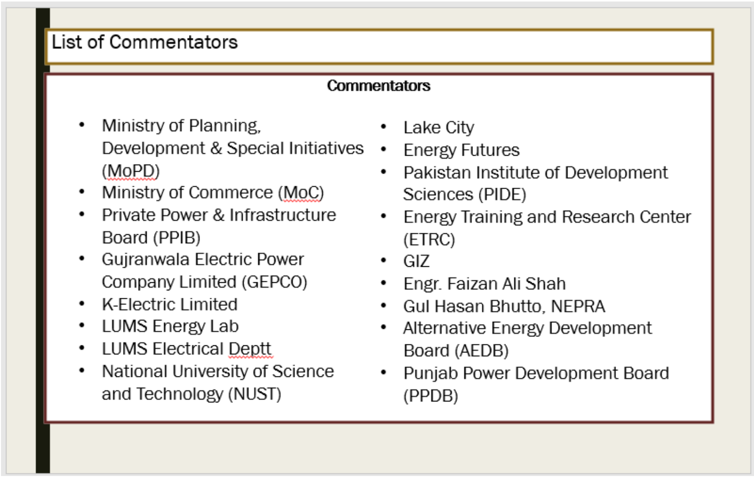
As mentioned in the previous sections, the issuance of MG regulations is one of the critical prerequisites in achieving widespread MG deployment in Pakistan. Fortunately, during the course of this study, i.e. in December 2021, NEPRA published the draft licensing regulations for MGs and sought comments from all the interested parties as shown in the Figure 27.

Figure 27: NEPRA's Call for Comments

Accordingly, the study team interacted with NEPRA and subsequently submitted a comprehensive set of comments and observations vide an email, attached as Annexure-II.

In the consultative session on regulatory regime for mini-micro grid system, conducted under the convenorship of Chairman NEPRA on 21st January 2022, the comments from this team were also discussed and deliberated, (as shown in the Figure 28).

Figure 28: NEPRA's Presentation



Finalization of the regulations is under process, it is expected to be approved and enforced in thecoming months.

BUSINESS MODELS FOR MGs

6.1 Introduction

In this chapter, potential business models for MGs deployment in Pakistan keeping in view existing policies and probable future regulatory framework are discussed.

6.2 Existing MG Activities in the Country

Although MGs have started being recognized by the Government of Pakistan mainly through the recently enforced ARE Policy 2019, there are proactive interventions already in place at the provincial levels. For this study, meetings were conducted with Punjab Power Development Board (PPDB) at Lahore, Pakhtunkhwa Energy Development Organization (PEDO) at Peshawar, to understand their workings at the provincial level pertaining to deployment of MGs.

The Government of Khyber Pakhtunkhwa (KP) has major focus on the social uplift of the deprived communities residing in far flung areas of the province. In this regard, they have carried out three projects i.e. a) Development of mini/micro hydro power plants; b) Solarization of schools and masajids; and c) Installation of solar mini/micro energy systems. For all these three projects, the project sponsor is the Government of KP, executing agency is PEDO and the energy systems are managed by the local community. The objectives of these intervention are: a) Increase economic activity in the region; b) Create employment opportunities; c) Optimum utilization of local resources for the community; and d) Supply of low cost, locally managed, clean energy.

Within the KP Province, 356 mini/micro hydro power projects ranging from 15 kW to 500 kW are located in Swat, Shangla, Kohistan, Chitral, Dir Upper, Dir Lower, Abbottabad, Battagram, Buner, Mansehra and Torghar. Out of these 356, 180 have already been completed, whereas rest of the projects are under construction. Completed projects are being operated and managed by the local community.

Capitalizing on these achievements and experience, Government of KP plans to provide electricity to 4,400 masajids, 8,000 schools, 187 basic health centers in the entire province and install 13 micro/mini solar power projects in rural districts of KP especially those that have been formed after merger of Federally Administered Tribal Areas (FATA) in KP. Solar PV MGs are planned to be installed at 13 districts: Bajaur, Mohmand, Khyber, Frontier (FR) Peshawar, Orakzai, Kuram, FR Tank, South Waziristan, North Waziristan, FR Bannu, FR Lakki, FR Dera Ismail Khan and FR Kohat. The MG infrastructure comprises of 175 kW solar PV, 250-300 kWh Lithium-ion battery system and AC transmission system to connect with the consumers.

Government of Punjab has also adopted a similar approach in the development and deployment of MGs in the province. The focus of Punjab is primarily on solar; they have utilized this clean energy to reduce reliance of public buildings mainly schools, universities and basic health units on the dilapidated electricity distribution infrastructure. The project was funded by Asian Development Bank and the executing agency is Punjab Power Development Board (PPDB).

PPDB has managed to solarize 2,324 basic health units in Punjab. The project began in 2018-19 with the survey and selection of the basic health units and was completed in 2020-21. This added a cumulative 7.204 MW of installed capacity of solar in the province with an estimated amount of

PKR 210 million. Likewise, 6,991 schools were solarized in Southern Punjab in the first phase. This furthermore, increased the installed capacity of solar in Punjab to 31.004 MW. The cost of project is USD 345 million. The Government of Punjab now plans to include 4,200 schools in Central and Northern Punjab as well. These projects are being operated and managed by local community or the building administration.

In a bid to reduce the carbon footprint, the Government of Punjab is the first to introduce a business model of Energy Service Companies (ESCOs) in the province. This initiative started with the solarization of public universities in Punjab on ESCO model; for the purpose of this model, CAPEX and OPEX will be borne by the ESCO and the buyer will pay to ESCO on a mutually agreed tariff. Major universities that are being benefited from this model include University of Engineering and Technology, Lahore and Islamia University Bahawalpur. The ESCO model has now been expanded to various commercial buildings as well as industrial facilities.

6.3 Potential Business Models

In this section, potential business models for MGs deployment are discussed in the light of ARE 2019 Policy and draft NEPRA Licensing (Microgrid) Regulations 2021 (expected to be approved and enforced shortly). ARE Policy 2019 includes off-grid Alternative and Renewable Energy Projects (AREPs) or MGs as per Section 1.3.2 and it further states in the Section 3.4 that public sector MG projects will undergo competitive bidding. For this purpose, Section 3.9 explains:

"NEPRA will modify its regulatory framework accordingly within six months of the promulgation of this Policy."

This became the basis of NEPRA Licensing (Microgrid) Regulations 2021. NEPRA started the preparation process of this important regulations. The MGs being installed or commissioned in the country are currently un-regulated and unstandardized, and major interventions have been done by the government through International Financial Institutions (IFIs) with increasing investment in CAPEX, but no plan to sustain the OPEX.

Any successful business model must possess three key features: a) Scalability; b) Interoperability; and c) Sustainability. Based on these principles, four potential business models are illustrated and proposed. For this study and on the basis of ARE Policy 2019, National Electricity Policy 2021 and draft NEPRA Licensing (Microgrid) Regulations 2021, business models are envisaged that capture the future outlook of the MG business activities in Pakistan.

Figure 29 provides a model where a government entity becomes the MG licensee and undertakes to plan, design, construct, operate and maintain the MG infrastructure along with associated generation. This is the existing structure that government is investing in a bid to provide economic stimulus to the deprived communities. However, in this model, there is no room for scalability and sustainability for the MG deployments.

Figure 30 shows the investor owned MG business model which is perceived from the prevailing policy and the draft regulation. This is similar to the first model shown in Figure 29, but here private sector undertakes all the activities of planning, design, constructing, operation and maintenance. For this model, major concern remains that the investor is deemed to have monopoly of supply in the specified service territory.

Figure 29: MG Business Model 1 – Utility Owned Model (Generation + Wire Business)

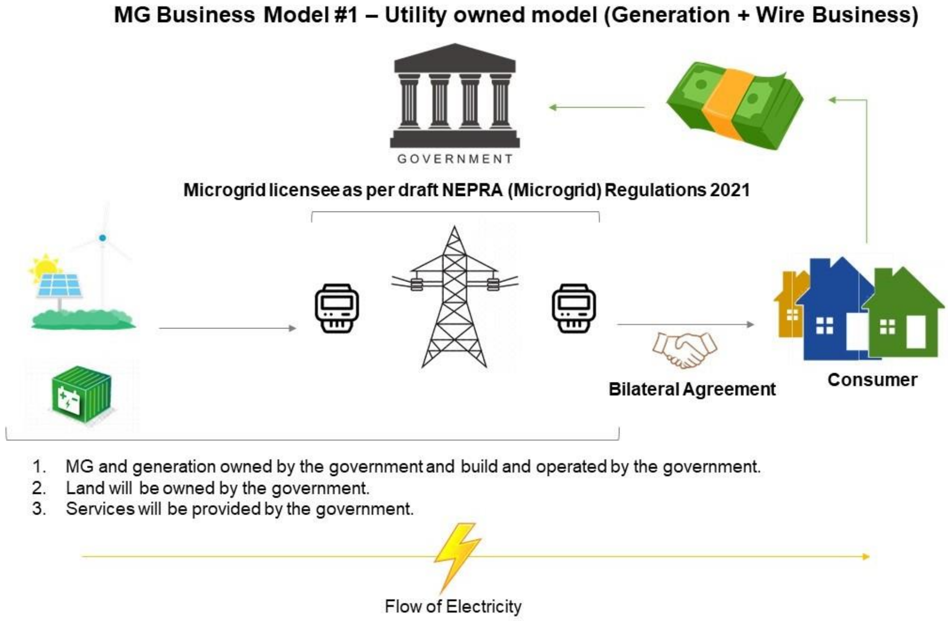
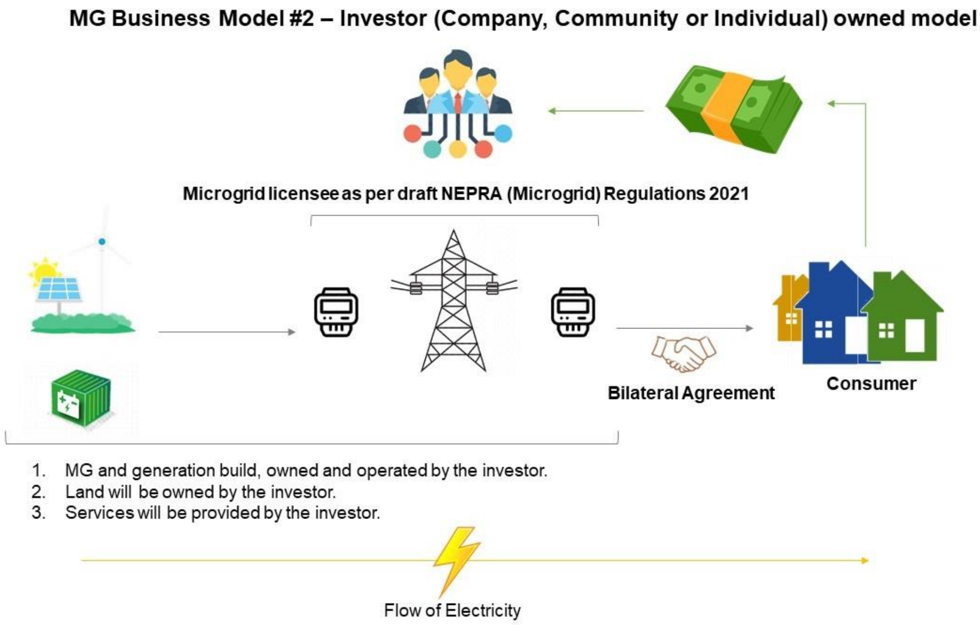


Figure 30: Investor (Company, Community or Individual) owned Model



The business models, as illustrated through Figure 31 and 32, have been proposed for upcoming MG enterprise which will outperform the existing and unsustainable business frameworks, increase private sector participation, provide effective operation and maintenance and ensure more transparency and sustainability in the energy system.

Figure 31 shows an investor-owned model which is more decentralized allowing more competition and increased private sector participation. In this model, MG licensee owns the wires and metering infrastructure. Generators on IPP mode provide supply of electricity that are contracted through Power Purchase Agreements (PPAs); this constitutes the CAPEX of the MG energy system infrastructure. The OPEX part for this model is undertaken and monitored by a Community Based Organization (CBO) which manages the distribution network and the flow of power across it from the generator to the consumer. Furthermore, it manages metering infrastructure for sale and purchase of electricity and provides authorized services to the consumers through bilateral agreements. The CBO also acts as a power purchasing agency which collects the payments from the consumers and disburse it to the wire business owners and the generators. This model manages community's ownership making the system more sustainable for longer period of time. The CBO includes representation from Generators, MG licensee and the community itself.

Figure 31: Investor-owned model with involvement of CBO

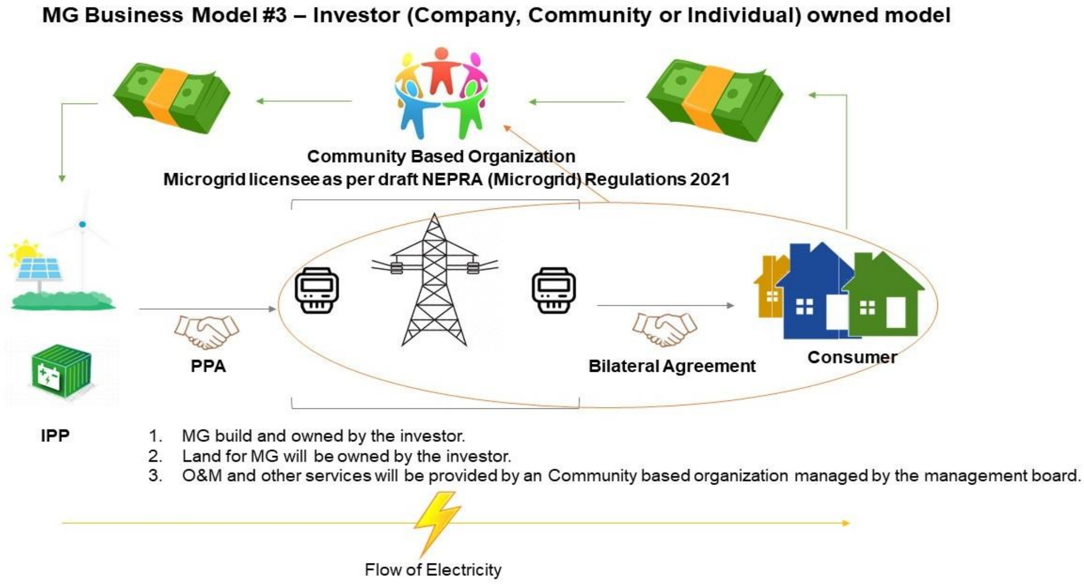
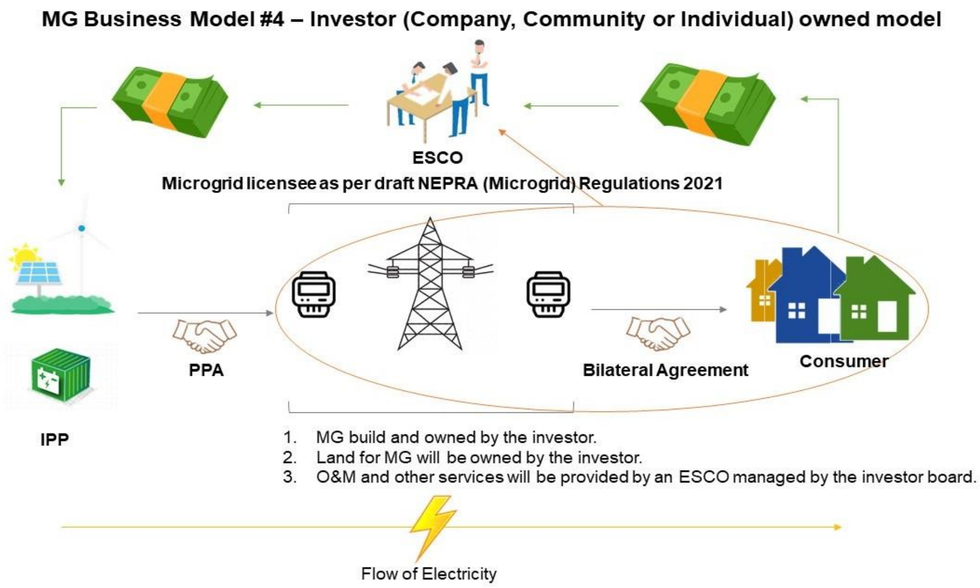


Figure 32: Investor-owned model with involvement of ESCO



A similar approach is adopted in the business model displayed in Figure 32, however, the mandate to operate and maintain the MG infrastructure is transferred to an ESCO which can be implied as for more advance network control and operations. The ESCO also acts as the power purchasing agency which manages sale and purchase of electricity. The ESCO is governed by the investor board which includes participation from Generators, MG licensee and the community.

The success of any of the business models discussed above is subject to the underlying issues regarding arrival of host distribution licensee grid, the stringent regulations even for investors in the range less than 100 kW and SOPs pertaining to billing and metering to be made by the electricity regulator. These issues are potential impediments to the economic stimulus in the MG business growth in Pakistan.

CONCLUSION & RECOMMENDATIONS

7.1 Conclusion

1. Comparison for different applicable MG scenarios as discussed and analyzed in Chapter 3is provided in Table 30:

Table 26: Summarized Comparison of Scenario:

Parameter	Scenario 1	Scenario 2	Scenario 3
LCOE ($/kWh)	0.111	0.0981	0.0929
Net Present Cost ($)	64,120	78,068	118,903
CAPEX ($)	27,836	34,213	16,048
OPEX ($)	1,587	1,918	4,499
Fuel Consumption Savings (Litre/year)	15,216	16,151	0
CO_2 Emissions Savings as comparedto Diesel Generator (kg/Year)	39,831	42,276	15,479
IRR (%)	79.5	66.1	20
Payback Period (Year)	1.34	1.57	5.22

NOTE:
*Scenario 1: Off-grid MGs application for rural villages/areas having solar PV and wind potential.
*Scenario 2: Off-grid MGs application for rural villages/areas having solar PV and micro-hydro potential.
*Scenario 3: Grid-connected MGs application for Housing Societies or Commercial Centres in Urban Areas having utility electricity access.

2. As shown in Table 30, MG deployment makes strong financial viability and presents a lucrative investment opportunity for investors. Concept of MGs, therefore, needs to be acknowledged as a business opportunity by a private sector.

3. Fuel based MG results in lot of CO_2 emissions which is detrimental for environment. Renewable Energy (RE) based MG saves significant emissions and are thus environment-friendly.

4. RE dominated MGs presents much more financial feasibility as compared to fossil-fuel based MGs.

5. Due to the increasing trend of electricity prices, MG solution has become a cost-effective solution as compared to conventional integrated grid for particular scenarios/applications.

6. MG option is better than conventional integrated grid only for the above specific scenarios/applications, not an optimal solution under all situations. The

feasibility will change significantly depending on various factors like no or lesser Renewable Energy (RE) potential, consumer requirement of 0% allowed capacity shortage, change in cost trends of REs vs fossil fuels, etc.

7. Technical issues associated with MGs are stability, safety, protective relaying, harmonics,voltage unbalance, etc. Although MGs present a very cost-effective solution for remote unelectrified areas of Pakistan, however, they may face technical issues if not properlydesigned. Owners of MG must take care of them as highlighted in Chapter 4.

8. Keeping in view Pakistan's context, fundamental outline of customized business models is presented in Chapter 6, which may be helpful for the investors and other stakeholders.

9. Existing policy and regulatory framework is insufficient to effectively upscale MGsdeployment in Pakistan.

10. DC MGs have become a reality in many countries during recent years. DC MG shows apromising 12 % decrease in cost of energy as compared to similar AC MG, i.e., from 0.111

    $/kWh to 0.098 $/kWh.

11. Application of MGs for irrigation purpose present an interesting case. As shown in Chapter 3, hybrid MG having application for irrigation has more economic viability since it shows a promising 18 % decrease in cost of energy as compared to similar normal ruralMG, i.e., from 0.119 $/kWh to 0.0976 $/kWh.

12. Allowed capacity shortage is an important factor to be considered for MG development. Cost of Energy decreases exponentially with the increase in the allowed percentage capacity shortage.

13. Discount rate and project lifetime are important factors to be considered to evaluate the feasibility of MG. The Cost of Energy (CoE) increases linearly with discount rate and decreases exponentially with project lifetime.

14. Allowed percentage capacity shortage significantly affects the energy mix decisions. With the consumer requirement of percentage allowed capacity shortage from 0% upto 0.4%,inclusion of conventional generator in the optimal energy mix is essential, and cannot beachieved with renewables and storage system only.

15. The load profile significantly affects the CoE of MG system; in case demand profile is changed from 24 hours to 12 hours (day-only load), it shows a promising 40 % decrease in CoE, from 0.111 $/kWh to 0.0677 $/kWh.

7.2 Recommendations

1. Dedicated and comprehensive policy should be issued to up-scale MGs development addressing long-term un-certainty of market development, financial support schemes and risks associated with the presence of the centralized grid.

2. For upscaling of MGs deployment in Pakistan, there is an urgent need of a regulatory framework to address various regulatory requirements, sustainable operation and cost-recovery mechanism.

3. DC MGs should be allowed in the regulations for Microgrids, to be issued by NEPRA.

4. Coordinated efforts by the stakeholder entities are to be channelized for utilizing applicability of MGs in terms of irrigation purpose in remote rural areas.

5. MGs should also be allowed to operate in grid connected mode; for this purpose, the draft regulatory framework may be customized.

6. While assessing electricity provision for remote unelectrified areas of Pakistan, it is imperative for the system planner to consider and evaluate MG option before proposinghuge investments for transmission and distribution infrastructure.

7. Based on the study findings, the optimal solution of MGs comes out with major share of renewable energy resources, therefore, renewables based MGs should be promoted in the upcoming policy and regulations.

8. For fossil fuel based MGs, CO_2 emissions should be compensated through a carbon-credit mechanism, to be provided in the upcoming regulatory framework.

9. In view of inverse relationship between CoE and the allowed capacity shortage, design of MG should be aligned with the affordability of the customers in the specific geographical area, to create a win-win situation for all the stakeholders.

10. A mechanism for dealing with the technical issues such as stability, safety, protective relaying, harmonics, voltage unbalance, etc., associated with MGs should be addressed in the draft regulations for Microgrids.

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ANNEXURES

ANNEXURE-I

Data Collection Form for Provincial/Territorial Governmentsand Other Stakeholders

<u>Data Collection Form</u>

Province/Territory	AJK / Baluchistan / GB / KPK / Punjab / Sindh *(please encircle one)*
Focal Person Name	
Designation	
Department	
Cell No(s).	
Email	

#	Parameter	Data
1.	Electrified population of the province(%)	
2.	Un-electrified population of province (%)	
3.	Is there any micro grid project currently operating/under development in the province/territory? If yes, please provide the details.	
a.	Micro grid projects currently operating /under development (Nos.)	
b.	Public Sector (Nos.) / Private Sector(Nos.)	
c.	Location	
#	**Parameter**	**Data**
d.	Size (kW)	
e.	Capital Investment (Pak Rs.)	
f.	No. of beneficiary families	
g.	Energy source (solar, wind, solar +distributed generation, etc.)	
h.	Interconnection arrangements withDISCO or National Grid, if any	
i.	Contact person name and contact details	

Please use extra sheet in case more than one micro grid projects are operating or being developed in the province/territory and provide data for the parameters from 3a – 3i		
4.	Please share electricity expansion plans, if any, of each of the DISCOs under the jurisdiction of the province/territory i.e. up to 132 kV grid station(s) andassociated distribution system	
5.	Kindly share details and copy of the existing policy, if any, of the provincial / territorial government for encouraging MGs development in the province/territory.	
6.	Does the provincial/territorial government have any formal rural electrification plans? If yes, please share it.	
7.	Any public sector/private sector/International FinancialInstitutions' funding available for setting up MGs. If yes, please provide details.	
8.	Potential of Micro/Mini Grids in the Province (Un-electrified Localities) where utility's network does not currently exist	
a.	No. of potential localities	
b.	Locality Name (Village, etc.)	
c.	Area of Locality (km^2)	
d.	Geographical Coordinates	
e.	Population of the Locality	
f.	Population breakup of the Locality with different income group (Rs. per monthper family)	Up to Rs. 20,000 (%) Between 20,000 to 40,000 (%) Between 40,000 to 80,000 (%) Between 80,000 to 120,000 (%) Higher than 120,000 (%)
#	**Parameter**	**Data**
g.	Distance from the nearest town/city (km)	
h.	Distance from the nearest electrical interconnection point (Grid Station, Distribution Line, etc.) of utility network (km)	
i.	How does different segments of this population manage their electricity needssuch as for heating, cooling, light, tubewell. etc.?	
j.	Priority factor assigned by the provincial / territorial government for each of the potential localities added in this section (use a scale of 1 to 5 with '1' being the topmost priority)	

k.	Estimated Electricity Demand (MW) forwinter	
l.	Estimated Electricity Demand (GWh) forwinter	
m.	Estimated Electricity Demand (MW) forsummer	
n.	Estimated Electricity Demand (GWh) forsummer	
o.	Availability of indigenous energy resources in MW for producing electricity such as Solar, Wind, Micro/Mini Hydro, other)	
Please use extra sheet in case more than one potential locality exist in the province/territory and provide data for the parameters from 8a – 8o		
9.	Areas falling under Weak/In-consistent Distribution Network (where heavy load shedding / electricity-outage is being enforced as a frequent feature).	
a.	Average number of hours per year loadshedding being performed	
b1.	Average number of hours per day loadshedding being performed in summer	
b2.	Average number of hours per day loadshedding being performed in winter	
c1.	Maximum number of hours per day loadshedding being performed in summer	
c2.	Maximum number of hours per day loadshedding being performed in winter	
d.	Frequency of power failure other thanannounced load shedding and its usual restoration time period	
e.	Known reasons of load shedding/power failure (In-sufficient capacity, Weak network, Non-payment by the customers,etc.)	
#	**Parameter**	**Data**
f.	No. of potential localities for setting upmicro grids in these areas	
g.	Locality Name (Mohalla, etc.)	
h.	Area of Locality (km^2)	
i.	Geographical Coordinates	

j.	Priority factor assigned by the provincial / territorial government for each of the potential localities (facing issues of severe unreliability of electricity supply) added in this section. Use a scale of 1 to 5with '1' being the top most priority.	
k.	Estimated Electricity Demand (MW) forwinter	
l.	Estimated Electricity Demand (GWh) forwinter	
m.	Estimated Electricity Demand (MW) forsummer	
n.	Estimated Electricity Demand (GWh) forsummer	
o.	Availability of indigenous energy resources for producing electricity such as Solar, Wind, Micro/Mini Hydro, other) with MW potential corresponding to eachresource	
Please use extra sheet in case more than one potential locality exist in the areas with Weak/In-consistent Distribution Network and mention the same parameters from 9a – 9o		
10.	Potential of Micro/Mini Grids in the Province / Territory (Future Planned Housing Societies / Commercial Centres, other similar localities) for Urban Areas	
a.	No. of potential localities	
b.	Locality name	
c.	Area of locality (km^2)	
d.	Geographical coordinates	
e.	Estimated population of the locality	
f.	Normal population breakup in this locality with different income groups (Rs.per month per family)	Up to Rs. 80,000 (%) Between 80,000 to 140,000 (%) Between 140,000 to 200,000 (%) Between 200,000 to 260,000 (%)Higher than 260,000 (%)
g.	Distance from the nearest electrical interconnection point (Grid Station, Distribution Line, etc.) of utility network (km)	
#	**Parameter**	**Data**
h.	Please share electricity expansion plans for this locality, if any, of each of the DISCOs under the jurisdiction of theprovince i.e. up to 132 kV grid station(s) and associated distribution system.	
i.	Estimated number of cars per family inthe locality	

j.	Estimated Electricity Demand (MW) forwinter	
k.	Estimated Electricity Demand (GWh) forwinter	
l.	Estimated Electricity Demand (MW) forsummer	
m.	Estimated Electricity Demand (GWh) forsummer	
n.	Availability of indigenous energy resources in MW for producing electricity such as Solar, Wind, Micro/Mini Hydro, other) with MW potential	
o.	Existing/ planned data regarding urban buildings/ homes to be shifted to roof topsolar PVs or other localized RE	
	generation and utilizing (or aim toutilize) net metering options	
Please use extra sheet in case more than one potential locality exist in the province/territory and provide data for the parameters from 10a – 10o		

In case of any query with respect to preparing and providing this data, please feel free to contact:

- Engr. Danial Saleem, Cell No.: 0322 4853086, Email: danial.saleem@ntdc.com.pk
- Engr. Yasoon Aslam, Cell No.: 0335 7401200, Email: yasoon.aslam@ntdc.com.pk

ANNEXURE-II

Comments/Observations/Suggestions on Draft National Electric Power Regulatory Authority (Microgrid) Regulations, 2021

20th December 2021

Firstly, we would like to congratulate NEPRA to start the developing process of such an important regulation. The Microgrids being installed or commissioned in the country are entirely un-regulated and unstandardized. We strongly hope that this regulation and associated documents will open the doors for upscaling setting up of microgrids and thus enhance the electricity access to a large size of population, In sha Allah. Also, we would like to extend our compliments to the NEPRA team, who have worked for developing these regulations, for accomplishing a great job.

Our team has thoroughly reviewed the document in light of ARE Policy 2019, National Electricity Policy 2021, on-going development of Microgrid projects in Pakistan and international best practices. Following are the comments and suggestions for the improvement of the draft regulations and, in larger context, for the betterment of Pakistan. We hope that this will add value in the draft regulation.

Preface/Introduction:

a. The draft regulations exclusively cater for the microgrids. It would be much morebeneficial to the stakeholders if minigrids are also included in the same regulations.

b. The underlined part in the statement "National Electricity Policy 2021 (NEP) has stressed on off-grid and micro-grid solutions in order to promote electricity access to areas where grid expansion is *financially unviable*", is suggested to be changed to,'*financially and/or technically unviable*'.

Section # 2 ((f), i, ii, iv), Definition of Microgrid:

a. Although putting maximum limit of peak load as 5 MW is a subjective decision, it needs to be reconsidered to increase this limit to 10 MW, keeping in view the load requirements, community size and probabilistic load growth pattern in areas/localities suitable for MG applications.

b. In order to facilitate small investors/new entrants, stringent technical and regulatory requirements may be relaxed depending upon the size of MGs. Therefore, classification of MGs may be included as below and different standardized procedures (technical, qualification and licensing requirements) may be applied according to the relevant category:

- Large Minigrid: 5 MW ≤ Large Minigrid < 10 MW
- Small Minigrid: 1 MW ≤ Small Minigrid < 5 MW
- Large Microgrid: 100 kW ≤ Large Microgrid < 1 MW
- Small Microgrid: 10 kW ≤ Small Microgrid < 100 kW

c. For the MG once installed/in-operation, the option of scaling up beyond its existing installed capacity specially in case of load growth, also needs to be catered for in the draftregulations.

d. Through the draft regulations, licensee is restricted to non-electrified areas or unservedmarkets. It is suggested to also include privately electrified areas (not a jurisdiction of DISCOs); price of electricity will govern the feasibility of MGs in such areas. For this purpose, both unserved market as well as BPCs (especially privately owned housing societies) intended to shift to MG system may be allowed to obtain MG license, under pre-defined terms and conditions.

e. It is not clear whether new housing societies, business centers, etc. within cities/rural areas or territory of DISCOs, where area is electrified, however, potential customer is yetto be provided connection by a DISCO, are considered as unserved market or not.

f. The draft regulations only address off-grid MGs, grid-connected MGs should also be catered for. Grid connected MGs are more stable and reliable than off-grid ones and results in increased efficiency of the system by exchanging (importing or exporting) electricity with the grid.

Section 3, Licensing of Microgrids, Subsection 1 (a & b):

a. According to Section No. 3 of Sustainable Development Goals Achievement Programme (SAP)'s Guidelines dated 09-03-2020 issued by Government of Pakistan Cabinet DivisionDevelopment Wing,

> *"At least, 10 residents of the area, will identify the scheme(s), and the scheme(s) with estimated cost ranging between Rs. 0.25 million to Rs. 50 million shall be included in the Programme. In case of the Gas Sector Scheme(s), the upper limit will be up to Rs. 300 million. In case of the Power Sector scheme(s) the lower limitshall be Rs. 0.15 million.*"

In order to align the objectives of MG regulations and SAP, and achieve optimal impact, it is suggested that the draft MG regulations should also include Community Based Organizations (CBOs) as eligible for securing MG license since collaboration under a CBOwould be ideal to fetch the benefits of a microgrid apart from addressing the lack of ownership issues (on the part of end customers).

b. The eligibility/qualification criteria i.e., minimum skills, experience, financial position, etc. required for the licensee to develop, own and operate the MGs seems to be missing;the same may please be mentioned/included in the draft regulations.

Section # 3 (3):

The emphasis on utilization of Renewables Energy (RE) sources is missing in the draft regulations which is, in our opinion, need to be incorporated. For example, it may be added that the RE sources shall be given preference at the location of the proposed MG, subject to the availability. Incentivizing RE-based MGs may also be looked into for this purpose.

Section # 3 (5):

a. Provision of grid-connected MG along with an option of net-metering may also beallowed/included in the MG regulations as this option is more reliable as well as cost- effective.

b. Section 3 (5) allows a provision for licensee to connect with host distribution licensee subject to Authority approval, however, the development of minimum standards at the point of common coupling are not covered in Section 5 "Minimum Standards" and the responsibility to develop such standards should also be mentioned or at least referred to (if available) in the regulations.

Section No. 4, Application Process, Subsection (2):

Mechanism for awarding a license appears to be missing in case of two or more candidates apply for the license for a same MG project.

Section # 5, Minimum Standards, Subsection (1):

a. Minimum standards for MGs (may be in the form of SOPs) need to be referred to in the regulations, to be developed in future and approved by the Authority.

b. It can be conveniently deduced that that the draft regulations do not include DC based MGs. Please refer to Chapter 4; Section 29 of the Electricity Rules 1937, which states that:

   "29. Declared frequency of supply to consumers. From the time of commencing the supply of energy to a consumer by means of an alternating current a licensee shall declare to the consumer the frequency at which he undertakes to supply energy and the licensee shall not, without the written consent of the consumer or the previous sanction of the Provincial Government, permit the frequency to vary therefrom by more than 4 per cent."

   In this regard, keeping in view the technological advancements and cost-effectiveness, DC based MG may also be covered/included in the regulations.

Section No. 6, Tariff, subsection 1:

Reference the statement “Tariff charged by the licensee to the consumers shall be negotiated between the parties bilaterally”, there must be an upper limit on tariff set by the Regulator. Moreover, there should be a competition during application phase between the potential licensees to secure the best price for the consumers.

Section 6(2):

a. The subsection (2) states that “*The licensee shall submit the bilateral agreement signed with consumers to the Authority for approval*”.

b. It is not clear whether MG owner will provide the agreements signed by all the consumers or just the authorized representative of consumers or some other type of agreements based on categorization of load i.e., domestic, residential, industrial, etc. areto be submitted to the Authority. The clause needs to be rephrased to bring more clarifyand to make the process simpler.

c. The clarity is required for the case of new consumers added after finalization of tariff orinstallation of MG, whether the owner will have to resubmit the bilateral agreement withnew consumers as well to the Authority.

d. Further clarity is required whether tariff for residential and commercial use within a specific MG would be same or different?

Section 7, Miscellaneous, subsection (1), Grid Arrival:

This clause seems unfair on the part of the licensee and it appears to support the host distribution licensee; it is, therefore, suggested that this clause be redrafted to introduce competition between licensee and the host distribution licensee based on price of the electricity (tariff) so that consumers are able to opt for the affordable electricity. Secondly, in case, the licensee voluntarily opts to relinquish the MG facility, appropriate provision should be added here to protect the rights of the licensee.

Section 7(1 (a)):

a. After grid arrival, the licensee may be empowered to give acquisition to DISCO (host distribution licensee) or continue the business as usual.
b. For an investor-based MG project, if the licensee has not fully recovered its investmentsyet, it will be unfair to acquire MG even before the break-even point or starts making profit. For this purpose, minimum period of operation of MGs linked with payback periodmay be defined for MG acquisition. Hence, the acquisition should primarily be voluntarilyfrom the licensee, the same may be incorporated in the regulations.

Section # 7 (2), Standard Operating Procedures:

The Standard Operating Procedures (SOPs) regarding billing and collection from consumers; connection and disconnection of consumers; suspension of service, etc. may be developed considering location, size, and other features of the MG. A single set of SOPs may not be applicable for all.

As per various MG case studies, custom made solutions are offered regarding MGs with features that may vary to produce efficient costing and effective business model for the consumers. Such requirements for adherence to SOPs will impede efficiency and effectiveness in the MG deployment.

Section # 7 (3), Accounting:

Keeping books of accounts, get it audited annually by a chartered accountant and filing the audited accounts with the Authority; and obtaining various other approvals from the Authority, etc., all this appear to be bureaucratic/tough/expansive (particularly for a small sized MG) which may be re-visited before finalizing.

Other General Comments:

In addition to above, the following aspects are also suggested to be included/covered in the final regulations:

a. How will the performance of MGs will be monitored? It is proposed that each MG licensee be required to periodically submit performance reports (the format to be stipulated by theAuthority) to the Authority.

b. Why there is no concept of competitive bidding proposed in the draft regulations for solicited projects?

c. MGs may be provided with an option to remain available and provide services only during a specific window of hours as per the requirements/needs of the consumers.

d. A legal binding may be imposed on DISCOs to share their expansion plans publically so thatdecision making with respect to investment for the potential MG developers may become easy.

e. Probable impacts of CTBCM regime and working of multiple license types need to be addressed for the case of MGs.

f. The target of 'Democratization of electric power sector' needs to be further depicted in thefinal regulations.

g. The renewable generation resources especially based on hydel (also for land provision in case of solar and wind) requires intervention of the provincial/territorial governments; thedraft regulations do not seem to address this critical aspect. Legal and regulatory framework, and mechanism for acquisition and utilization of public sector land for the purpose of MGs development and operation may be formulated and referred to in the MG regulations.

h. It is suggested to have some binding on MG licensee to serve for minimum number of years to the consumers, may be secured through some security deposit mechanism.

i. In order to promote MGs development in Pakistan initially, especially during the transition phase, certain regulations may be added for incentivizing the stakeholders.

ANNEXURE-III

Site Visits/Tour Reports

3A Meeting with Pakhtunkhwa Energy Department Organization (PEDO) in Peshawar on 8th November 2021 and 9th November 2021

Background

With reference to the data collection form which was submitted to stakeholders including ex-WAPDA Distribution Companies and provincial energy departments on 19th August 2021 pertaining to Microgrid/minigrid (MG) development in their respective regions, a 2-day tour was planned at PEDO office to understand the requirements of the Kyber Pakhtunkhwa (KPK) province and the efforts put forward by the government in this regard.

Meetings were carried out on 8-9th of November 2021 at PEDO office and on one of the project sites with Project Director (Solar) PEDO and his team. The information collected verbally during the conversations with the PEDO officers in relation to their solar power based MG development is described below;

PEDO Working on MG

Description: Government of KPK plans to provide electricity in rural districts of KPK especially those which have been established after merger of Federally Administered Tribal Areas (FATA) in KPK in order to alleviate poverty and ensure economic growth in the districts.

Location: Solar PV MGs are planned to be installed at the following districts of KPK.

a. Bajaur
b. Mohmand
c. Kyber
d. Frontier (FR) Peshawar
e. Orakzai
f. Kuram
g. FR Tank
h. South Waziristan
i. North Waziristan
j. FR Bannu
k. FR Lakki
l. FR Dera Ismail Khan
m. FR Kohat

Specifications: The MG infrastructure comprises of 175 kW capacity solar PV, 250-300 kWh Lithium-ion battery energy storage system and AC transmission system to connect with the consumers. The electricitysystem is envisaged to provide supply of electricity to 100 commercial consumers mainly shops.An area of 10 kanals, owned by the Government of KP, has been allotted in the vicinity of the selected location of consumers for the installation of Solar PV cells and battery system.

Financials and Tariff: The tariff estimated for the supply of electricity for 5 hours of the day is 10-20 PKR/kWh with a cost recovery in 5-7 years. It is important to mention here that the cost of land has been excluded from the tariff calculation which resulted in lower tariff. This tariff has not been approved by NEPRA, but it is expected to charge to the consumers for the supply of electricity provided through the MG system.

Cost of MG installation at each project site is 4.5 Million PKR. The draft PC-1 is yet to be submitted to the KP government by PEDO which details the complete business model of the MG.

Project Timeline: The project is expected to be completed by June 2022.

Project Status: Visit of a MG solar installation at Mohmand district in KP was conducted. The construction worksand installation of equipment at the project site is underway. Similarly, the status of other sites isthe same.

However, a critical activity i.e. identification of 100 commercial consumers is being planned by PEDO. Development of evaluation criteria to select prospective consumers is in process, however, it is expected that the provision of electricity to consumers, seeking a new connection, will be on *first-come-first-serve* basis.

Meeting with Punjab Power Development Board (PPDB) at Lahore on 19th November 2021

Background

With reference to the data collection form which was submitted to stakeholders including ex-WAPDA Distribution Companies and provincial energy departments on 19th August 2021 pertaining to Microgrid/Minigrid (MG) development in their respective regions, a meeting was planned at PPDB office to understand the requirements of the Punjab province and the efforts put forward by the government in this regard.

Meetings were carried out on 19th November 2021 at PPDB office with Manager (Thermal) and Manager (Renewables and Bio-fuels). The information collected verbally during the conversations with the PPDB officers in relation to their solar power based MG development is described below.

PPDB Working on MG

Description: The focus of Punjab Government is primarily on solar power and it has utilized this clean energyto reduce reliance of public buildings mainly schools, universities and basic health units in remoteareas of Southern Punjab.

The Government of Punjab is, furthermore, the first to introduce the business model of Energy Supply Companies (ESCOs) in the province. Major universities that are being benefited from this model include University of Engineering and Technology, Lahore and Islamia University Bahawalpur. The ESCO model has now been expanded to commercial buildings as well as industrial facilities.

The focus of Punjab Government is primarily on solar power and it is the first provincial government which has taken initiative to introduce the business model of Energy Supply Companies (ESCOs) for educational institutes in its jurisdiction. For instance, major universities that are being benefited from this model include University of Engineering and Technology, Lahore and Islamia University Bahawalpur. The ESCO model has now been expanded to commercial buildings as well as industrial facilities.

Location: The Solar PV MG systems have, predominately, been installed by the Government of Punjab in schools and basic health units in the Southern Punjab region. Many universities, factories and public buildings all around Punjab have deployed Solar PV MGs on their own through ESCOs.

Project Timeline: The project began in Fiscal Year (FY) 2018-20 with the survey and selection of the basic health units and was completed in FY 2020-21. The Government of Punjab now plans to include 4,200 schools in Central and Northern Punjab as well.

Project Status: PPDB has managed to solarize 2,324 basic health units in Punjab. This added a cumulative

7.204 MW of installed capacity of solar in the province with an estimated amount of 210 Million PKR. Likewise, 6,991 schools were solarized in Southern Punjab in the first phase. This has further increased the installed capacity of solar in Punjab to 31.004 MW. These projects are being operated and managed by local community or the building administration.