Journal of Energy and Economic Development,
Niroo Research Institute.
Vol. 1, Issue. 2, Autumn 2022 , Pages 31-49
Journal homepage: https://jeedev.nri.ac.ir

Electrical Distribution Network Indices Gap Analysis between Iran, the European Union, and the United States

Mohsen Arzani[1*], Faramarz Ghelichi[2], Sara Namdar[3]

1. Distribution Networks Department, Monenco Iran Consulting Engineers, Tehran, Iran,

2. Infrastructure Division, Monenco Iran Consulting engineers, Tehran, Iran,

3. Distribution Networks Department, Monenco Iran Consulting Engineers, Tehran, Iran

Original Article

Abstract. Globally, most electric power companies are complying with the trend of reducing greenhouse gas emissions (GHG) and the detrimental pollution effects of thermal power plants on the atmosphere. Therefore, the future's electric grid is modelled on a low-carbon or carbon-free grid infrastructure. Moreover, modern electric grid infrastructure mandates that different network sectors evolve with Renewable Energy Resources (RESs) integration. To reach a stable and reliable electric grid, the penetration rate needs to get increased. Using a microgrid (MG) or a smart grid system can help achieve this goal. Additionally, it facilitates the transition from the current dumb electric distribution network to an intelligent grid by leveraging smart assets. These implementations will be a part of the future network once the infrastructure is revolutionized. Furthermore, distribution grid conditions should be monitored regularly to ensure reliable and high-quality power exchange in grid sectors. Measuring different indices in various aspects of the distribution network gives us insight into evaluating the grid condition. By comparing available distribution data and indices on a global scale, a Gap Analysis (GA) can be obtained. It is necessary to design roadmaps, techniques, and solutions to improve distribution grid operation. This paper compares several indices and indicators of Iran's current distribution network to that of the European Union and the United States. Finally, a conclusion is reached.

***Keywords*:** *GA, Distribution Grid, Developed-Countries, Indices, Operation Monitoring*

1. INTRODUCTION

The electric grid is the integration of an interconnected network. It is like an infinitely wide spider web that takes energy from its generators and delivers it to consumers. On the other hand, with energy consumption growth, the power distribution sector faces new challenges and endures more stress. This makes transferring reliable energy to end-users the primary objective of the electric power industry. In load research, network characteristics such as the increasing number of customers, accurate forecasts of load demand, and their usage patterns that affect the distribution grid are examined.

---

[*] *an early version of this paper was presented in International Power System Conference(PSC)*
Corresponding author E-mail addresses: Arzani.mohsen@monencogroup.com

Received Date: 2022-09-06 ; Accepted Date 2022-12-06
https://doi.org/10.30503/jeedev.2022.360854.1018

In addition, it shows the requirements for proper distribution network design, Operation, and planning. Moreover, the grid is more generation-centered and power flows in a one-directional manner, causing unstandardized power losses in the distribution sector. Electric power deregulation is another pathway that has altered the role of Generation Companies, (GENCO) and Distribution System Operators (DSOs) in the integration of Distribution Energy Resources (DERs) and the electricity market. Accordingly, further studies have been conducted to optimize energy and fuel consumption (Arzani,2019; Arzani, 2018; Arzani et al., 2015). In (Arda Halu et al. 2015) the demand and generation profile of an urban MG is modelled using data from the Geographic Information System (GIS). GIS-based information for the monthly energy consumption of an area in Cambridge, MA. is depicted in Figure 1-A. which is an illustration of load growth in the area.

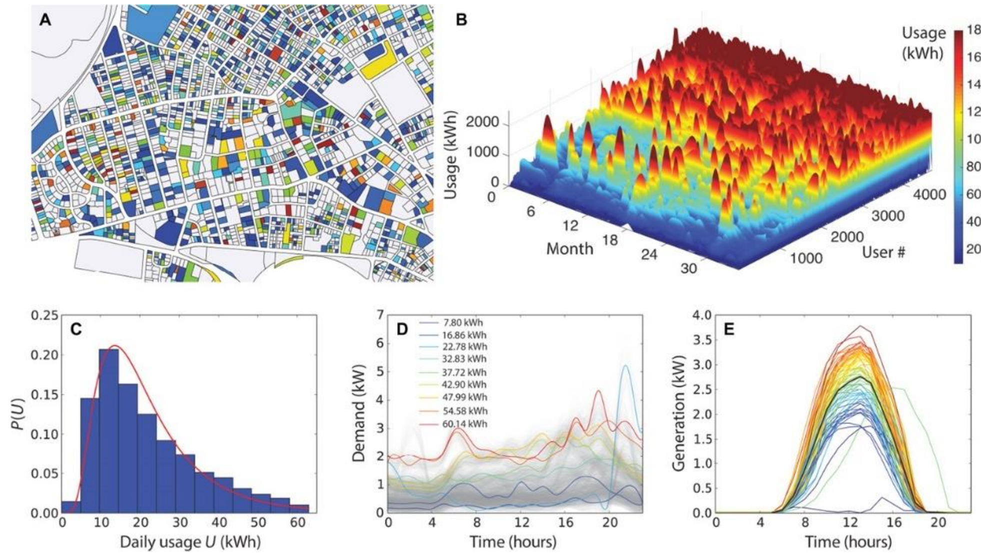

Figure 1. Temporal patterns of electric energy demand

According to Figure 1 (A) Part of Cambridge, MA. Map, monthly electricity consumption is depicted in colors. (B) The monthly electricity consumption of 4683 users over 3 years. (C) The daily consumption distribution for an average day in July. The solid red curve denotes a lognormal fit. (D) A typical day's hourly demand profile in July, with representative daily curves marked with colors and their respective daily consumption values. (E) Hourly solar generation profiles for typical residential-size installations.

Today, the world is working towards addressing the mentioned problems and developing a more efficient grid infrastructure. In well-developed countries, an efficient electric distribution grid relies on energy production, resource strength, and reasonably balanced electric consumer demand. To achieve this objective, a thorough knowledge of energy indices and the current global energy situation is essential. To monitor the current distribution grid conditions, a gap analysis between the target country and the reference countries should be prioritized. Fossil fuel depletion, climate change concerns, and enabling high-RES penetration require electric grid transformation. As a result of grid modernization, various indices are introduced to the new network. Active Distribution Networks (ADN), MGs, and Power Electronic Interface Generation (PEIG) based DERs are integral parts of the future electric distribution infrastructure. In times of catastrophic blackouts, faults, or disturbances, MGs are introduced into the distribution network to support local loads. Additionally, they are provisions for maintaining the desired sensitive loads with a 24/7 energy supply. It is operated in grid-connected or islanded mode and provides consumers with high reliability and continuous energy services. The resiliency metrics (RM) or index (RI) include robustness (strength) and recovery, two terms referring to the grid's ability to recover and survive failures. In this regard, the RMs of Cambridge's MGs are examined in (Arda Halu et al. 2015).

The figure below is an example of an MG that is integrated and penetrated to the Low Voltage (LV) side of the distribution grid. Distribution systems are built in different topologies, most of them being tree-based (radial, meshed, open, or closed loops). Solar Photovoltaic (PV) integration as a DER is placed in a radial and tree-based electric distribution topology to represent the MG model in Figure 2.

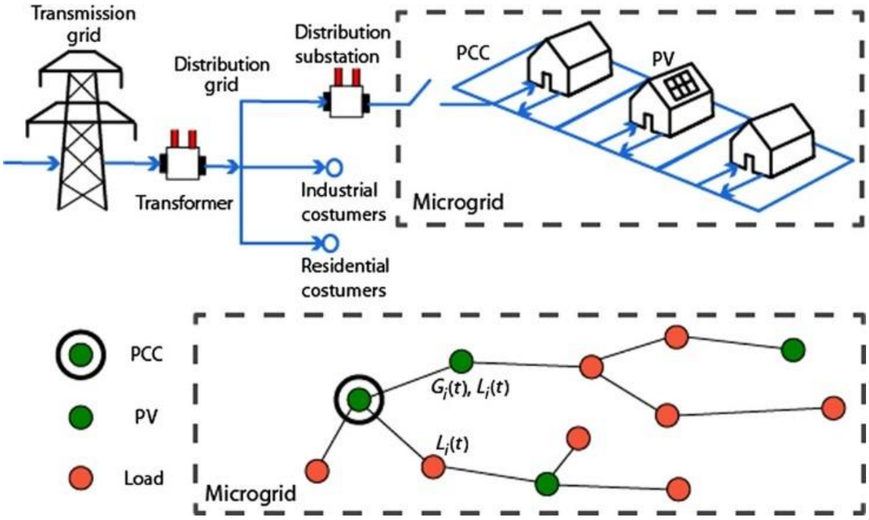

Figure 2 Microgrid and its network representation (the point of common coupling (PCC) connects the MG to the distribution network) (Arda Halu et al. 2015)

1.1 Background and Related Works

Well-developed countries are proposing and enacting novel incentives and policies to increase the reliability and stability of distribution operations. In some countries, such as the US, the distribution infrastructure is among the largest and most complex interconnected networks. In this infrastructure, energy is transmitted from the utility grid to consumers smoothly and without interruption. As a result of consumers changing their role to prosumers, the reliability of the SAIFI and SAIDI indices improves. An islanded MG, which is connected to Electric Vehicles (EVs) and RESs, causes some Key Performance Indicator (KPI) challenges such as excessive frequency nadir, abnormal Rate of Change of Frequency (RoCoF), and severe instability. Consequently, by integrating non-conventional renewable energy (NCRE) as an alternative to local electricity generation, energy becomes extremely valued by consumers. These resources are introduced as grid-forming and grid-following to calibrate the frequency of the system and provide an instantaneous balance between power generation and demand. Distribution companies consider Demand Response (DR) and Demand Side Management (DSM) as roadmaps to manage the energy consumed by consumers, enabling Ancillary Services (ASs) and managing the distribution grid’s congestion (Arzani, 2017; Arzani et al. ,2021).

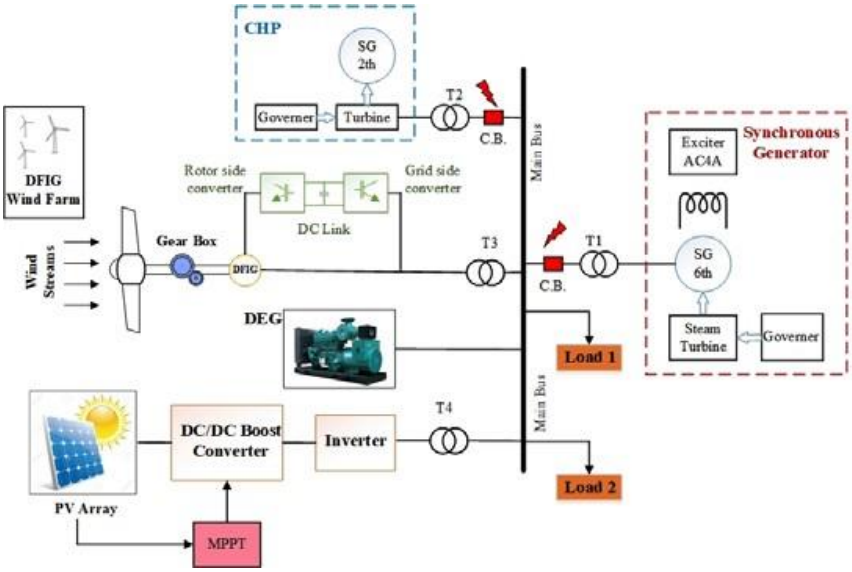

Figure 3. A sample of future MG infrastructure with high WTG and CHP penetration (Arzani et al., 2021)

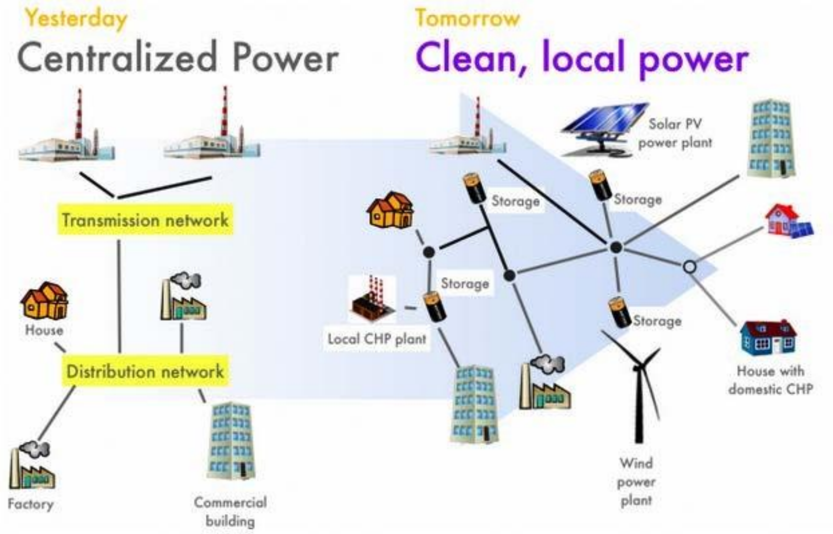

Figure 4. Future's distribution grid with the transformation from a centralized network to decentralized[1]

Figures 3 and 4 give us a full understanding of the future distribution network structure. An optimal MG design for fast frequency regulation would include Combined Heat and Power (CHP) integration as a rapid active power resource injector with different RESs such as Diesel Generator (DES) and Wind Turbine Generator (WTG). This is more effective if a high penetration rate is considered for WTG and CHP in the desired MG. Also, Conventional Power Plants (CPPs) are being replaced with manage these changes, as well as the integration of large-scale RESs, the term "Power system flexibility" is introduced to the network.

The Electric Reliability Council of Texas (ERCOT) specifies a penetration rate of RESs exceeding 1 GW, mandating flexibility for the distribution network. Another study reports the flexibility needed for the VERs penetration rate to be greater than 30%. This is an indication of penetration rates that are proportional to the demand for flexibility.

---

[1] Farrell, J. (June 12, 2020). The Challenge of Reconciling a Centralized vs.

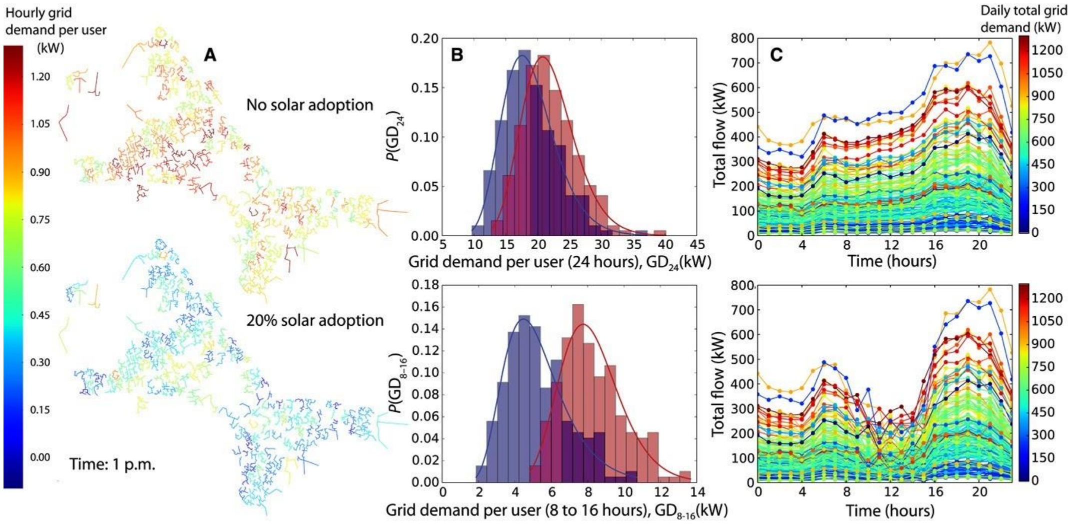

Figure 5. The role of MGs in the consumption of electric energy (Arda Halu et al. 2015)

(A) Proposed Cambridge MG. The color denotations are the grid's demand per customer in the MG at 1 p.m. for the no–solar adoption (top) and the 20% solar adoption (bottom) case. (B) Grid demand distributions for the 200 MGs for the whole day (top) and daylight hours (bottom) for the no-adoption (red) and the 20% adoption (blue) case. The red and blue solid lines indicate lognormal fits for the no-adoption and 20% adoption cases, respectively. (C) The MG total power flow as a function of time of day for no solar adoption (top) and 20% solar adoption (bottom). The colors are denoted by the total daily grid demand of each MG. inertia less inverter interfaced generation that uses clean resources in addition to loads. The developed distribution grid takes advantage of PEIG's fast active power injection. As a result, a more convenient generation-demand balance is achieved.

The K-means clustering method was used to partition a part of Cambridge city for MG construction purposes. One of its considered constraints is the cost related to line length that determines the distribution network's topology. Furthermore, the MG nodes are specified as well. For the MG demand measurements, a base case and 20% solar penetration are assumed for comparing energy consumption. The MG energy consumption study in illustrates that although the MG is highly penetrated with PVs, it still relies on the grid's generation resources.

The International Renewable Energy Agency (IRENA)'s Road Map (RE) analysis proposes a 61% energy production from Variable Energy Resources (VERs). Due to their intermittent nature, uncertainty, and location-based features, they are considered unpredictable resources in which the growth of VERs jeopardizes the grid's reliability.

According to the International Energy Agency (IEA), North American Electric Reliability Corporation (NERC), and the Electric Power Research Institute (EPRI), flexibility is defined as how the electric grid can modify its production or consumption regarding variability. Flexibility needs can be categorized into the following aspects: (1) Flexibility for power, (2) Flexibility for Energy, (3) Flexibility for Voltage, and (4) Flexibility for Capacity. In this regard, power system stabilizers (PSS), Fast Frequency Response (FFR), virtual inertia, Battery Energy Storage (BESS), DR, EV, hydrogen storage, CHP, ASs, and VERs are used to provide flexibility. Traditional electric grid planning is concentrated on generation capacity, improving system strength, power factor limitations, and enhancing network maintenance and life cycle. Therefore, with the implementation of flexible resources, extra investments in the grid could be avoided or delayed to make provision for peak demand. It is evident that the future's electric system is flexible (Hillberg, 2019; Akrami et al., 2019).

1.2 PROBLEM DEFINITION AND MOTIVATION

The distribution grid is one of the most critical parts of the electrical grid. Therefore, its health conditions should be screened on a timely basis. For most climate change policymakers, understanding global warming is another key task that must be addressed concerning the electric grid. The main components of distribution assets include substations, switches, recloses, fuses, cables, transformers, breakers, and sectionalizes. As such, they should be managed properly. In the case of Iran’s grid, where the failure rate of equipment and feeders is relatively high, repair time needs to be proportionally higher. Therefore, the reliability assessment of the network indicates a low-reliability state and indices, such as SAIFI and SAIDI that are not in line with standard cases. Faults, outages, and blackouts are inevitable parts of a distribution grid failure that most DSOs try to avoid. In this regard, the grid must restore resiliency as soon as possible, detect faults and clear them quickly. Moreover, in an interconnected and complex network, where intelligent devices enable the traditional grid to be converted to a Synchronous Generator (SG), more data will be generated by each measuring unit, leading to large-scale data known as big data. These data should be analyzed to make better decisions about the operation and planning of the distribution side. For this purpose, big data analytical approaches are proposed. Overall, today's grid challenges include power loss, low energy delivery efficiency, low reliability, power quality, and long centralized energy distribution with high GHG emissions. Future development plans should address these issues. Specifically, the goal of progress in the electric distribution sector is to operate the grid in a carbon-free manner.

If we would like to meet the challenges in the power industry, we should consider the indices that affect the output of projects for design and operation. In this context, we need to observe the challenges, their solutions, and the projects comprehensively. Furthermore, we need to use effective indices to analyze the input and output of its advantages and disadvantages. It seems that modern industry can only overcome market challenges by emphasizing effective indicators. In the researched indices and factors, the developed country roadmap was based on problem-solving, critical thinking, and specialization approaches. This highlighted the importance of indices in the planning and development of the distribution grid.

To outline and compare the extracted indices, we summarize the deliverables and drivers that Europe and the United States are considering. However, Iranian distribution companies do not have the necessary records for the following reasons:

- Increased natural catastrophic incidents and their proliferation, leading to power system blackouts and failures
- Increased population growth and energy paucity
- Increased investment in the generation sector that mandates focusing on the demand side control and reducing or avoiding the generation side investment
- Electricity theft and bitcoin energy consumption
- Increasing the grid’s efficiency
- The entrance of new assets such as EVs and PEIG RESs
- Deregulated and restructured electric infrastructure
- Growth of big data generated by smart meters and assets, weather, GIS, PMUs, and SCADA
- A need for computational strategies for condition monitoring of LV distribution equipment

1.3 Papers Organization

In this work, the condition of Iran's distribution network is analyzed, monitored, and juxtaposed with that of developed countries. Then, a roadmap and future insight into the Iranian distribution network is extracted. The structure of this paper is as follows: Section two discusses Iran's distribution network situation case. In section three the methodology is discussed, followed by section four, in which a deduction is made from the distribution network's indices comparison table. Finally, a conclusion is inferred.

1.4 Contributions

The indices of distribution systems in well-developed countries, such as the European Union and the United States are extracted through comprehensive research and using various databases. We can conclude several key points by tracing and following the roadmaps and plans of these countries. At the same time, Iran's electric distribution grid faces many challenges that need to be addressed and covered by a strong pattern. Distribution grid indices of developed countries are used for this purpose and a roadmap for the future Iranian distribution grid is outlined.

2. THE SITUATION OF IRAN'S DISTRIBUTION NETWORKS

In Iran, the structure of the distribution network is different. Therefore, it needs further research and investigation. Power loss and Carbon Dioxide (CO_2) emissions are the main concerns of Iran's grid. Moreover, its infrastructure is more centralized and energy is supplied by CPPs. There are fewer RESs implemented and the distribution infrastructure suffers from many deficiencies. The optimal value for electric grid power loss is around 10% worldwide. Today, one of the most influential factors in energy efficiency, power loss in Iran's distribution grid has been reduced to approximately 9%. This is compared to its previous 15% amount in 2014. The old and outdated distribution network structure is confirmed as one of the loss factors. Iran's energy efficiency is around 30%-40%. This is while the standard and typical efficiency percentage in most developed countries is around 70% (Azad F et al., 2014).

Moreover, Iran's distribution grid is dealing with the following problems:

- Vast oil and gas resource management
- Dependency of the government budget on oil and gas revenues
- Oil and gas expropriate investment
- The low productivity in the energy sector
- Consumers' high energy consumption
- Oil and gas exports sanctions
- Low-priced energy and abnormal electric consumption growth
- Oil well shares with neighbouring countries
- Complex energy production
- Vast geographical area and energy security issues
- Inexact statistics and estimation of resources
- Resource extraction policies
- Power plants efficiency and power loss
- The Low level of electric power consumption equipment technology on a large consumer scale
- Aged distribution and transmission infrastructure
- providing CPPs with energy supply concern
- Unforeseen behavior of consumers to energy price variation (Heidari et al. ,2017)

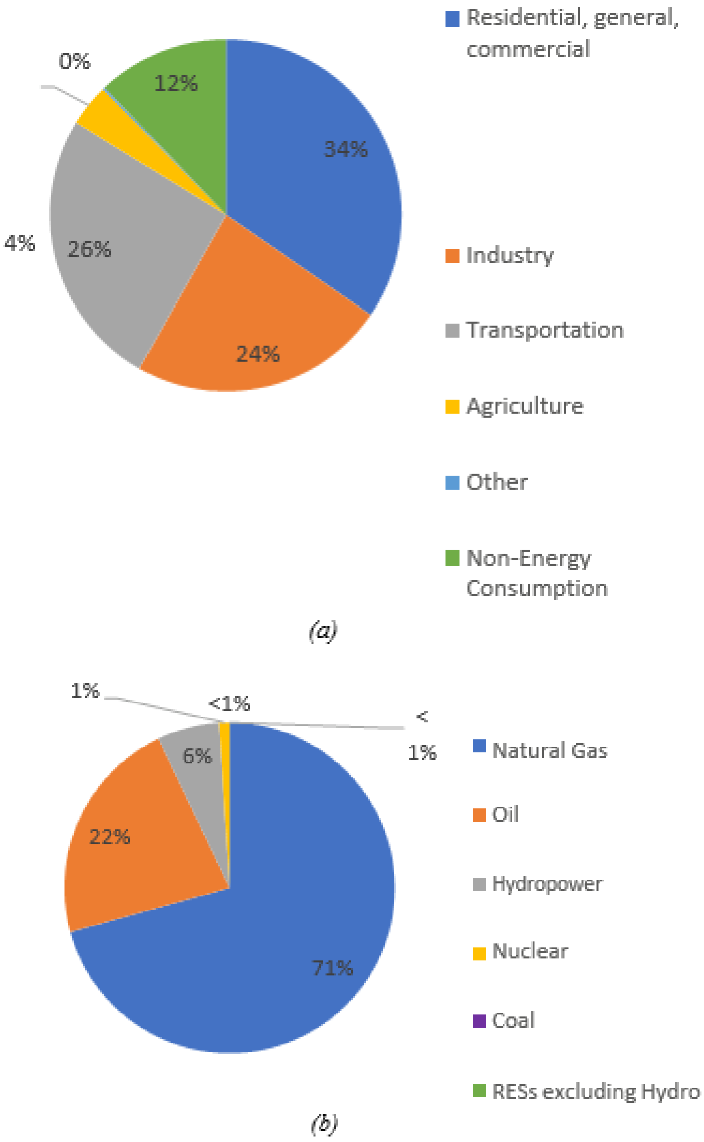

Figure 6 .(a) Iran’s total final energy consumption by sectors (b) Iran’s energy generation capacity by fuels (Aien, M, 2020)

Greenhouses are another large energy consumer, similar to data centers in the Information and Technology (IT) industry. Moreover, the greenhouse industries in Iran are expanding and are one of the energy demand sectors of the power (Arzani, 2019).

According to Iran’s Ministry of Agriculture’s recent statistics, the greenhouse industry compromised 25,495 ha (with 3.8 million tonnes yield of production) in 2021. Furthermore, this number is expected to increase to 48,355 ha with an expected 7 million tonnes growth yield in 2025. To support these industrial development plans, adequate energy is required to avoid fossil fuel scarcity in the near future. In this context, (Arzani et al.,2011) has shown the demand for RESs integration into Iran’s distribution grid. This is a solution to the sharp depletion of natural resources and the increase in fossil fuel usage. Investments in Iran’s distribution network are getting more attention from the ministry of electric power to overcome these barriers. In this regard, GA is a tool used for determining the optimal distribution grid condition based on examples from well-developed countries to close the gap.

3. METHODOLOGY

The distribution sector in the United States and the European Union is undergoing several projects and technological advancements to improve the grid’s condition. These include network resilience, reliability, and efficiency enhancement.

The global trend and roadmap for distribution grid modernization emphasize minimizing CO_2 emissions and reducing thermal plant usage and environmental impacts. These countries have also planned other implementations of IT and Internet of Things (IoT) services in their distribution network development programs. The investment primarily aims to replace CPPs and centralized resources with distributed inertia less PEIG that energizes consumers locally. This paper has collected some key information and data about the future of distribution grid development in the European Union and the United States. This data is then compared to Iran’s current system and discussed. Measures include reliability, produced energy, network controllability and observability, and investment foresight in various distribution grid sectors. For a precise GA, the collected data should be updated periodically. Following this methodology, a comparison was drawn between distribution network modelling in developed countries and Iran’s current system. This GA extracts the optimal situation that developed countries have previously reached. Other objectives of this paper include assessing Iran’s present distribution grid condition and reaching the gap evaluation in this part. The results are ultimately forwarded to specialists in electric power for further consideration and for proposing effective ideas and strategies to overcome this gap and deficiencies.

4. RESULTS AND DISCUSSION

In this paper, a thorough research has been conducted to sort various indices that are critical features in defining distribution grid operational health. It has been determined that the distribution network is moving toward fulfilling three innovations and facility updates: decarbonization, decentralization, and digitalization of the grid, known as the “3Ds” megatrend. Other trends and developments in the electric grid’s future also include the integration of energy sectors and inclusion (Accessible energy for all by increasing electrification). Environmental factors are being emphasized as the core of the energy transition process. Data-driven tools, such as big data analytics, improve the grid’s situational awareness of failures. Furthermore, increased RES penetration rates are employed along with loads to omit the expenses of Generation Expansion Planning (GEP), Transmission Expansion Planning (TEP), and Distribution Expansion Planning (DEP) in the electric infrastructure. Thanks to the islanding mode operation of the MGs, critical load reliability has been improved. Additionally, MGs enable high penetration of DERs. Most developed countries are shifting from passive to active networks by setting 100% RES shares in their grid. Grid-scale storage is on the rise as a way to store electricity during periods of RES intermittency and fluctuations, making 100% RES penetration possible. As grid parity has been achieved in the majority of these developed countries, the cost of RES investment by consumers is competitive with traditional thermal power plants. This is done by optimizing its location, cost, and considering its intermittency and load defection constraints. With the deployment of Smart Grid, the grid becomes more intelligent by enabling two-way directional power flow among the resources. AI implementations are expanded to include automatic and smart fault diagnosis. Moreover, ArcGIS and Oracle software are widely used for mapping and monitoring the distribution grid in these developed countries.

As consumer demand grows, MGs are being proposed as a solution in urban and rural settings. As this part of the energy supply is far away, MGs can be an energy supply program for rural customers and that is why rural settings were included. On the other hand, urban sites need to reduce their greenhouse gas emissions, TEP costs, and the length of their cables from centralized sources to local users. In an intriguing study by MIT researchers, parts of

Cambridge were clustered into small MGs. For example, 200 MG was used in Cambridge, which was mentioned earlier with DGs (Solar Energy). In addition, the animation: Cambridge's Microgrid infrastructure with RESs penetration shows the proposed MGs in Cambridge, MA, Massachusetts. In this case, grid behaviour and load demand during the day are modelled for 20% solar energy penetration. Colours are a grid demand code for each consumer during the day for 20% solar integration. The animation shows that at the beginning of the day, demand is blue. As the sun's energy increases throughout the day, it changes to green, which indicates a decrease in demand. When sunlight diminishes at 4 p.m., this situation reaches its most dire state and turns purple and pink. Although the demand and the amount of solar energy vary throughout the day, demand is calibrated at 1 p.m. Demand per user in MG colour varies from 0.75-1.2 to 0.5-0.15 with 20% PV penetration.

At the next level, the role of DSOs has been altered and emphasized at a more substantial pace thanks to the development of new distribution networks. They are the center of the future’s electric grid energy transition, congestion management, and providing peak periods for the system. In addition, DSOs are Europe's main innovators in the electricity market, distribution grid reliability, RES integration, EVs, and defining novel and appropriate tariffs. In the United States, DSOs are, as Lawrence Berkeley National Laboratory (LBNL) reports, an entity which is for planning and operational roles alongside the distribution grid modernization and high levels of RESs penetration.

In the US DSO settings, DSOs have the following responsibilities:

- Integrating DERs for market participation
- Implementing a modern distributed energy resource management system (DERMS) as a foundational tool in managing DER technology, road mapping, Use-case development, Architecture development, and migration strategy
- Local DER optimization for transmission grid services
- Local supply and demand balance
- maximizing return on investment (ROI) on distributed energy resources (DERs)
- DERs intermittency management (Rettico et al., 2020; Thomas, 2018; Itron, n.d.; quanta-technology, n.d.)

Besides these policies and developments, automation is also considered for each component of the distribution grid, such as substations, breakers, etc. to expel the analog-based interface that has been established among these distribution system elements.

With the above-mentioned vital developments in the electric distribution side of the European Union and the United States, and comparing it to Iran’s current electric distribution network situation, the following observations can be made: Iran’s electric distribution is still in its initial progress stage with the country’s target policies. There is little if any, investment and construction planned for MGs, SG, and IOT infrastructure, keeping the grid numb and non-intelligent. The agenda for investing in RESs is not sufficient for a higher penetration rate installation. The grid is still fuelled by centralized CPPs, which illustrates that the Kyoto and Paris climate change policies are not part of the country’s distribution grid development plans.

Overall, Iran’s distribution grid is still a one-directional network that relies on traditional thermal resources. Zeroing CO_2 emissions and enabling a carbon-free infrastructure is currently out of reach. DSO’s responsibilities are still defined as the framework of selling energy to customers and are not being standardized on a global scale basis. Meanwhile, Iran’s main plans to upgrade its distribution grid infrastructure in the future to cover this gap are as follows:

- Embedding future’s critical load continuous supply and resiliency with MGs’ application

- Increasing Phasor Measurement Units (PMU) placement and Advanced Meter Infrastructure (AMI) assets (Increasing the use of smart meters by investing in a smart grid)
- Reducing and detecting electricity theft by applying smart assets
- Gradually substituting overhead lines with underground cables
- Expanding the construction of smart greenhouses
- Implementing congestion mitigation strategies, such as bigger transformers, upgrading cables, altering the topology for Available Transfer Capability (ATC) enhancement, and reducing transmission expansion and construction cost (This can be achieved with the MG definition)
- Taking advantage of ArcGIS in the mapping distribution grid and the distribution network data management with Oracle software, and GIS for DEP purposes
- Due to the location of the country on the solar radiation belt and the abundance and availability of this resource, this idea can be used to meet the challenges of increasing demand while reducing peak-hour's demand
- Implementing novel DR and DSM programs to reduce peak hours
- An increase of 6,625 MW RESs share by 2030
- More of its RESs share is nonconventional renewable energy (NCRE) which is a combination of solar & wind integration
- Improving reliability indices (SAIFI and SAIDI) by using various novel strategies
- Optimizing power loss and the distribution network cost
    - Increasing the implementation of information and communication technology (ICT) services to establish a self-healing, two-way communication infrastructure between energy consumers and producers for at least 20% of the grid's infrastructure
    - Lowering the use of carbon for its generation structure, thus reducing GHG emissions
    - Increasing the energy export and power factor of the electric grid
    - Increasing the lifespan of distribution assets by optimizing grid support
    - Producing electric distribution equipment made by domestic engineers

Table 1. Various Index comparisons of Iran and well-Developed Countries' Distribution network[2]

Distribution Network Indexes	**European Union**	**United States**	**Iran**
1-Reliability Index (RI): SAIDI SAIFI *SAIDI (In Hours): System Average Interruption DurationIndex* *SAIFI (In Hours): System Average Interruption FrequencyIndex* *APPA: American Public Power Association*	2.105 1.8 average (by2020)	4.66 (by 2019) 0.99 For APPA Region (by 2018)	*Total SAIDI (2019):* *9.18* *Tehran (2011):* *4.584* *4.029* *Isfahan (2019):* *3.674* *3.229*
2-Power Loss (MW)-% of Output	5.09 %	6%	9.76%
3-Number of DSOs *DSO: Distribution System Operator*	2500	3100	40
4-Number of Costumers	260 million	150 million	36.6 million
5-DR or DSM program installed in place *DR: Demand Response DSM: Demand Side Management*	38.5% (% of DSO participants) -Current $0.9 billion markettoward $3.5 billion by 2025 -DR alone achieves 25-50%of the EU's 2020 targets concerning energy	64% of total U.S. customeraccounts (or 93 million customers) -20 million smart thermostats installed, resulting in an 8.3 GW peak demand reduction by 2017	Current: ~10% Potential: 30%

---

[2] Most Important Sources : www.iea.org ,www.epa.gov, www.eia.gov

Distribution Network Indexes	European Union	United States	Iran
	savings and CO2 emission reduction -The current DR market size is 20 gigawatts. However, the potential could reach 160 gigawatts in 2030		
6-Active Customers or prosumers(% managed by DSOs)	13% -2018 is shaping up to be theyear of the energy prosumer -PV prosumers alone couldrepresent up to 700 GW by 2030 and about 1500 GW by 2050 -25 TWh of electricity willbe generated and self-consumed on-site in Germany, Italy and the United Kingdom, in aggregate by 2020	*Further Investigation & Research required for obtaining the related Data*	*Further Investigation & Research required for obtaining the related Data*
7-Total Underground & Overhead line Length	9.7 million km -78,530 substations	8.85 million km and some 600,000 distribution circuits originating from an estimated 60,000 substations	0. 8 million km
8-AMI and smart meter installation by DSOs (%) *AMI: Advanced Meter Infrastructure*	38.5% - 200 million smart meters by 2020	47% by 2016(71 million Smart Meters) -78 million smart meters (60% of U.S. homes)by 2017 -reach 90 million smart meter installations by 2020	1.4%
9-Controllable Substations (% of DSOs)	75%	76% by 2005	*Further Investigation & Research required for obtaining the related Data*
10-Distribution grid equipped by SCADA (% of DSOs) *SCADA: Supervisory Control and Data Acquisition*	97%	93%	10-20%
11-Important factors in substation control considered (%of DSOs)	83% respond: 1-voltage control at the buslevel 2-overload control transformers, and bus protection 66% respond: 3-Load balancing	Mostly conveyed:1-voltage control 2-monitoring the flow of electricity 3-monitoring reactive powerflow 4-reactive power compensation 5-improving power factors	Mostly conveyed: 1-Feeder Data 2-Feeder congestion management 3-Power Loss
12-Feeder Control (% of DSOs)	70% can perform 1-automatic switching for network reconfiguration 58% can perform 2-voltage control30% can perform 3-reactive power control	*DA Asset Total Installed* Remote Fault Indicators 13,423 Smart Relays 11,033 Automated Feeder Switches9,107 Automated Capacitors 13,037	Mostly conveyed: -Reconfiguration -Restoration -Changing manoeuvre points

Distribution Network Indexes	European Union	United States	Iran
		Automated Voltage Regulators 10,665 Automated Feeder Monitors4,447	
13-Outage detection and prediction (% of DSOs)	74%	65% of utilities use local weather forecasts 23% of utilities use an actual outage prediction model Total: 88%	*Further Investigation & Research required for obtaining the related Data*
14-VERs energy production (% of Generation) *VER: Variable Energy Resources*	20% by 2020 and 32 % by 2030	17.33% (2020) -104 GW installed (14% of the nation's summer peak)	5% (According to Mapna3%)
15-RESs Addition Capacity installed technology (Solar +Onshore & Offshore Wind + Hydropower + Bioenergy + Geothermal) by 2025 *RESs: Renewable Energy Resources*	850 GW -small-scale power generation will reach 6.5%in 2020, 10% in 2030, and 13.9% in 2050	290 GW (387 GW by 2025 DERs)	875 MW (2020) (2025,2030): 5000 MW,7500MW
16-Energy Production and Consumption, CO2 Emissions(2018)	1984.271(MTOE), 3053.6(TWh), 3,986(MTOE) - The goal of achieving net-zero carbon emissions by 2050 - Household electricity prices in the EU are highest in Germany (EUR 0.30 per kWh) and lowest in Bulgaria(EUR 0.10 per kWh) in the second half of 2020	2172.52(MTOE), 4288.76(TWh), 4921.13(MTOE)-(25% from Electricity) -Objective: 50-52 percent CO2 emissions below 2005 levels in 2030 -100 percent carbon pollution-free electricity by 2035 - households' Electricity prices 2020 (kWh, U.S. Dollar) 0.148	406.25 (MTOE), 273.28 (TWh), 579.55 (MTOE) - 0.005 U.S. Dollar per kWh (2020), -the average price of electricity in the world for that period is 0.137 U.S. Dollars per kWh for households
17-Global Energy Investment to Net Zero CO2 emissions by 2050	1-457 Billion \$ Fuel production 2- 530 billion \$ Power generation 3-544 billion \$ Energy infrastructure 4-39 billion \$ Industry 5-65 billion \$ Transport 6-216 billion \$ buildings		
18-Total Energy Supplied (TES) by source (KTOE) by2018 *KTOE: Kilo Tonne of Oil Equivalent*	522742 Oil,160262 Biofuels, 54360 Wind & Solar, 30081 Hydro,215550 Nuclear, 392329 Natural Gas, 224437 Coal	988692 Oil, 130346 Biofuel, 51471 Wind & Solar, 61391 Hydro, 249025 Nuclear, 880267 Natural gas, 347966 Coal	82056 Oil, 130346 Biofuel, 47 Wind & Solar, 1356 Hydro, 1978 Nuclear, 178765 Natural gas, 1321Coal
19-RESs clean energy investment (Billion USD) by the year 2020	39.3	10.1	0.59
20-DER management Tool (% of DSOs) *DER: Distributed Energy Resources*	38%	Further Investigation & Research required for obtaining the related Data	Further Investigation & Research required for obtaining the related Data
21-Storage Ownership	5.26 GW (2020)	23.2 GW (2020)	5%
22-Number of PMUs placements *PMU: Phasor Measurement Unit*	525	1,700 Today, more than 2500	63
23-Impact of Covid-19 on Demand	20-25% Reduction in Demand, 12% CO_2 Reduction	6-8% Reduction in Demand,7.8% CO_2 Reduction	4.5% Increase in Demand

Distribution Network Indexes	European Union	United States	Iran
**Note that Covid-19 has led to 14.8% in VERs Electricity Generation Worldwide*	-10% electricity demand reduction according to		
24-Electricity production from renewable sources, excluding hydroelectric (% of total)	18.042%	7.387%	1.05%
25-Access to electricity Urban (% of Urban Population) & ArcGIS software implementation for GEP and Mapping the distribution grid purposes	100%, Yes	100%, Yes	100%, Yes
26-Voltage levels and ranges used for power distribution & Type of Lines	< 1kV to 36 kV & 60% LV lines	7.2, 12.47, 25, and 34.5 kV (Wiki) & Consumer Level 110V	33,20,11 kV & Consumer Level 380 V
27-Total Annual Energy Production (GW)	12.92e06	25.23e06	0.317560e06
28-RESs Penetration level and Target	19.73 % (2020) & 35% (2030)	23% (2020) & 100% (2035)	<1% & 10% (2030)
29-MGs Power Capacity Market Share *MGs: Microgrid*	9% of the global microgrid market	34%- 3.8 GW (0.15e-4% The equivalent of energy production) Capacity Installation by 2021 -160 MGs provide less than 0.2 percent of U.S. electricity - about 1.6 gigawatts (GW) of installed MG capacity out of 1,066 GW total capacity -That is expected to increase to 4.3 GW by 2020	0%
30-DSO Investment Plan in smart grid technologies, grid modernization	133 billion USD (Western Europe-2017) - $23.9 billion on Distribution Automation	268 billion USD (2019) ($3.4 billion for distribution grid modernization) $110.3 billion in cumulative investment for DER employment (2025) $675 billion through 2030 in the distribution sector -reaching 18.7 million EVs, 20% of all new vehicle sales by 2030	$52.8 billion until 2050 $18.6 billion (on smart homes) $27.7 billion on RESs

***Note:** The Above Table information is extracted from the references at the end of the paper*

CONCLUSION AND FUTURE WORK

Generally speaking, The European Union and the United States distribution grid infrastructure are the most complicated and bulk interconnected networks, consisting of millions of Medium Voltage (MV) and LV lines feeding millions of customers. With a thorough look at these developed distribution network indices and evolution roadmaps, we can observe great operational improvements in the new fascinating settings, mostly pushing the network towards a low-carbon grid. New technologies are a part of this achievement, making the distribution grid's information readily available for condition monitoring purposes. In line with modernizing the grid, developed countries are implementing advanced control and communication equipment for improved decision support systems. This will reduce GEP-related costs drastically.

To conclude, addressing the present and future Iran’s customer energy needs is an important task that should be addressed wisely. Therefore, the utility grid should obtain information and data from its consumers instantaneously and in a proper time interval. In this regard, novel strategies and assets that are in line with many studies and investigations carried out by scholars and researchers are proposed for the European Union and the United States. Operating cost, power loss minimization, and providing customers with reliable, safe, and efficient electricity are the objectives of most of these studies. As a result, traditional power plants' detriments are alleviated by the local green generation resources emplaced beside loads. Some of the proposed approaches bring some problems to the network. For instance, RESs employment is offered as a solution to produce clean energy because of its increased popularity in different countries. However, for Iran’s future electric distribution grid, the challenges it produces should be taken into careful consideration.

Finally, new windows must be opened to interactions between Iran’s energy consumers, distributors, and producers. This needs special consideration with an emphasis on consumers better understanding the energy paid utilization. For Future work, part of the distribution grid in developed countries can be modelled and mapped alongside Iran’s distribution network by deploying various power distribution analysis tools for further GA purposes.

ACKNOWLEDGMENT

This work contributes special thanks to Monenco Consulting Engineers (MI) for their continuous encouragement, guidance, and support.

REFERENCES

Arzani, Mohsen,2019. Modelling and Analysing industrial Loads: A 7- Bus Multi-Machine Case Study, Sixth National Congress on Electrical Engineering and Computer Engineering of Iran with a New Approach to New Energy, Tehran

Arzani, Mohsen, 2018. An overview of existing approaches to load research in Electric Distribution Systems of the electric industry, Third National Conference on Electrical and Computer Engineering, Tehran, [In Persian]

Generation Expansion Planning in the presence of Electricity Markets, 2015. Arzani Mohsen, Seifi Hossein. 5th Conference on Emerging Trends in Energy Conservation ‹Tehran [In Persian]

Data-driven modelling of solar-powered urban microgrids data-driven modelling of solar-powered urban microgrid.by Arda Halu, Antonio Scala, Abdulaziz Khiyami, Marta c. González. SCIENCE ADVANCES 15 JAN 2016 : E1500700

Arzani, Mohsen, 2017. WECC Network Frequency Stability Using Droop Control and Load Response Method, 5th International Conference on Electrical and Computer Engineering with Emphasis on Indigenous Knowledge, Tehran [In Persian]

Arzani M, Abazari A, Oshnoei A, Ghafouri M, Muyeen SM. Optimal Distribution Coefficients of Energy Resources in Frequency Stability of Hybrid Microgrids Connected to the Power System. Electronics. 2021; 10(13):1591.

Flexibility needs in the future power system Discussion paper, Emil Hillberg (RISE), ISGAN Annex 6 Power T&D Systems, March 2019

Akrami, A., DOOSTIZADEH, M. & Aminifar, F. Power system flexibility: an overview of emergence to evolution. J. Mod. Power Syst. Clean Energy 7, 987–1007 (2019).

Reducing energy losses in the power distribution network, an essential solution to energy conservation, A Case study. Azad F, Abasi M. (2014), Emerging Trends in Energy ETEC, Tehran. [In Persian].

Alireza Heidari, Alireza Aslani, Ahmad Hajinezhad & Seyed Hassan Tayyar (2017) Strategic Analysis of Iran's Energy System, Strategic Planning for Energy and the Environment, 37:1, 56-79

Aien, M., Mahdavi, O. On the Way of Policy Making to Reduce the Reliance of Fossil Fuels: Case Study of Iran. Sustainability 2020, 12, 10606.

Arzani M., Alahverdizadeh A., and Arzani K. (2011). The position of electric energy consumption in the greenhouse industry of Iran: The importance of using sustainable green sources of energy. Oral presentation at International Conference & Exhibition on Soilless Culture (ICESC-2010), 8-13 March 2010, Singapore

Arzani, M. (2019). Electric energy consumption in the greenhouse industry of Iran: The importance of using the alternative energy resources and the new available LED lighting system, ECO International Energy Conference, Tehran

Rettico, G., Marinopoulos, A., and Vitiello, S. Distribution System Operator Observatory 2020: An in-depth look at distribution

Evolution of the Distribution. System & the Potential for. Distribution-level Markets: A Primer for State Utility. Regulators. Sharon Thomas

Hyland, M., Hofmann, A., Doyle, T., & Lee, J. Y. (July 2019). 2018 Distribution System Reliability and Operations Report. The American Public Power Association.

Eurelectric (2020), Distribution Grids in Europe: Facts and Figures 2020. D/2020/12.105/67, Brussels: Union of the Electricity Industry.

https://data.worldbank.org/

Kufeoglu, S., Pollitt, M., & Anaya, K. (2018). Electric Power Distribution in the World: Today and Tomorrow. https://doi.org/10.17863/CAM.27667

Prettico, G., Marinopoulos, A. and Vitiello, S., Distribution System Operator Observatory 2020, EUR 30561 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-28431-4

https://cdn.eurelectric.org/

https://ec.europa.eu/eurostat/

https://iea.org

https://www.eea.europa.eu/data-and-maps/indicators/renewable-gross-final-energy-consumption-5/assessment

2019 Utility Demand Response Market Snapshot. (2019, September). Smart Electric Power Alliance.

Electricity Transmission and Distribution." National Academy of Sciences, National Academy of Engineering, and National Research Council. 2009. America's Energy Future: Technology and Transformation. Washington, DC: The National Academies Press. DOI: 10.17226/12091.

https://en.wikipedia.org/wiki/Electricity_sector_of_the_United_States

https://www.epa.gov/greenpower/us-electricity-grid-markets

Sioshansi, F. (2018, February 9). Microgrids: from niche to $100 billion market. Energy Post. http://energypost.eu/microgrids-from- niche-to mainstream/

https://en.wikipedia.org/wiki/Mandatory_renewable_energy_target

http://energy_water.isti.ir

http://energyatlas.iea.org/tellmap/1076250891

https://www.mapnagroup.com/features/renewable-energy

Microgrid Market Research Report: Information by Type (Grid Connected & Off-Grid), Component (Hardware, Software, & Services), Power Source (Natural Gas, Solar PV, Diesel, Fuel Cell), End-Use (Industrial, Healthcare) and Region - Global Forecast till 2027, February 2021

W. Newton, C. (2006, juillet). Highlights from the North American Study of Substation Automation and Integration Activities and Plans. Electric Energy Magazine.

NASPI Synchrophasor Starter Kit, Draft 1, October 9, 2015. Available at https://www.naspi.org

https://www.energy-storage.news.com

Centre for Sustainable Systems, University of Michigan. 2020. “U.S.

Grid Energy Storage Factsheet.” Pub. No. CSS15-17

E.DSO Shaping Smarter Grid for your future, Lead the Transition– Serve the Customers. (2020, June). E.DSO - European Distribution System Operators. Rue de la Loi 82, 1040 Brussels, Belgium, info@edsoforsmartgrids.eu

https://www.satba.gov.ir

CIGRE, 2018. 2018 National power system Iran.

F. Ichord, R. (2020, May 8). The COVID-19 crisis and US and EU emissions in the new decade: Opportunities for clean energy recovery.

https://www.atlanticcouncil.org/blogs/energysource/the-covid-19- crisis-and-us-and-eu-emissions-in-the-new-decade-opportunities-for- a-clean-energy-recovery/

https://www.statista.com

DNV GL's Energy Transition Outlook 2020

https://www.irena.org

National Research Council 2013. Emerging Workforce Trends in the U.S. Energy and Mining Industries: A Call to Action. Washington, DC: The National Academies Press.

Energy Technology Systems Analysis Program (ETSAP) (2014) Technology Brief E12, Electricity Transmission and Distribution (http://www.iea-etsap.org).

.S. power customers experienced an average of nearly five hours of interruptions in 2019 - Today in Energy - U.S. Energy Information Administration (EIA)"

https://en.wikipedia.org/wiki/World_energy_supply_and_consumptio n

Statistics of Iran's Electricity Industry Electricity Distribution Division in 1398, Tavanir Specialized Parent Company, Vice President for Research and Human Resources, Information Technology, Communication and Statistics Office, September 1399 [Reference in Persian]

Performance Report for 1399 Water and Electricity Industry, Deputy of Research and Human Resources, Information Technology and Statistics Office, July 1400 [Reference in Persian]

CEER. CEER Report on Power Losses, 2nd ed.; Ref: C19-EQS-101- 03; Council of European Energy Regulators: Brussels, Belgium, 2020

Warwick, Mike & Hoffman, mike. (2016). Electricity Distribution System Baseline Report for DOE Quadrennial Energy Review.

Wang, J., Chen, C., & Lu, X. (2015). Guidelines for implementing advanced distribution MANAGEMENT SYSTEMS- REQUIREMENTS for DMS integration with DERMS And microgrids.

Musiał, W.; Zioło, M.; Luty, L.; Musiał, K. Energy Policy of European Union Member States in the Context of Renewable Energy Sources Development. Energies 2021, 14, 2864.

Simionescu, M., Strielkowski, W., & Tvaronavičienė, M. (2020). Renewable Energy in Final Energy Consumption and Income in the EU-28 Countries. Energies, 13(9), 2280

Jiang, P., Fan, Y. V., & Klemeš, J. J. (2021). Impacts of COVID-19 on energy demand and consumption: Challenges, lessons, and emerging opportunities. Applied Energy, 285, 116441.

Alasali F, Nusair K, Alhmoud L, Zarour E. Impact of the COVID-19 Pandemic on Electricity Demand and Load Forecasting. Sustainability. 2021; 13(3):1435

Liu, Chen-Ching, and Stewart, Emma. 2021. Electricity Transmission System Research and Development: Distribution Integrated with Transmission Operations. In Transmission Innovation Symposium: Modernizing the U.S. Electrical Grid, U.S.

Department of Energy

Baker, P. (2020). Challenges facing distribution system operators in a decarbonised power system. Regulatory Assistance Project.

https://www.igmc.ir/news/ID/12949

https://www.irena.org/publications/2017/oct/electricity-storage-and- renewables-costs-and-markets

http://www.sabaenergy.ir/contracting-service/

Patricia Hoffman, Assistant Secretary, and Devon Streit United States Electricity Industry. Primer Report, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy. DOE/OE-0017. U.S. Department of Energy Office of Electricity Delivery and Energy Reliability. July 2015

Baravati, Peyman & Moazzami, Majid & Shahinzadeh, Hossein & Moradi, Jalal & B. Gharehpetian, Gevork. (2019). Long-Term Energy Planning of Iran Respect to the Implementation of Smart Grid Infrastructures. 1-10. 10.1109/SGC49328.2019.9056615.

http://www.barghnews.com

https://coronomy.ir/

Kezunovic, M., Pinson, P., Obradovic, Z., Grijalva, S., Hong, T., & Bessa, R. (2020). Big data analytics for future electricity grids. Electric Power Systems Research, 189, [106788].

https://www.tdworld.com/smart-utility/metering/article/20970615/us- electric-utility-customer-base-now-exceeds-150-million

The Weather Company, “Utility Outage Prediction 2.0.”

DOE OE, Distribution Automation: Final Report from the SGIG Program (September 2016).

https://www.woodmac.com/news/editorial/der-growth-united-states/

https://www.epa.gov/ghgemissions/sources-greenhouse-gas- emissions

https://www.itron.com/-/media/solutions/what-weenable/dem/targeted-demand-management.pdf

The United States Nationally Determined Contribution Reducing Greenhouse Gases in the United States: A 2030 Emissions Target

https://www.greentechmedia.com/articles/read/5-takeaways-on-the- future-of-the-u.s-distributed-energy-resources-market

https://quanta-technology.com/investor-owned-utilities/technology-integration-smart-grid/der-control-and-management-derms/

https://www.greentechmedia.com/articles/read/distributed-energy-poised-for-explosive-growth-on-the-us-grid

https://www.c2es.org/content/microgrids/

Grid 2020 Towards a Policy of Renewable and Distributed Energy Resources, Resnick Institute Report, September 2012.

https://www.ncsl.org/research/energy/modernizing-the-electric-grid-state-role-and-policy-options.aspx

Wolfgang, O. et al., (2018) Prosumers' role in the future energy system A position paper prepared by FME CenSES. CINERLI / Zero Emission Neighbourhoods in Smart Cities.

Petrick, K., Fosse, J., Klarwein, S. (2019). Principles for Prosumer Policy Options. PROSEU - Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition (D3.3).

https://new.abb.com/news/detail/3883/prosumers-pave-path-to-energy-self-reliance-for-sustainable-living

https://www.smart-energy.com/news/eu-demand-response-market- frost-sullivan/

Capgemini (2008) Demand response: A decisive breakthrough for Europe

https://www.euractiv.com/section/energy/interview/energy-execs-the-market-for-demand-response-is-only-going-to-grow/

https://ses.jrc.ec.europa.eu/smart-metering-deployment-european- union

https://www.globalpetrolprices.com/electricity_prices/

Technical assessment and regulatory status of the European electricity grid, (2020). Interplan integrated operation planning tool towards the Pan-European Network

https://www.smart-energy.com/industry-sectors/smart-grid/23-9-billion-anticipated-substations-automation/

A. ABBREVIATIONS

Table 2. Abbreviations

MG	Microgrid
SG	Smart Grid
ADN	Active Distribution Network
PEIG	Power Electronic Interface Generation
VER	Variable Energy Resource
DSO	Distribution System Operator
LV, MV	Low Voltage, Medium Voltage
RES	Renewable Energy Resource
PMU	Phasor Measurement Unit
AMI	Advanced Meter Infrastructure
DSM	Demand Side Management
DR	Demand Response
DERRI	Distributed Energy Resource Reliability Index
SCADA	Supervisory control and data acquisition
MTOE	Million Tonnes of Oil Equivalent
KTOE	Kilo Tonnes of Oil Equivalent
IEA	International Energy Agency
GA	Gap Analysis
CPP	Conventional Power Plant
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
AS	Ancillary Service
AI	Artificial Intelligence
KPI	Key Performance Indicators
WTG	Wind Turbine Generator
GENCO	Generation Company
GHG	Greenhouse gas emissions
ATC	Available Transfer Capacity
RM & RI	Reliability Metrics and Reliability Index
GEP, TEP, DEP	Generation, Transmission and Distribution expansion planning
DEG	Diesel Generator
NCR	Non-Conventional Renewable Energy Resources
FFR	Fast Frequency Response
NERC	North American Electric Reliability Corporation
IEA	International Energy Agency
ERCOT	Electric Reliability Council of Texas
EPRI	Electric Power Research Institute
RE	Road Map