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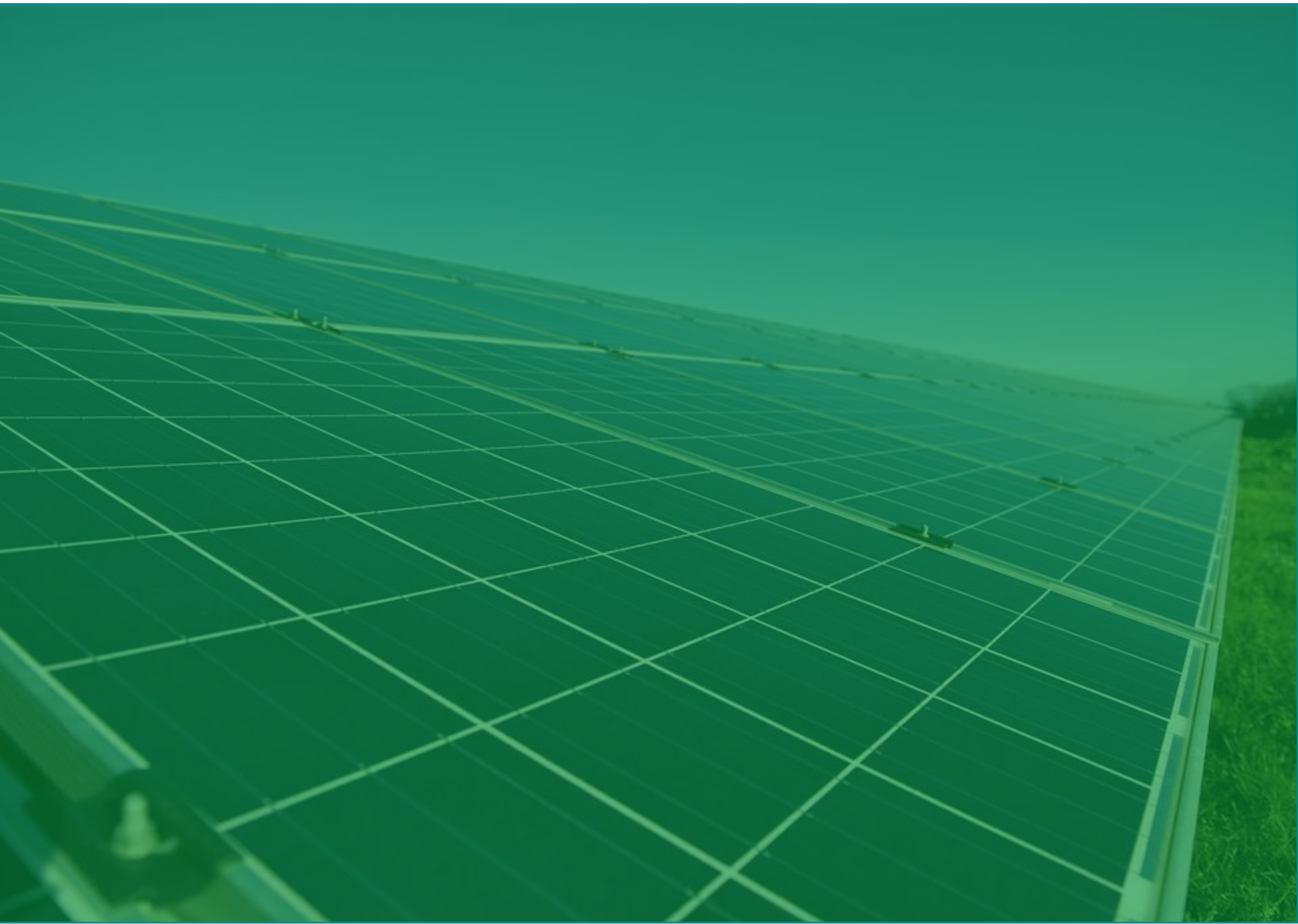
Grid stability: How PV inverters can help overcome challenges in the 21st century



Introduction

As the world moves towards decarbonization, sources of renewable power such as solar will play a crucial role in new energy generation. Energy generation is gradually shifting from conventional fuels such as coal, oil and natural gas, while demand for electricity is growing rapidly. The electrification of the economy is a major global trend underlying the need for stable, reliable electrical grids. This whitepaper outlines the various challenges for maintaining grid stability in an era of increasing installations of renewable sources such as solar, and the role that technology companies play in ensuring a stable and resilient electrical grid.

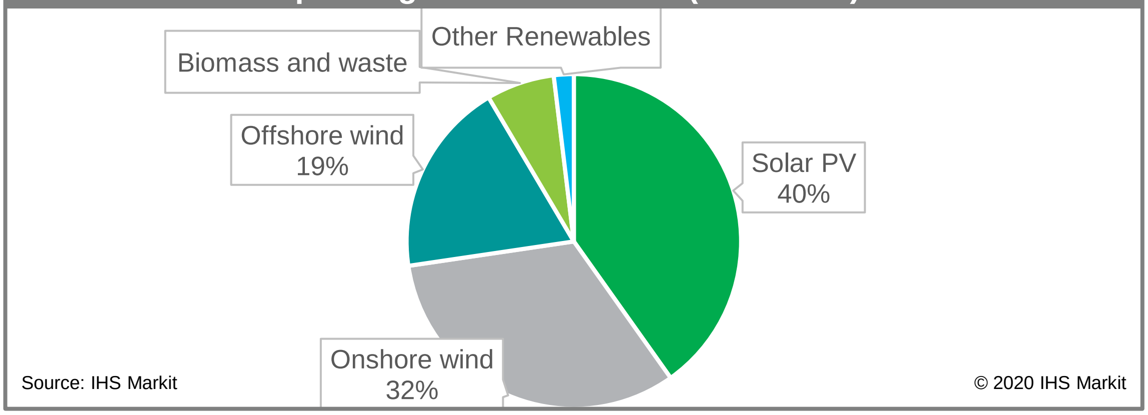
Key takeaways:

- A global push to lower carbon emissions is rapidly increasing demand for electricity sourced from renewables. A stable electrical grid is required to support the growing generation and demand for electricity.
- Electrical grid operators are faced with two main challenges. The first challenge is the stable operation and functioning of the grid. The second is the careful balance of supply and demand of electricity.
- Technology companies such as PV inverter suppliers must develop next-generation products to address these challenges. Reactive power, dynamic transient behavior, advanced communications, and Artificial Intelligence (AI) are examples of features that enable PV inverters to help stabilize electrical grids.
- Energy storage is the key to unlock the full value of solar and is an important tool which grid operators can use to balance electricity supply and demand. Batteries in particular have stepped up to this challenge due to the wide range of services these systems can provide for the electrical grid.

Generation and consumption of electricity are changing fast

As the cost of renewable energy continues to decrease, it is becoming a highly competitive form of electricity generation. According to data from IHS Markit, the levelized cost of energy (LCOE) for solar PV is forecast to decline by 27% between 2020 and 2030 in China (mainland), the world's largest market for solar PV. Meanwhile, the LCOE for solar PV in the world's second largest market, the United States, is forecast to decline by 38% in the same time period. Furthermore, renewables have increasingly stepped in to help re-electrify communities after natural disasters have disabled power plants and grid infrastructure in a region. For example, in 2017, Hurricane Maria devastated Puerto Rico and left its inhabitants without power for weeks. In its wake, installations of solar and battery energy storage systems boomed. Solar plus energy storage systems can also be capable of black start, allowing them to resume operation even after an entire electrical grid shuts down. As a result of these trends, renewables are expected to account for an ever-increasing amount of power generation, with 40% of power generation coming from Solar PV, and 51% from wind in 2050.

Global renewable power generation in 2050 (% of GWh)



Source: IHS Markit

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In terms of consumption, IHS Markit is forecasting that growth in demand for electricity will outpace traditional fuel types such as gas, coal and oil. For example, transportation is undergoing a major shift as the use of electric vehicles is rapidly growing. IHS Markit estimates that one in five light vehicles sales will be plug-in electric by 2030. As the world moves from gasoline-burning vehicles to electric, electrical grids around the world will be required to meet an ever-increasing demand to charge these vehicles. Similarly, many industries are expected to turn to electricity as a fuel instead of burning gas or coal for heating in many industrial processes. IHS Markit estimates that electricity consumption will double from 2020 to 2050.

Electrical grids are faced with several challenges in the modern world

Electrical grids are complex physical networks constructed to connect the generation and consumption of electricity. They are vital infrastructure and enable economic activity in the modern world. Electrical grid operators are faced with numerous challenges with maintaining the stable operation of the grid. For example, routine maintenance is required for equipment such as substations, transmission lines and distribution lines. Additionally, utilities must continuously monitor generation and consumption to ensure that electricity supply meets demand. Unforeseen events such as natural disasters can wreak havoc on an electrical grid by damaging power plants and transmission lines. The smooth operation of electrical grids is an ongoing responsibility for utilities and grid operators, especially as electricity demand increases.

As the world moves towards decarbonization, an increasing proportion of new generation capacity is coming in the form of renewable energy. Intermittent generation sources such as solar and wind have introduced specific technical problems to electrical grids which require new technologies to overcome. Electrical grid instability can be categorized as any number of disruptions or anomalies to the normal functioning of the grid. For example, a major concern related to the increased use of intermittent generation sources, such as PV power plants, is the issue of frequency and voltage anomalies. Most electricity production comes from power plants which employ electromechanical generators such as coal, natural gas, or hydro power plants. These generators transform energy from rotating turbines into electricity. In the unlikely event of a power plant failure, these physical rotating structures tend to keep moving for a few seconds, allowing the grid operators time to respond to the disruption and maintain the frequency in the electrical grid. This is often referred to as "inertia" in an electrical grid and helps allow for electricity to flow through the grid at expected parameters.

Inertia from spinning generators has been a key aspect of conventional electricity generation that has helped with overall grid stability. However, solar PV systems do not benefit from rotating mechanical structures to maintain inertia. Consequently, in extreme cases, PV plant failures can cause widespread disruption in an electrical grid. Wind power plants are also capable of causing disruptions on electrical grids. For example, in 2016, inclement weather in Australia caused wind power plants to reduce their power output. The sudden reduction in output from these large wind power plants initiated a cascade of disruptions along the grid which eventually led to widespread blackouts. In 2019, a series of disruptions along the electrical grid in the UK led to large power plants shutting down, including a large offshore wind power plant. The effects quickly rippled across the electrical grid, disabling large areas and leaving millions of people without power. Electrical grids are faced with the potential for instability with a high penetration of renewables. Therefore, regulators around the world are quickly announcing new standards and requirements to mitigate the risk of these types of blackout events.

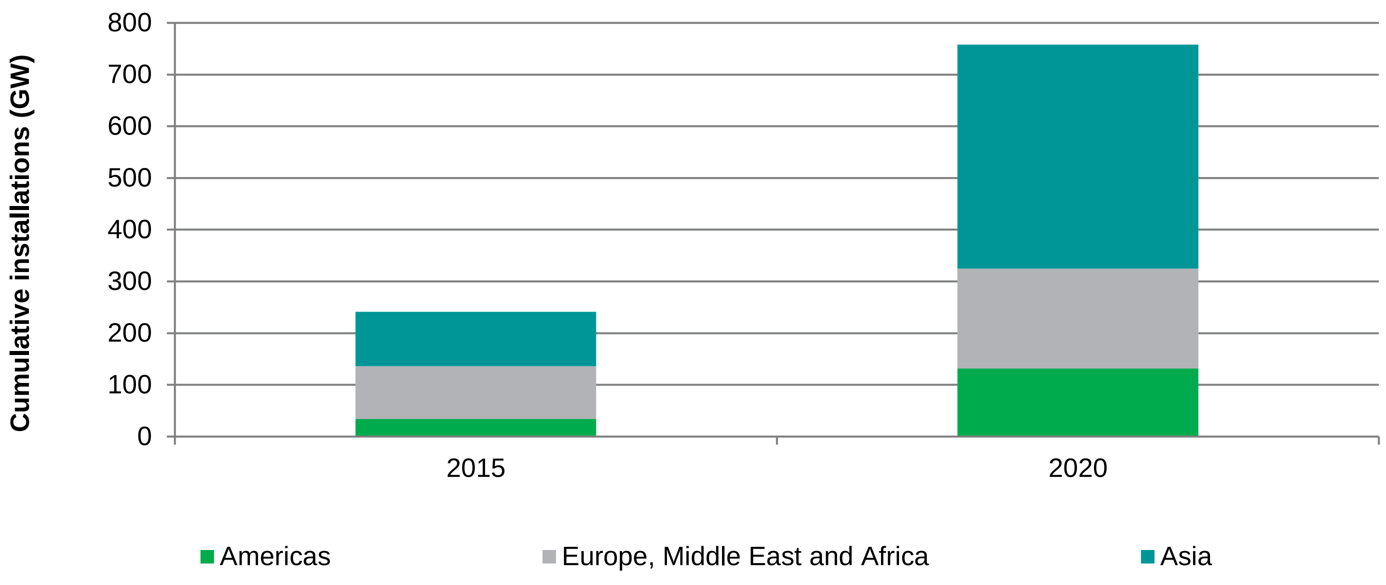
The increasing presence of renewables on electrical grids also presents new challenges related to balancing electricity supply and demand. Electricity demand naturally fluctuates throughout the day, and demand patterns vary by region and by season. A well-known phenomenon in many regions is the surge in residential electricity demand as residents get ready for work and school in the morning, a subsequent decline in demand throughout the day, followed by peak demand when they return home in the evening. This particular phenomenon of supply and demand mismatch is amplified as solar installations grow worldwide because energy generation from PV installations is highest at midday and falls to zero at night, aligning poorly with when electricity is in its lowest and highest demand.

Net load is the difference between the load on an electrical grid and electricity production. In places with a high concentration of solar installations, when net load throughout the day is plotted on a graph, the resulting chart shows a deep trough at midday resulting from the combination of lower electricity demand coupled with high electricity generation from PV power plants. Commonly referred to as the “duck curve”, this steep profile leads to challenges for grid operators to balance supply and demand. Today, natural gas peaker plants are typically used to meet peaks in demand. However, grid-connected stationary energy storage is also increasingly being offered as a solution to help balance electricity supply and demand.

PV inverters are key to stabilizing the electrical grid of the future

Solar installations have rapidly grown across the world. Global cumulative PV installations have swelled from 241 GW in 2015 to 758 GW in 2020. The PV inverter is the heart of a PV system and is the main component responsible for interacting with the electrical grid. Additionally, PV inverters are built with advanced software and communications capabilities that allow them to intelligently manage energy generation.

Global cumulative PV installations by region



Source: IHS Markit

Utility-scale PV power plants are expected to react automatically to changes in the electrical grid. PV inverters can provide grid support services such as helping maintain voltage and frequency parameters. For example, China recently released a revision to GB/T 37408, “Technical requirements for photovoltaic plants grid-connected inverter” in December 2019. It includes stricter requirements on PV inverters, including the need to maintain active output power during high voltage ride-through and requirements to help restore the normal voltage range in the electrical grid. Overall, modern PV inverters are designed and expected to operate in weaker electrical grid environments.

Regulators around the world continue to release new electrical grid standards to cope with the increasing penetration of new energy sources. Regulators closely monitor the plant short circuit ratio (SCR) as an indicator for the reliability of the electrical grid in which a new PV plant is being connected. A higher SCR indicates a lower penetration of renewable energy sources, while a lower SCR indicates a higher penetration and therefore a potentially weaker electrical grid. Several recent examples can be found worldwide of regulators modifying their standards to require that

PV plants be able to operate within electrical grids with lower SCRs. The Spanish transmission agent and operator, Red Eléctrica de España, is in the process of reducing the minimum SCR in which wind and solar power plants must be able to operate. Similarly, in Australia the revised National Electricity Rules specify that PV plants need to operate within electrical grids with an SCR as low as 3. The North American Electric Reliability Corporation (NERC) revised its guidance to require local power transmission companies to monitor SCR. For their part, PV inverter suppliers have responded by designing products which are rated to operate at lower SCRs. Leading suppliers have released inverters that can operate in a weak grid with an SCR as low as 1.5.

National and regional grid codes have heightened the requirements of PV systems to play a role in ensuring overall grid stability. For example, in California, a set of interconnection requirements commonly referred to as "Rule 21" have made autonomous control, standard communications protocols and interoperability required features in PV inverters. Similar grid codes have been introduced in other states including Hawaii and Vermont. Another example of grid codes which mandate grid-stabilizing features in PV inverters is in Germany's "Technical Connection Rules" (TCR). These rules outline requirements for PV systems installed in low, medium and high voltage grids. They define PV inverter features such as "dynamic network support", or the ability for solar power plants to remain on the grid during grid voltage anomalies. Additionally, they require PV inverters to be able to reactively feed power into the grid during moments of low frequency. These requirements, and others, are designed to ensure that PV systems play a dynamic role in responding to weak grids in order to help mitigate the issues presented by a high penetration of solar PV systems.

Additionally, the stability of the overall electrical grid is increasingly dependent on the reliability of grid-connected distributed energy resources such as residential and commercial PV systems because these systems feed electricity back into the grid and contribute to the overall balance of electricity supply and demand in the grid. The PV inverters in these systems have evolved to have autonomous features to help with grid stability, such as frequency ride-through, voltage ride-through and soft start reconnection. These autonomous features are designed to help PV systems maintain stable operation during different events, even for weak electrical grids.

However, forming regulations is not without its own challenges. For example, In Australia, regulators rushed to implement requirements related to under voltage ride-through, putting pressure on inverter suppliers to quickly get their products tested. In the United States, each phase of California "Rule 21" has been the subject to lengthy deliberation which has led to uncertainty for PV inverter manufacturers. Therefore, it has been incumbent on PV inverter suppliers to stay ahead of the curve by continuing to innovate next-generation software and capabilities into their products so that they are capable of operating in all electrical grids and under a wide range of local grid codes. Recently, PV inverter suppliers, module suppliers and other solar companies have formed alliances to produce and promote higher power modules exceeding 600 Watts, setting the stage for new innovations, and likely new technology standards.

Energy storage is a powerful tool to balance supply and demand in the electrical grid

The balance of electricity supply and demand is an increasing challenge for utilities and grid operators. For example, energy generation from wind power plants is dependent on weather while PV systems can only generate electricity during the hours of daylight. Energy storage is a key solution to addressing the issues related to balancing intermittent electricity generation from renewables with demand.

When electricity demand peaks, peaker power plants can be dispatched to help meet rising demand. These plants sit idle until demand rises enough to require them to be powered up. Power plants using gas combustion turbines, or hydroelectric power, have been the most common type of peaker plant. However, battery energy storage systems have become a competitive solution for meeting peak electricity demand. IHS Markit expects a rapidly increasing proportion of peaking capacity needs to be met by energy storage systems over the next 10 to 20 years.

Installing solar and energy storage behind-the-meter may also enable large electricity customers to avoid costly demand charges. The impact on the electrical grid is a flattened load profile which can have many benefits. It reduces how rapidly conventional power plants need to power up to meet peak demand. Additionally, infrastructure investments to electrical grids can be delayed due to the flatter load profiles.

PV inverter suppliers play a critical role in solar plus energy storage systems. The system architecture of a project will dictate the type of inverter used. For example, PV inverter suppliers can offer solutions for DC-coupled or AC-coupled systems. For residential systems, suppliers are also increasingly offering hybrid inverter solutions. These "battery-ready" inverters combine components of a solar inverter and a battery inverter. They allow for energy storage to be installed now or retrofitted in the future.

In addition to helping define the overall system architecture of solar plus energy storage systems, PV inverters are increasingly becoming responsible for the management of energy storage – controlling when the electricity is stored and discharged and optimizing the performance of the system. For example, PV inverter suppliers have developed sophisticated software platforms which can connect production from the PV system, energy storage and electricity loads. Advanced connectivity and data analysis software has also enabled customers to closely monitor their system and identify and diagnose any faults that may occur.

The electrical grid of the future will require smarter inverters

Full decarbonization of the world's energy needs will require electrical grids to evolve significantly from their current form. Electrical grids are also likely to evolve into different forms around the world. For example, the construction of microgrids blossomed in Puerto Rico in the immediate wake of Hurricane Maria. These small, localized PV systems provided electricity to individual homes, businesses, or even small communities. They are capable of operating independent of a wider electrical grid. For certain geographies, especially in emerging markets, wide-scale use of microgrids may be the most reliable means to ensure access to electricity. At the center of these microgrids are intelligent PV and energy storage inverters capable of managing energy generation and consumption. PV inverter suppliers are expected to continue to release products that can function in both on-grid and off-grid situations.

The aggregation of distributed energy resources will become more important as solar and energy storage systems are installed in more homes and businesses. Aggregation of these distributed resources can be a powerful way to efficiently balance the supply and demand needs of a wider region. For example, virtual power plants (VPP's) can aggregate the energy generation capacity of distributed PV systems and batteries and are capable of quickly dispatching energy generated at key times in the day to assist with balancing the grid. The communications, interoperability and data analysis capabilities provided by PV inverter suppliers will be key to the operation of virtual power plants.

The grid of the future will require distributed energy resources to communicate with each other and with grid operators to a higher degree. The capability of PV and energy storage systems will grow as critical components such as PV inverters continue to adapt to the evolution of the electrical grid.

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CUSTOMER CARE AMERICAS
T +1 800 447 2273
+1 303 858 6187 (Outside US/Canada)

CUSTOMER CARE EUROPE, MIDDLE EAST, AFRICA
T +44 1344 328 300

CUSTOMER CARE ASIA PACIFIC
T +604 291 3600

E CustomerCare@ihsmarkit.com

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