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A Global Analysis on Microgrids through the PESTEL Framework

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***Abstract*— Microgrids enable distribution of electricity with higher shares of variable renewables, higher power quality, greater reliability and higher efficiency. There are a large number of factors in addition to the technology, which affect their shift towards market competitiveness and widespread adoption. The PESTEL framework, covering Political, Economic, Social, Technical, Environmental and Legislative factors, is used to identify and describe the drivers and barriers for microgrid development at the global level. The framework enables a broader approach to describe potential for microgrid applications. The results aim to provide engineers, project developers and microgrid specialists with an overview of the prospects for microgrid deployment.**

***Keywords*- Microgrid, PESTEL, closed distribution network.**

I. Introduction

Microgrids have been investigated for their promise to provide higher reliability, higher power quality, higher energy utilization [1], lower costs for first time electrification [2], better solutions for decentralized or distributed generation (DG), improved resilience of the electricity grid and inclusion of a higher share of variable renewable energy (VRE) in the supply mix [3]. Further, they offer additional abilities such as autonomy, scalability, generation technology-neutral design, stability through transients and new economic models for energy trading between prosumers which are not feasible with large centralized grids[2].

A microgrid is currently being designed for implementation at the Green Village, a site for experimentation of innovative technologies on the campus of the Technical University in Delft, the Netherlands. The microgrid will integrate a reverse electro-dialysis battery [4] and a hydrogen fuel cell vehicle capable of delivering electricity to the grid [5], [6] with local distributed generation (PV array) and loads (office), governed by industrially developed control system . This research is part of the investigation into the larger scalability of the technology and its application in a more commercial environment.

Although microgrids have high potential, there are also significant barriers preventing their widespread usage, which are not limited to the technology domain [7]. Microgrids have significant overlap with concepts such as community energy initiatives [8], rural electrification [2], [9], Zero Energy Buildings [10], [11] and the energy transition. Few, if any, of these are technology-driven. It is thus essential for a broader analysis of both the drivers and barriers to microgrid development and application. The PESTEL (Political Economic Social Technical Environmental and Legislative) framework has been adopted in this study so as to provide a broader and more holistic overview of the current status of microgrids.

This study has been structured into sections as follows: Section II provides a brief overview of microgrids and the scope of the technologies considered in this study; Section III describes the methods used for this research; Section IV includes the analysis itself and discussion related to it while Section V concludes with the final summary of the outlook on microgrid technologies and areas for future research.

II. Microgrids: definitions and scope

The most commonly agreed upon definition of a microgrid is provided by the U.S. Department of Energy [12] as "*a group of interconnected loads and distributed energy resources within clearly defined boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and islanded mode*".

Another similar definition is provided by the Conseil International des Grands Réseaux Électriques (CIGRÉ) [13] as "*Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded*". Either of these definitions may be considered valid for description of the technology considered within the scope of this study.

Microgrids may also be divided into AC, DC and hybrid microgrids [14], with further subdivisions such as RACDS (Resilient AC Distribution Systems), DC zonal microgrids,

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Solid State Transformer (SST) based microgrids, etc.. Although technical parameters, (notably, control techniques, protection devices and architectures) as well as legislative standards (interconnection, safety) can vary significantly across AC and DC microgrids [15], [16], these differences are not addressed in this work with the view of keeping the scope as broad as possible.

There are also a number of ownership models for microgrids ranging from Distribution System Operator (DSO) owned microgrids to privately owned microgrids where companies design, build, own, operate and maintain (DBOOM) their microgrids while exchanging energy and service contracts with other parties [17], [18]. Once again, this study aims to cover issues which are universal to most microgrid ownership models. However, certain ownership models may have specific legal and economic attributes which are deemed out of the scope of this work.

III. METHODS

The research conducted was primarily through a survey of scientific and non-scientific literature conducted in 2019 on microgrids and their application. The author's experiences in design, planning, contracting and analysis of operation of microgrids in the Netherlands also contributed towards this work.

The PESTEL framework was chosen for this study due to its broad reach in the factors considered to describe the status of new technologies. As described in [19], the PESTEL framework provides further insights than the more widely used SWOT (Strengths Weaknesses Opportunities Threats) analysis. The PEST (Political Economic Social and Technical) framework was initially developed for the strategic evaluation of business environments, but has more recently found increasing application in other fields. With the addition of environmental and legislative factors, PESTEL analyses are now commonly used for the evaluations of the status of emergent technology [20]–[22]. However, there is limited investigation into the relative weights of the considered factors, as in a Multiple Criteria Decision Making (MCDM) model, which due to its complexity, is deemed out of the scope of this study.

While certain factors within the framework, especially political and legislative, are by their nature location or country specific, it is the objective of this study to be global in its outlook. Thus, wherever possible, an overview of common features across different locations is provided. However, due to the increased number of microgrid tests and research literature available in Europe and the USA (in the English language), these locations are expected to be addressed in greater detail than others. Nevertheless, literature specific to other locations, especially larger markets, such as Brazil, India and China has also been covered and further information may be found in the references section.

IV. PESTEL ANALYSIS AND DISCUSSIONS

Each of the factors within the PESTEL framework is addressed individually in the following sections. Within the framework, the drivers and barriers for microgrid development and application within the scope of each of the PESTEL factors are addressed.

A. Political

The political drivers for microgrids are primarily the desire for greater control over the energy system at various levels. At a national level, the desire for greater energy security and reduction of dependence on import of fuels support the development of microgrids. It may be noted that microgrids and their development have received considerable military attention and investment, especially in the USA, due to their characteristics like self-sufficiency, high resilience and survivability, low dependence on fossil fuels and reliable operation in remote locations [20]. Both from a national security and a military perspective, the greater resilience of microgrids to physical and cyber-attacks are strong political motivators for their use [3], [20].

At a more local level, the desire for greater sustainability as well as a desire for greater transparency in the costs of energy production are both important drivers for customer or community microgrids [21], [22]. Recent European legislature (mid-2019) provides legal recognition to 'Citizen Energy Communities' in response to this trend [23].

Although there are no specific policies at the pan-European level on microgrids (the most relevant being those on closed distribution networks), allied policies related to increasing the use of renewable energy, emission reduction policies in the electricity sector and requirements for end-use efficiency provide an environment conducive to the developments of microgrids [24].

However, the political barriers to microgrid development include a technology and institutional lock-in into energy regimes which are largely reliant on fossil fuels and nuclear power and powerful lobbies and advocacy for the same [8], [25]. Opposition from utilities to microgrids can also be significant. The reasons for this opposition are:

1) Microgrids can cannibalize existing revenue streams based on electricity sales and capacity fees due to self-consumption within microgrids and reduction in grid connection sizes. This, in turn, increases the costs for existing customers, escalating the effect [3].

2) DSOs see microgrids with large shares of DG are seen as harmful for the reliability of the main grid [7]. This is also linked to current regulation preferring 'docile citizen' (fully DSO controlled microgrids) or 'good citizen' (immediate islanding of systems or islanding after the required ride through time duration in case of grid faults) as opposed to 'ideal citizen' approaches where connected microgrids trade energy and services with the grid and disconnect only to protect the microgrid customers from grid disturbances [26].

Uncertain government planning [27] and shortsighted energy policy [8] are also cited as political barriers to microgrid development.

B. Economic

Microgrids have economic potential for a variety of reasons. Due to their ability to manage demand and have relatively low energy exchange with the larger grid, they can be used to avoid or defer grid investments. As an example, the expense of $1billion in traditional grid investment in Brooklyn and Queens, New York was deferred by at least 7 years through the implementation of various demand side management solutions at a fraction of the cost [28]. For remote microgrids, for which grid connection is either geographically or financially infeasible, savings on fuel through shift away from fossil fuel-based generators can be considerable [29].

Trading of energy or services at the Point of Common Coupling (PCC) which offer financial incentives for prosumers within the microgrid can result in lower energy costs for them [7]. Microgrids are also widely considered for rural electrification and sustainable development projects as the costs of first time electrification can be drastically reduced, while offering a much higher quality of supply than solar home systems [2].

Increasing costs of electricity can also lead to more opportunities for microgrids. For example, high energy prices were a problem for the public sector in Brazil in 2016. Due to this, the Ministry of Education, which included 65 federal universities, actively promoted self-generation and energy efficiency at these locations [17].

However, capital costs for microgrid still remain high. In pre-grid parity situations, costs of generation for solar PV, wind and other DG may be unviable without financial support, though this is likely to change. Storage may also be financially unfeasible in an unsubsidized market with typical grid connected storage costs in the range of US $2018400-1000/kWh [30]. The cost of microgrid control and energy management softwares can also prove to be high. In multiple demonstration projects, this was found to be a challenge, particularly since market support was provided only for DG units and not for the control system that integrated them [7], [27]. This is particularly critical since the control platform is essential for both the integration of the various components as well as the successful business model deployment [18].

C. Social

Social drivers for microgrids are similar to the political drivers in terms of the desire for community owned energy and the push towards the energy transition and emissions free energy, as previously addressed. Additionally, there is also the demand for higher quality of electricity supply since interruptions can lead to complaints from customers, economic damage, risks to healthcare equipment and other critical loads, loss of access to potable water, damage to refrigerated perishables, etc. [31].

Social barriers to microgrid development are often related to the lack of knowledge about the available technologies among customers and funding institutions. General dislike of DGs due to their influence on landscapes, not-in-my-backyard attitudes to sustainable energy [8] and considerable effort needed in order to convince communities involved in microgrid projects of their benefits [7] have all been cited as barriers to microgrid project implementation. Lack of knowledge about microgrid technologies and potentials have led to difficulties in securing funding and investment for projects [27]. Further, many projects involved a large number of stakeholders and achieving cooperation and consensus among them generally proved to be challenging [7], [8].

D. Technical

Previous academic works have focused heavily on the technical aspects of microgrids. A major technical driver for microgrid technologies is recent development at the material and engineering level of power electronics. Most forms of DG require power electronic interfaces for grid integration. Additionally, for control within microgrids through various strategies like droop and reverse droop, power electronics are essential. The increasing efficiencies, faster switching capabilities, higher power densities and lower materials requirements of semiconductor based power conversion electronics accompanied by falling costs [32], [33] are very favorable for microgrid development.

For microgrid fault detection and protection through Wide Area Monitoring (WAM) methods, decisions for the entire microgrid are taken by a Supervisory Remote Control Unit (SRCU) based on the information collected from various points in the network [34]. These systems need to rapidly and accurately detect faults in both modes (islanded and non-islanded) and across different energy mixes, based on which isolation measures can be taken. The requirements for data transfer between the SRCU and other components of the Supervisory Control And Data Acquisition (SCADA) system include high reliability and low latency (millisecond level) of data transfer. Both reliability and latency of data transfer are improved considerably through the deployment of 5G cellular network and communications technologies [35].

In the storage sector, newer technologies are proving to be capable of providing a variety of services at different storage response rates, storage timescales, power capacities and voltages. These include power-to-gas (electrolysis), mechanical storage (flywheels), electrochemical storage (new battery chemistries and flow batteries), electrical storage (supercapacitors) and thermal storage [36]. Greater availability and technical maturity of the technologies mentioned along with allied ones enable customizable storage solutions for microgrid-specific applications.

Although there are many examples of highly successful microgrid projects, there still remain some technical challenges to implementation. However, as discussed in [7], microgrids often integrate innovative technologies, converters and softwares, which can fail, leading to disrupted microgrid operation. These failures of individual components are often mislabeled as microgrid failure. However, as availability of suitable components such as droop-controlled inverters capable of parallel operation or DC components remain a challenge, component availability and procurement can be challenging.

More generally, the technical challenges to microgrid development include

1) Reliable, safe, selective, sensitive and directional protection against various types of faults under all operation conditions and

2) Reliable and fast communication among components in the SCADA system for dynamic and adaptive control

While there are technical solutions for these problems, neither the components nor the expert knowledge about their choice in systems are easily accessible.

E. Environmental

Microgrids are generally seen as climate friendly due to the fact that they enable higher shares of variable renewable energies (VREs) within the supply mix of a given system. Further, microgrid demonstrations typically focus on VRE integration, cogeneration and energy efficiency – all of which are common emissions reduction measures. Thus, microgrid development definitely holds potential for decarbonization of the electricity system.

However, a large majority of currently implemented microgrids use diesel to address energy adequacy, stability and reliability issues. This is primarily due to the significant expense of storage alternatives which would provide the same functionality. Further, for those that did use storage, the use of lead acid batteries in older demonstration projects such as the Isle of Eigg and Kythnos island as well as the use of lithium ion batteries in more recent projects are associated with toxic materials, heavy metals and recycling concerns.

F. Legislative

Previous scientific literature cites a large number of legislative challenges to the development of microgrids. The main challenges are listed in Table 1:

TABLE I: LEGISLATIVE BARRIERS AND LOCATIONS

Sr. no.	Legislative barrier to microgrid development	Location	Source
1	Non-recognition of microgrids in legislation or incorrect classification of microgrids as utilities leading to issues with connection, ownership, etc.	Brazil, EU, Massachusetts, Singapore	[17], [37], [38]
2	Anti-islanding legislation	Japan, Spain, USA, Canada, global	[7], [26], [39]
3	Regulations preventing microgrids from feeding energy to the grid	The Netherlands, USA, Japan, Brazil	[7], [17]
4	Rules preventing storage or other DG between PV arrays and the meter, and similar metering legislation	Spain	[7]
5	Non-recognition of storage as a grid asset or incorrect classification of storage as generation assets	EU	[36]
6	Double taxation of storage assets (with energy charged and discharged being taxed)	UK, many countries in the EU	[36], [40]
7	Inability of DSOs to own and operate grid assets	EU	[36]
8	Lack of legislation related to DSO services such as inertial response, upgrade deferral or avoidance, voltage support, reactive power support, black start, etc., all of which microgrids could participate in.	Global	[36], [41]
9	Conflict of microgrid customers with fair competition legislation which prevents them from becoming ‘captive customers’ of the microgrid.	EU, Singapore	[38], [42]

It may be noted that recent EU legislation drafted in 2019 addresses issues such as definition and recognition of storage and storage facilities, double taxation, DSO ownership, etc. However, these issues still proved to be major barriers to microgrid implementation in recent years. Further, until the integration of these laws at the national level and their enactment, they will continue to impede progress in this field, and are hence addressed in this work.

V. CONCLUSIONS

The study presents an overview of microgrids and the status of the technology, making use of the PESTEL framework for the analysis. Many strong drivers across a range of domains are identified which have influenced their development and implementation. Particular trends such as improvements in power converter technologies, drives towards community-owned power and increased costs of maintenance of grid stability are identified as influencing factors on potential commercialization of microgrids. In addition, recent legislative progress in the recognition of storage, the removal of tax barriers and greater opportunities for both DSOs and private entities for designing, building and operating microgrids are also addressed.

The most significant barriers identified are the high costs of certain generation assets, storage and control softwares along with low DSO involvement or lack of market structure and network operator involvement for microgrids to offer solutions for specific energy applications.

Based on these factors, it is clear that microgrid technologies (both at the component as well as at the system integration level) together with the legal framework for their deployment are extremely close to maturity. For specific applications like military deployment, remote systems and locations where grid reinforcement is the alternative, microgrids are already strong contenders as a design choice for energy distribution. However, for others, such as citizen/community energy initiatives, zero-energy neighborhoods, institutions and campuses, stronger business cases may be needed for microgrid implementation.

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