Distributed Generation of Electricity: A solution to the energy problems in India

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Distributed Generation is a widely used term that has been defined and interpreted in different ways across Central, and State jurisdictions. The basic definition of distributed energy is that it is the process of generating energy close to its point of delivery. [1]The paper reviews the main drivers for the renewed global interest in distributed generation; the benefits that can be derived from adopting this technology; the factors mitigating against it despite the potential benefits; as well as the possible solutions to the challenges faced by this emerging technology.

The desire for green, pollution free electric generation to meet environmental targets and technological advancements in renewable energy sources are some of the reasons for the increased growth of distributed generation resources. So, instead of generating power from big power plants (coal, nuclear, etc.), which is then transmitted over a vast and complicated network of power lines and transfer stations to be delivered to eventual homeowners, you have smaller power plants that generate decent and moderate amount of energy located at closer proximity to the homes and officers that will use it. Moreover, distributed generation to customers, the electric system, and society is rising because environmental and public health concerns have translated into a consumer preference for clean, distributed energy resources. In recent years, there has been an acceleration of the insertion of distributed energy resources, mainly due to the reduction in investment and transaction costs, the greater dissemination of telecommunication and control technologies, and more active role of consumers. [2]

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[1] Distribute Power Generation - https://www.sciencedirect.com/topics/engineering/distributed-power-generation

[2] How to infuse distributed generation with institutional capital - https://www.sciencedirect.com/topics/engineering/distributed-power-generation

At the micro level, distributed generation can mean a single rooftop solar installation servicing a home in a remote area and at the macro level it can mean a locally based solar project that delivers energy to the already existing grid and is distributed through a utility company to thousands of people in an area in vicinity to the solar project. This type of distributed generation of electricity uses the grid infrastructure and utility systems that are already in existence, saves money on transmission costs and allows for energy procurement from a variety of sources to ensure uninterrupted service.[3] Further, reduced transmission costs can equal reduced energy prices for consumers and affordable implementation of new technology for the utility. The coal-powered plants of the previous century are aging, and cheaper modes of energy in the form of natural gas and renewables, along with stricter clean energy government mandates, are resulting in their decommissioning. When international concern about climate change and consumers' growing emphasis on cleaner energy choices are added to the infrastructure issues, change becomes inevitable.[4]

Distributed energy resources (DER) are electric generation units located within the electric distribution system at or near the end user. DER have been available for many years, and are known by different names such as generators, back-up generators, or on-site power systems. DER technologies consist primarily of energy generation and storage systems placed at or near the point of use. Distributed energy encompasses a range of technologies including micro turbines, fuel cells, reciprocating engines, load reduction and other management technologies. DER involves power electronic interfaces, as well as communications and control devices for

[3] Grid-integrated Distributed Solar - https://greeningthegrid.org/integration-in-depth/distributed-generation
[4] Investing in a Distributed Energy Resource Future - https://www.renewableenergyworld.com/2017/03/02/investing-in-a-distributed-energy-resource-future/#gref

effective dispatch and operation of single generating units, multiple system packages, and aggregated blocks of power.[5]

Distributed Generation investment is on rise and has increased to a good extent because the cost of distributed generation is declining and the value to the electricity system, consumers, and society is increasing. Public support for clean energy has developed a favourable policy environment at the National level and in many states that has led to favourable incentive payments and tariffs, interconnection rules, and tax treatments in the places where the respective policies apply.

Distributed Generation of electricity offers several benefits and advantages over centralized systems, including:

Higher quality electricity: The closeness of distributed generation of distributed generation sources to end-users typically results in higher quality of electricity because there is less transmission losses, frequency variations, voltage fluctuations, and other disruptions.[6] Distributed generation also helps in reducing congestion in traditional transmission lines and prevent black-outs.[7] Moreover, distributed generation of electricity can also serve as a backup to the grid, acting as an emergency source for public services in the case of a natural disaster.
Lower environmental impact: Environmental issues are probably the major driving force for the demand of distributed generation of electricity. Since the renewable energy sources are by nature small-scale and dispersed over the grid, installing distributed generation provides the opportunity to exploit the cleaner energy within proximity.[8] Distributed generation remain autonomous of the grid, they can deliver emergency power for many public services such as

[5] Distributed Generation of Electricity and its Environmental Impacts - https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts
[6] Distributed Generation: What are the benefits? - https://alcse.org/distributed-generation-benefits/
[7] Benefits of Distributed Generation - https://www.dg.history.vt.edu/ch1/benefits.html
[8] The potential benefits of distributed generation and rate-related issues that may impede their expansion - https://www.ferc.gov/legal/fed-sta/exp-study.pdf

hospitals, universities, and airports.[9] Many distributed generation technologies, such as solar panels, wind turbines have significantly lower environmental impact than centralized power systems which comes out as an attractive solution for consumers and businesses looking to reduce their carbon emissions.[10] The avoided emissions are in a first approximation similar to the amount of energy saving. Further, distributed generation can create efficiency improvements, for example when otherwise waste heat is put to use, through combined heat and power equipment.[11]

Reliability: Another motivating factor for using distributed generation is the reliability. The liberalization of electricity markets makes consumers extra conscious of the importance of reliability of electricity supply. Companies may find the reliability of the grid at a dangerously low level and agree to invest in distributed units to upsurge total reliability of supply to the wanted level. Besides, voltage drops to near zero, one of the major reliability problems, one can also have smaller deviations of voltage.[12] As mentioned above, power quality incorporates reliability. Distributed generation technologies can also contribute in providing benefits in the form of greater reliable power for industries which necessitate uninterrupted service.

Greater energy independence: Distributed generation could partially serve as an auxiliary network for investments in transmission and distribution capacity or as a bypass for transmission and distribution costs. Distributed generation of electricity is also an important resource for providing access to power in remote areas and hence offers an opportunity to

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[9] The opportunities of distributed generation - https://www.c2es.org/2013/11/the-opportunities-of-distributed-generation/

[10] Why a distributed energy grid is a better energy grid - https://www.swellenergy.com/blog/2016/05/20/why-a-distributed-energy-grid-is-a-better-energy-grid

[11] Assessing the cost and benefits of distributed energy to the grid of the future - https://www.utilitydive.com/news/assessing-the-costs-and-benefits-of-distributed-energy-to-the-grid-of-the-f/402515/

[12] The potential benefits of distributed generation and rate-related issues that may impede their expansion - https://www.ferc.gov/legal/fed-sta/exp-study.pdf

increase national energy security and independence by reducing dependence on a few centralized plants.

Peak Shaving: Distributed generation technologies are flexible and these aspects include size, operating mode, and extent of expandability. Utilizing distributed generation allows to respond amenably to variations in electricity price developments. Distributed generations then serves as a border against these price instabilities. It may also reduce peak demands at the national level, thus decreasing the country's generation capacity requirements and potentially replacing use of Carbon dioxide emitting plants, as well as providing lowering ramp rates in demand. This is the primary driver for the demand for distributed generation in various countries i.e. using distributed generation for continuous or peaking purpose.[13]

Cost Efficient: Distributed generation of electricity can help consumers and businesses control electricity expenses as locally-derived renewable energy is not subject to market fluctuations in the price of fossil fuels.[14] Distributed generation of electricity offers cost savings opportunities by helping facilities decrease peak demand, and can even provide additional income from the sale of excess power back to grid. Distributed Generation technologies also represent a lower investment risk than traditional centralized systems.[15]

Grid Support: Distributed generation can also contribute in the delivery of subsidiary services, like those essential to maintain a steady grid operation of the customers including the ability to generate active power when demanded by grid network operator, for instance, to keep a system

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[13] Distributed Generation - https://openei.org/wiki/Distributed_Generation

[14] The potential benefits of distributed generation and rate-related issues that may impede their expansion - https://www.ferc.gov/legal/fed-sta/exp-study.pdf

in steady state when its frequency is declining due to a sudden drop in generation or due to a severe fault on the main grid.[16]

Enhancement of Energy Security: Distributed generation deliver more energy security as compared to large conventional power plants in case of harsh weather conditions, natural disasters, cyber-attacks, and human error. If a centralized power plant collapses, an enormous blackout may occur in the adjacent residential area and it can lead to a calamity for the people nearby. For instance, after the Tsunami in Japan, the failure of cooling systems at Fukushima-I Nuclear Power Plant and issues concerning other nuclear facilities in Japan on March 11, 2011, a vast blackout occurred for a long duration of time. A nuclear emergency was declared in Japan and some 140,000 residents, within 12 miles' radius of the plant, were vacated. [17]

Challenges faced in implementing distributed generation of electricity

Variable nature of distributed generation: Most individuals and businesses require reliable, consistent and efficient supply of electricity. The fluctuating nature of many renewable sources poses significant operational challenges, both to utilities that must integrate variable power inputs into electricity grid, and to customers.

No proper network technology: The conventional electricity system regulatory structure was designed around a limited number of large-scale centralized generation assets connected to a grid that carried electricity in one direction, to customers, and divided the one-way flow of power into depositories of various roles across the value chain.[18] With distributed generation of electricity, distribution grids become active and see power flowing in both directions, with

[16] Distributed Generation - https://openei.org/wiki/Distributed_Generation
[17] Energy Efficiency and Distributed Generation for Resilience: Withstanding Grid Outages for Less - https://www.energy.gov/sites/prod/files/2019/06/f64/EEDG-Resilience.PDF
[18] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

higher number of customers to manage and a change in the load profile by decreasing demand from the central generation. The requirements that allow management of the flow of electricity in real time, including proper network technology, are yet to be fully developed in most of states, along with solid schemes for valuing distributed generation services.[19]

Lack of price signals: Further, there are structural barriers which include lack of price signals to encourage distributed storage. Efficient storage depends on storing and discharging electrons at optimal times, and that in turn depends on clear and automatic pricing signals sent to smart storage systems. Presently, most electric systems don't possess such real-time pricing signals at the customer level. [20]

Single-Phase Connection: Some Distributed Generation sources input single phase power into the distribution grid, for example, small photovoltaic systems. This disturbs the balance of the three-phase current as unbalanced neutral current rises. This results in the flow of stray earth currents.[21] It is quintessential to restrict this current to avert the issue of overloading and to ensure safety of personnel.

Reverse Power Flow: One of the challenges to protecting an active distribution system is because power can flow in both directions in each feeder of the grid as power sources are located on both sides. It is important to mention that power flow also changes its direction, when local generation is greater than local consumption. Power quality issues can arise because of this reverse flow of power, that, in turn, leads to large variations in system voltage. Due to

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[19] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

[20] Effect of the Photovoltaic Distributed Generation on Electricity Distribution System Voltage - https://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-89132018000200206

[21] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

reverse power flow, conventional overcurrent protection is not applicable. This protection only applies to situations where fault currents flow in one direction. [22]

Regulatory challenges: Moving ahead, there are certain regulatory challenges that are faced by Distributed generation technologies for instance investment in distributed technologies is presently often dependent on financial incentives and subsidies, and uncertainty surrounding the extension of these incentives can halt widespread adoption of distributed generation of electricity. [23]

Solutions to overcome the barriers in implementation

Energy Storage Technology

The development of energy storage technology and its commercialization will have a significant impact on power system in future. Due to the fluctuating characteristic of wind and solar power generation, energy storage technology has become one of the central tools for integrating renewable energy generation with power grid. There are five major categories of energy storage technology- mechanical energy storage, heat-energy storage, electrochemical energy storage, magnetic energy storage and chemical energy storage.[24] Mechanical energy storage technology mainly includes the pumped storage, compressed-air energy storage etc. The pumped storage is the most mature technology, with having large capacity, long service lifespan and low unit cost. The compressed air energy storage has the benefit of large capacity,

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[22] Distributed generation and the grid integration issues - https://www.eusustel.be/public/documents_publ/WP/WP3/WP%203.4.1%20Distributed%20generation%20and%20grid%20integration%20issues.pdf

[23] Distributed Generation of Electricity and its Environmental Impacts - https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts

[24] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

long operation time and also capable of supplying combined heat, cold, and electricity by converting the compressed air into other alternative energy.[25]

The second kind of energy storage technology is the heat storage. A heat storage can achieve the purpose of heat storage by increasing the temperature of the heat storage material, which usually uses water as the heat storage medium. The heat storage system in the photo thermal system can provide the heat energy needed or generate electricity when the solar radiation is insufficient in rainy days. Hence, the output of electricity from heat storage system can be adjusted according to the grid operation requirement. Molten salt storage technology is presently a research hotspot which is applied to the concentrated solar thermal power plant. It has the advantages of high heat capacity, low cost and safety.[26]

The third energy storage technology is electrochemical energy storage which include lead-acid battery, sodium-sulphur battery, lithium-ion battery, redox flow battery. Traditional lead-acid battery technology is well-developed and has the advantages of low cost and easy maintenance. Presently, developed countries are committed to develop more advanced lead-acid battery, and they have developed several types of batteries including lead-carbon battery, super battery and so on.[27]

The fourth energy storage technology is electromagnetic energy storage which mainly contains super capacitor and superconducting magnetic energy storage. Super capacitor has advantages of fast response, high efficiency, high power density, and long cycle life. The last energy storage technology is the chemical energy storage and is considered as a secondary energy carrier using hydrogen or synthetic gas, of which hydrogen is electrolyzed, and it can be

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[25] Global Renewable Energy-Based Electricity Generation and Smart Grid System for Energy Security - https://www.hindawi.com/journals/tswj/2014/197136/
[26] Energy Storage - https://www.eesi.org/papers/view/energy-storage-2019
[27] Global Renewable Energy-Based Electricity Generation and Smart Grid System for Energy Security - https://www.hindawi.com/journals/tswj/2014/197136/

synthetized into natural gas i.e. methane with carbon dioxide. This green technology without any pollution could lead to formation of large – scale energy storage which can store more than 100 GWh energy. [28]At present, hydrogen energy storage technology has also been new area of research in many countries. Main way of hydrogen utilization is through fuel cell. The energy storage technology is a breakthrough to electrical generation and it is adequate for various application fields, including renewable energy grid integration, power transmission and distribution, micro-grid, and distributed generation. Therefore, through the application of energy storage, discharged wind and solar power can be stored and power grid is in turn is able to provide more stable power output, which provides fast support to the active power, enhances the capability of grid frequency regulation, and leads to large-scale wind and solar generation connecting to grid both reliable and stable.[29]

Many proponents of renewable energy are convinced that the grid will adapt largely by introducing more natural gas generators, able to cycle quickly to accommodate fluctuating production from wind and solar power plants. GE has even developed a natural gas turbine with the purpose of more effective backup to variable renewable energy sources.[30]

Smart grid

Smart grid can be defined in simple terms as a grid that maximises information and automation to operate peak efficiency. The improvements range from the central and distributed generator through the high-voltage transmission network and distribution system. Tools like robust real-time price signals, and two-way power flow control could alter the grid so that it can operate more efficiently. One of the application area in smart grid communication is called Advanced

[28] Energy Storage - https://www.eesi.org/papers/view/energy-storage-2019
[29] Global Renewable Energy-Based Electricity Generation and Smart Grid System for Energy Security - https://www.hindawi.com/journals/tswj/2014/197136/
[30] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

Metering Infrastructure (AMI).[31] In the traditional way, where technicians are sent to each consumer site monthly to record the data manually for the billing purpose, the smart meters in AMI provide real-time monitoring capability of electric loads remotely. [32]The real-time data is efficient and precise. This allows utility companies to analyse consumer energy consumption data and to provide billing information using two-way communication. Further, through AMI, consumers can be provided with historical data for energy consumption and dynamic pricing. This will encourage active participation and response of the end users in energy management. [33]Therefore, taken together, these steps can result in an electric power system that can intelligently integrate the actions of all connected users right from the power generators to electricity consumers to those that both produce and consume electricity.[34]

Micro grids

Micro grids defined as localized grids that can be disconnected from the traditional grid to operate autonomously. It is an energy distribution network that depends on local means of producing electricity. This will provide a single point of common coupling with the traditional grid thus making it easier to integrate different energy source to the main grid and also making the distribution network less complex and more efficient. Micro grids are majorly depended on gensets or fuel generators.[35] Fuel is easily stored and with high power factors which is easily managed and less demanding. Further, the term micro-grids are often used to describe Pico grids and Nano-grids as well. Pico grids are small power supply system that provide the connected items with limited capacity. They are mainly used for rural areas with electrifications

[31] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

[32] Energy Storage - https://www.eesi.org/papers/view/energy-storage-2019

[33] Global Renewable Energy-Based Electricity Generation and Smart Grid System for Energy Security - https://www.hindawi.com/journals/tswj/2014/197136/

[34] Energy Storage - https://www.eesi.org/papers/view/energy-storage-2019

[35] Features and Benefits about Micro-grids - https://www.districtenergy.org/microgrids/about-microgrids97/features

issues where the energy demand is too low. Nano-grids are single domains of power with a single layer of power distribution. Nano-grid applies or Solar Home Systems where each home is powered by an autonomous photovoltaic system.[36] Utilities may find that the growth of micro-grids and distributed energy resources offer opportunities to save money. Increase in micro-grids mean less demand on the central power plant and fewer investments in capital improvements. For instance, if a storm knocks down transmission lines, many micro-grids would likely continue operating, which means the utility can dispatch fewer service personnel to deal with emergency repairs. Therefore, micro-grids can operate independently or in synchronization with the electricity grid, ensuring the supply with local, efficient, and reliable energy at all times.[37]

Demand Response Applications

Demand-side management can benefit the smart grid systems on a large scale. The major goal of demand-side management is to allow the utility company to manage the user-side electrical loads. A popular component of demand-side management is developing incentives for the smart grid customer, such as residential home users, to modify their temporal use of electricity, for reducing the peak-to-average load on the grid. Incentives can come in the form of lower pricing or coupons.[38]

Integration of New Transport Technologies

New transport technologies such as electric and hydrogen vehicles have the potential to be better integrated with the power system for a much more efficient result. The insertion of

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[36] Features and Benefits about Micro-grids - https://www.districtenergy.org/microgrids/about-microgrids97/features
[37] Features and Benefits about Micro-grids - https://www.districtenergy.org/microgrids/about-microgrids97/features
[38] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

electric mobility, for instance, can allow the batteries to be used for energy arbitrage, soothing the load curve. Additionally, the increase in electric mobility decreases fuel consumption projections, the need for refining facilities, and reduces the production of biomass for electric generation. [39]

Collecting large volume of data

The execution of previous solutions will require collecting and processing a larger volume of data regarding consumption, generators, transmission, tariffs and storage infrastructure status, among others, with higher resolution and more immediate access. The concept of Big Data needs to be applied to the power sector and energy planning. The installation of smart meters is one of the pre-conditions to make possible the greater digitisation of the sector and the data collection.[40] Further, the advancement of the internet of things should help this process by increasing the connectivity of home appliances, vehicles and buildings. An apt instance of this application is the use of geospatial data from smartphones, could help in the prediction of the load curve. Another potential application would be to collect data to arrive at the estimate cost of electricity deficit, which is an input for the energy expansion models.[41]

Collaboration and Coordination: Major Providers, Micro-Grids, and Individuals.

Producers, consumers, and distributors must collaborate to meet their individual energy needs. Even as battery storage improves, it will be difficult for a micro-grid or individual to generate and store enough power to be self-sufficient. There will days when storage batteries are fully charged and solar panels produce surplus electricity that can be sold for profit and used to

[39] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation
[40] Renewable Energy: Distributed Generation Policies and Programs - https://www.energy.gov/eere/slsc/renewable-energy-distributed-generation-policies-and-programs
[41] Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities - https://www.sciencedirect.com/science/article/abs/pii/S0378779606001908

support peak demands. Transmitting surplus energy to places in need of power will keep commerce from being disrupted and reduce equipment problems caused by blackouts.[42]

Collaboration among parties in the utility network can be facilitated by GIS. User-friendly visual displays and real-time mapping will give each party involved a view of changing energy demands and resources. GIS can provide insight on population trends and residential patterns or changes at street level for long term planning. A utility, for example, does not want to dig up streets to maintain its assets right after the city fixed the roadway.[43] A shared GIS database helps both sides coordinate work. Coordination takes place in real time by sharing information with emergency management departments. Utilities will be able to learn more about the potential power disruptions due to natural disasters. GIS can help the energy provider in locating the impacted transmission lines in order to see which consumers will be affected by an outage. They can share the information with emergency services providers and coordinate the best course of action. Utilities can look at the growth patterns and consumer demographics that is visible on GIS to predict future needs. Analytics based on GIS will help providers customize offerings for residents with solar panels and those who prefer to buy renewable energy. [44]

Regulatory changes

The traditional utility business model does not incentivize neither customer generation of power nor efficiency. Most regulatory policies are not designed for customers who are also generators which limits deployment. The existing model has encouraged competition in

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[42] Real-Time Reconfiguration of Distribution Network with Distributed Generation - https://www.intechopen.com/books/real-time-systems/real-time-reconfiguration-of-distribution-network-with-distributed-generation

[43] Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities - https://www.sciencedirect.com/science/article/abs/pii/S0378779606001908

[44] How to tackle the challenges of distributed generation on the grid- https://www.power-grid.com/2014/10/08/how-to-tackle-the-challenges-of-distributed-generation-on-the-grid/#gref

generation and supply of power but is unable to encourage clean energy supplies. In order to shift towards smart grids and micro-grids, the prevailing policy and regulatory frameworks must evolve. An efficient and equitable regulatory environment for energy technologies would encourage greater adoption of smart-grids.[45] Policymakers and regulators should implement a framework which optimally spread the risk over the whole value chain i.e. to guard the investors from risk and to yield the result at lower cost to the customers. Many countries are exploring "green banks" as an option which provide low-interest, long term financing for clean energy development. India could also include micro-grids as eligible technologies for clean and renewable incentives to help drive market growth.[46] Valuing environmental, economic, and security benefits would further clarify the role of these technologies and allow investors to monetise their attributes for a speedy return on investment. To overcome technical and financial hindrances, regulations must clarify the rules for integrating micro-grids. [47]Additionally, government support for research and development and public-private partnerships will lead to lower-cost technologies and encourage market adoption which result in cheaper, cleaner and stronger grid.

The paper has presented an overview of definitions of distributed generation, presented with advantages and disadvantages of distributed generation of electricity. It also addressed the challenges faced in the implementation of distributed generation as well as suggested potential solutions to such problems. As the distribution system locates the end of power system and is connected to the customers directly, so the reliability of power supply mainly depends on distribution system. Several compact distributed generation technologies are fast becoming

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[45] Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities - https://www.sciencedirect.com/science/article/abs/pii/S0378779606001908

[46] Features and Benefits about Micro-grids - https://www.districtenergy.org/microgrids/about-microgrids97/features

[47] Renewable Energy: Distributed Generation Policies and Programs - https://www.energy.gov/eere/slsc/renewable-energy-distributed-generation-policies-and-programs

economically viable. Integration of distributed generation into an existing utility can result in several benefits. These benefits included reduced environmental impacts, line loss reduction, increased overall energy efficiency, voltage support, and relieved transmission and distribution congestion.