



Distributed Generation as a Complement to the Reliability of Electricity Supply: For Peruvian Social Economic Development

La Generación Distribuida como Complemento para la Confiabilidad del Suministro Eléctrico: Para el Desarrollo Económico Social Peruano

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ABSTRACT

Recent events, such as the massive blackout that occurred in Chile on February 25, 2025, which left 95% of the national territory without electricity supply, affecting approximately 20 million people for more

than six hours, highlight the importance of having an adequate regulatory and technical framework to prevent systemic failures. The reliability of the electricity supply is a fundamental pillar for economic and social development. In the case of Peru, geographical diversity and the existence of non-interconnected territories pose unique challenges to guarantee a continuous and stable service. In this context, distributed generation (DG), defined as the production of energy close to the consumption points, emerges as a strategic complement to improve the flexibility of the electricity system, especially in remote areas and in situations of high demand. This paper analyzes the potential of DG to improve the reliability of electricity supply in Peru and proposes adjustments to the regulatory framework to facilitate its effective integration as a complement to the SEIN (National Interconnected Electric System).

ABSTRACT

Eventos recientes, como el apagón masivo (Blackout), ocurrido en Chile el 25 de febrero de 2025 que dejó sin suministro eléctrico al 95% del territorio nacional, afectando a aproximadamente 20 millones de personas durante más de seis horas, ponen de relieve la importancia de contar con un marco regulatorio y técnico adecuado para prevenir fallas sistémicas. La confiabilidad del suministro eléctrico es un pilar fundamental para el desarrollo económico y social. En el caso del Perú, la diversidad geográfica y la existencia de territorios no interconectados plantean desafíos únicos para garantizar un servicio continuo y estable. En este contexto, la generación distribuida (GD) definida como la producción de energía cerca de los puntos de consumo emerge como un complemento estratégico para mejorar la flexibilidad del sistema eléctrico, especialmente en zonas remotas y en situaciones de alta demanda. El presente trabajo analiza el potencial de la GD para mejorar la confiabilidad del suministro eléctrico en el Perú y propone ajustes al marco regulatorio que faciliten su integración efectiva como complemento al SEIN (Sistema Eléctrico Interconectado Nacional).

Keywords / Palabras clave

Distributed generation, massive blackout, electric reliability, regulatory framework.

Generación distribuida, apagón masivo, confiabilidad eléctrica, marco regulatorio.

Introduction

In 2021, Peru emitted 96 million metric tons of carbon dioxide equivalent, which represents only 0.21 % of global emissions . In this context, promoting exclusively traditional renewable energies as the main solution is not entirely appropriate for the Peruvian reality. On the contrary, it is essential to recognize the high potential of other sources, such as biomass from solid waste, to move towards a more balanced and sustainable energy development. The recent blackout in Chile on Tuesday, February 25, 2025, which affected 95% of the country and left nearly 20 million people without electricity supply for more than six hours, demonstrates the urgency of strengthening the regulation and planning of interconnected electricity systems. Faced with this scenario, distributed generation (DG) is presented as a strategic alternative to improve the reliability of electricity supply, especially in countries such as Peru, which face significant geographical and infrastructure challenges.

This paper analyzes the potential of DG as a complement to the National Interconnected Power System (SEIN), evaluating its impact on the reduction of outages and the operational efficiency of the system. Based on a regulatory proposal inspired by international experiences adapted to the national reality, regulatory adjustments aimed at an optimal integration of DG are proposed. The objective is to ensure its effective contribution to the reliability of the electricity system, without compromising its safety and operational stability.

This study seeks to answer the following questions:

How can DG improve the reliability of electricity supply in Peru?

What regulatory barriers limit its effective integration as a complement to the SEIN?

What policies can be implemented to maximize its benefits without affecting system stability?

The path of electricity begins in power plants, where energy is generated (Generation). This energy is then transported through high-voltage lines supported by towers (Transmission). When it reaches the cities, transformer substations reduce the voltage so that the energy can be safely distributed to household meters (Distribution). The Peruvian electricity sector is structured in these three main activities, established by the Law of Electrical Concessions

(LCE). This organization responds not only to technological criteria, but also to economic and regulatory considerations. The Electric Concessions Law (LCE) establishes the organization of the Peruvian electric sector as follows:

In this regard, the Committee for Economic Operation of the System (COES) is the technical body responsible for coordinating the operation of the national electricity system, always seeking the lowest possible cost and at the same time guaranteeing the security of supply. The COES is made up of the owners of the generation and transmission companies that operate interconnectedly in the system. In addition, it has the participation of the Supervisory Body of Investment in Energy and Mines (OSINERGMIN), the entity in charge of the supervision and regulation of the electricity sector.

Distributed generation (DG) is the production of electricity on a small scale, close to where it is consumed or to the distribution network, and can use renewable or non-renewable energies, available in each localized area, allowing it to operate in an interconnected (on-grid) or isolated (off-grid) manner. This modality not only facilitates the purchase and sale of electricity within the interconnected system, but also contributes to reducing dependence on the grid and improving energy security. In addition, DG plays a key role in increasing the reliability of the transmission and distribution system, optimizing the use of energy resources.

Decentralization, proximity to consumption and use of diverse technologies, including renewables and non-renewables.

Methodology

The appropriate technologies for distributed generation are those that allow the production of electricity close to the point of consumption, improving efficiency and reducing distribution losses. Law No. 1002 establishes that non-conventional renewable energies (NCRE) are those energy sources that regenerate naturally and whose use contributes to the protection of the environment and the energy sustainability of the country. According to the law, the following are considered NCRE:

Solar Photovoltaic (PV): Solar panels that convert sunlight into electricity. PV is by far the most important solar technology for distributed solar power generation. PV uses solar cells assembled into panels to convert sunlight into electricity. It is an ever-growing

technology, with worldwide installed capacity doubling approximately every two years. PV systems can range from small distributed residential and commercial rooftop installations to large centralized utility-scale photovoltaic plants.

Wind Energy: Wind energy is a renewable energy source that harnesses the power of the wind to generate electricity using wind turbines. It is a clean and sustainable alternative that contributes to the reduction of greenhouse gas emissions.

Biomass generation: Biomass generation is a process that produces electrical or thermal energy from organic matter, such as agricultural, forestry or urban waste. It is a renewable source that contributes to the reduction of waste and carbon emissions.

Microturbines and Combustion Engines: Small units that run on natural gas or diesel.

Storage Systems: Batteries that allow energy to be stored for later use.

In the search for cleaner and more efficient energy, energy storage systems have acquired a fundamental role in today's energy system. Among them, the Battery Energy Storage System (BESS) stands out for its ability to optimally store and supply electrical energy, improving grid stability and efficiency.

A BESS system is composed of multiple batteries connected in series or in parallel, working together to store and supply electrical energy efficiently. These batteries can be of various types, such as lithium-ion, lead-acid, nickel-cadmium, among others, each with particular characteristics and advantages. The selection of the appropriate battery type will depend on the specific requirements of the system, considering factors such as capacity, useful life, efficiency and cost.

Results

DG encompasses technologies such as solar panels, mini-hydro and biomass generators, with capacities typically less than 50 MW. Their contribution to reliability is manifested in:

Reduced outages: By acting as backup sources in case of main grid failures.

Local stability: Mitigation of voltage fluctuations in weak or isolated grids.

Complementarity with the SEIN: Relief of congestion in transmission lines during demand peaks. Reliability indicators used in electrical systems are variables used to calculate and evaluate service continuity. Some of the most important ones are :

SAIDI (Average interruption duration per user).

SAIFI (Average frequency of interruptions per user).

Distributed Generation (DG) can improve these indicators when implemented with adequate technical and regulatory schemes.

This type of analysis is based on key parameters such as failure rate and repair rate, which allow evaluating the reliability and availability of the system.

Failure rate: Defined as the number of failures or interruptions that occur in a system during a specific period of time, generally expressed in failures per year or per hour.

Repair rate: It is defined as the failure time over the number of failures recorded at time t (years, months, days, etc.). The time window used must coincide with the one used for the failure rate.

In Peru, Osinergmin supervises reliability in electrical systems through the SAIFI and SAIDI indicators that cover generation, transmission and distribution activities. This monitoring aims to promote preventive and/or corrective actions by the concessionary companies to improve the quality and continuity of the electric service.

It is observed that, between 2018 and 2023, the SAIFI and SAIDI indicators have shown a slight improvement. However, the levels remain high, especially in the distribution segment, which directly affects end users. In 2018, a user experienced on average 7.85 interruptions per year, while in 2023 this figure was reduced to 6.11 times. Despite this decrease, the situation remains critical compared to other countries in the region, where, globally, the average frequency of interruptions is measured in fractions and their duration, in minutes.

The main problems by activity are as follows:

Electrification coverage: According to the National Institute of Statistics and Informatics (INEI), in 2023 electrification coverage in Peru reached 94% nationwide, with 96.3% in urban areas and 85.1% in rural areas. Below is a summary table of electricity coverage in the country:

Distributed Generation (DG) off-grid (off-grid) represents a viable solution to expand electricity coverage in rural areas. According to the 2023 results, 85.1% of the rural population has access to electricity service through the public grid.

Installed capacity by system and origin (MW)

According to general data from the Ministry of Energy and Mines, the installed capacity in 2022 was 15,761 MW. The participation of energy resources according to the type of generation of the National Interconnected Electric System (SEIN) and Isolated Systems (SS.AA.) is presented in the following table and graph:

Peru has a theoretical hydro energy potential estimated at around 73,000 MW, thanks to its mountainous geography and abundance of rivers. The total technically usable potential is estimated to be approximately 58,000 MW, considering factors such as accessibility, available technology and environmental conditions. Currently, the country uses about 5,515 MW of installed capacity in hydroelectric power plants, which represents less than 10% of the technically usable potential.

The estimated theoretical wind potential of more than 22,000 MW, especially in areas such as the northern coast (Piura, Lambayeque), the south (Ica, Arequipa) and some high Andean areas. These regions have average wind speeds greater than 7 m/s, which is ideal for large-scale wind power generation. As of 2024, the installed and operating potential barely exceeds 539 MW, which represents less than 2% of the total theoretical potential. There are some wind farms in operation in departments such as Piura, Ica and Marcona, but still with low participation in the national energy matrix. Wind energy contributes approximately 1.5% to 2% of the national electricity generation, according to COES data.

It is estimated that solar potential exceeds 2000 kWh/m²/year in areas such as the southern Andean region (Arequipa, Moquegua,

Tacna and Puno). At the national level, the total estimated potential exceeds 3000 GW (gigawatts), considering its surface area and average solar radiation levels. Despite the high potential, the installed capacity of solar photovoltaic energy is small in comparison. As of 2022, Peru had approximately 287 MW (megawatts) of installed solar capacity. This represents less than 1% of the theoretical potential available.

Generation with Biomass (organic plant or animal waste): High generation of organic waste: In Peru, approximately 20,000 tons of solid waste are generated per day, of which more than 50% corresponds to organic matter (food waste, agricultural pruning, among others). This volume represents a valuable resource with high potential for biogas and bioenergy production.

Success story in the country - Huaycoloro Solid Waste Plant (Lima): This plant produces energy from biogas captured in a sanitary landfill. During 2024, it has processed an average of 1,200 tons per day of municipal solid waste (MSW), which represents between 15% and 20% of the total waste generation in the metropolitan area of Lima and Callao. More than 50% of this waste has a high potential for energy recovery.

The plant operates by capturing biogas in the landfill, which is channeled to electric generators powered by internal combustion engines. It has an installed capacity of 4 MW and an average plant factor of 75%, which allows it to generate approximately 26 GWh per year. This production is equivalent to the average electricity consumption of about 8,000 Peruvian households.

In addition to contributing significantly to the reduction of environmental pollution, the generation of energy from biomass offers important advantages for the country. These include distributed generation, an ideal solution for rural communities or communities far from the electricity grid, as it allows local and sustainable access to electricity. It also boosts the circular economy by promoting local economic development through job creation in activities such as organic waste collection, treatment and operation of biomass plants.

In order to promote Distributed Generation connected to the Public Electricity Grid -which allows users to produce their own energy from renewable or non-renewable sources and feed surpluses into the grid

in exchange for compensation- it is essential to have an adequate legal framework.

In Peru, although regulatory progress has been made in the area of renewable energies, there is still no specific and solid legislation regulating distributed generation, which represents a barrier to the development of this decentralized model of electricity generation.

Legally establish the figure of the user-generator, defined as the individual or legal entity that, in addition to consuming electricity, generates electricity from renewable sources and injects the surplus into the public electricity grid. The powers considered must contemplate the currently existing ranges for distributed generation, which vary between 500 kW and 50 MW, either in low or medium voltage.

Implement a bidirectional metering system that registers both the energy consumed and the energy injected by the user to the electric grid, allowing the compensation of the surpluses generated.

Create a public registry of user-generators, administered by the Ministry of Energy and Mines or by the corresponding regulatory body, in order to facilitate the control, monitoring and follow-up of these systems.

- Incentives and benefits.
- Provide for incentives such as:
- Tax exemption for the acquisition of renewable equipment.
- Facilities for grid connection.
- Incentive tariffs for injected energy.
- Participation of distribution companies

Obliging distribution companies to facilitate the connection of user-generators to the grid, with standardized, transparent procedures and reasonable deadlines.

Align the implementation of distributed generation with the goals of the National Energy Plan, GHG reduction commitments (NDCs) and the Sustainable Development Goals (SDGs).

- Technical and regulatory considerations
- The adequacy shall contemplate aspects such as:
- Technical interconnection standards.
- Guarantees of security and quality of supply.
- Supervision and oversight by OSINERGMIN.

Regulatory implementation represents a key opportunity to promote the energy transition in the country. A modern and participatory legislation on distributed generation will empower users, reduce dependence on fossil sources, and build a more resilient, fair and sustainable energy system.

Conclusions

In electricity distribution systems, service quality indicators, such as SAIDI and SAIFI, continue to register high levels, which directly affects end users. In 2018, a user experienced on average 7.85 interruptions per year; by 2023, this figure was reduced to 6.11. However, despite this improvement, the situation remains critical compared to other countries in the region and the world, where the frequency of interruptions is usually measured in fractions of an event per year and their duration, in minutes.

DG is not only an alternative, but a necessary complement to ensure the reliability of electricity supply in Peru, especially in isolated areas and under demand stress. However, its potential will only materialize with a regulatory framework that encourages investment through clear incentives and guarantees technical security with adapted standards.

The implementation of Distributed Generation requires an adequate regulatory framework, investment in technology and training of the actors involved. DG is not only a technical solution, but also an opportunity to promote social and economic development in underserved areas.

Distributed generation minimizes technical losses because it is located close to consumption centers.

The application of biomass in distributed generation is not only an environmentally sustainable solution, but also an economic and social opportunity for Peru. Its implementation would strengthen regional energy autonomy, promote labor inclusion and support the transition to a low-carbon economy.

Promoting exclusively traditional renewable energies as the only way to implement distributed generation is not entirely appropriate in the Peruvian context. On the contrary, it is essential to recognize the considerable potential of other sources, such as biomass from solid waste, to achieve a more balanced and sustainable energy development.

Considering that Peru emitted 96 million metric tons of carbon dioxide equivalent, which represents only 0.21% of global emissions, it is pertinent to evaluate the application of microturbines and combustion engines as alternatives for distributed generation.

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