

Distributed Energy Resource Control: Energy Transformation with IEEE 1547-2018 Compliance

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Introduction

Distributed Energy Resources (DERs) are decentralized energy sources and systems located near the point of consumption. These resources can generate, store, or manage energy as well as operate independently or in coordination with the central grid. They play a crucial role in enhancing grid resilience, promoting renewable energy integration, and enabling more efficient energy management. Here are some types of DERs:

Solar Photovoltaics (PV): Solar panels convert sunlight directly into electricity. They are one of the most common forms of DERs due to their scalability and decreasing costs.

Wind Turbines: Wind turbines harness wind energy to generate electricity. They can be deployed in various settings, from small-scale residential installations to large wind farms.

Energy Storage Systems (ESS): Batteries and other storage technologies store excess energy generated by DERs for later use, improving grid stability and enabling load shifting.

Microgrids: Microgrids are localized energy systems that can operate independently from the main grid or connect to it as needed. They often incorporate multiple DERs, such as solar PV, wind turbines, and energy storage to provide reliable power to a specific area or community.

Fuel Cells: Fuel cells generate electricity through electrochemical reactions, typically using hydrogen as a fuel source. They are clean and efficient and can serve as both a primary power source and a backup during grid outages.

Hydropower: Hydropower systems generate electricity using flowing water. They are particularly suitable for areas with access to rivers or streams.

Biogas Digesters: These systems convert organic waste, such as agricultural residues or sewage, into biogas, which can be used for electricity generation or heating. Biogas digesters provide a sustainable way to manage waste while producing renewable energy.

Benefits of DERs

The integration of DERs into modern energy systems is essential for building a more sustainable, resilient, and efficient energy infrastructure that meets the evolving needs of society while addressing environmental challenges. These DERs reduce reliance on centralized generation and transmission infrastructure, making the grid less susceptible to disruptions caused by natural disasters, cyberattacks, or equipment failures. Distributed generation and energy storage can provide backup power during emergencies, ensuring continuity of critical services.

DERs also allow for improved energy efficiency, enabling localized generation and consumption of energy, therefore reducing transmission and distribution losses associated with transporting electricity over long distances. For example, Combined Heat and Power (CHP) systems capture waste heat for use in heating or cooling applications, significantly improving overall energy efficiency.

By adjusting energy consumption patterns and utilizing stored energy during peak demand periods, DERs can also help alleviate strain on the grid, lowering electricity costs and minimizing the need for expensive peaking power plants. DERs can also help with the integration of renewable energy sources, such as solar and wind, into the grid by providing distributed generation capacity. This reduces greenhouse gas emissions and mitigates climate change, making it more sustainable and environmentally friendly.

DERs provide grid operators with additional tools for managing grid operations and maintaining system stability. Through advanced control and communication technologies, DERs have several uses such as frequency regulation, voltage support, and grid balancing. This helps to enhance overall system flexibility and provides reliability.

Decentralizing power generation, promoting energy independence, and local economic development are also benefits of using DERs. Their deployment drives innovation in clean energy technologies, grid management solutions, and business models. This helps foster job creation, stimulates investment in renewable energy infrastructure, and allows for economic growth in the clean energy sector.

Understanding IEEE 1547

By establishing technical requirements for interconnection, operation, and performance standards of DERs, it helps mitigate potential risks, enhances grid stability, and promotes the widespread adoption of clean and renewable energy technologies.

IEEE 1547 originated from the growing need to establish standardized requirements for the interconnection of DERs with electric power systems. As renewable energy technologies such as solar photovoltaics (PV), wind turbines, and small-scale generators became more prevalent, there was a lack of uniformity in the technical specifications and interconnection processes across different regions and jurisdictions. Recognizing the importance of addressing these challenges to facilitate the integration of DERs into the grid, the Institute of Electrical and Electronics Engineers

(IEEE) initiated the development of IEEE 1547. The standardization process involved collaboration among stakeholders from industry, academia, government agencies, and utility companies to define consistent guidelines and performance standards for the interconnection and operation of DERs.

First published in 2003, the standard underwent rigorous review and consensus-building processes within IEEE's working groups and committees, ensuring that it represents the collective expertise and consensus of the stakeholders involved. Since that time, there have been subsequent revisions and updates to reflect advancements in technology, regulatory requirements, and industry best practices.

Today, IEEE 1547 serves as a widely recognized and adopted standard for DER interconnection worldwide, providing a framework for ensuring safety, reliability, and grid compatibility of distributed generation resources. Its origin underscores the importance of collaboration and standardization in enabling the seamless integration of renewable energy and distributed generation into modern electric power systems.

Here are a few key aspects of that standard:

Interoperability: IEEE 1547 establishes technical specifications to ensure that DERs can safely and reliably connect to the grid and operate in coordination with existing infrastructure. This promotes interoperability among different types of DERs and grid equipment, facilitating their integration into the electric power system.

Safety: Safety is paramount when integrating DERs into the grid. IEEE 1547 mandates requirements for voltage and frequency regulation to prevent potential hazards such as electrical overloads as well as voltage fluctuations. Compliance with these safety standards helps protect both workers and the public from any incidents that may occur.

Grid Stability and Reliability: DERs have the potential to impact grid stability and reliability. IEEE 1547 includes provisions for grid support functions, such as voltage regulation, reactive power control, and frequency response, helping to maintain system stability and ensure reliable operation under varying operating conditions and grid disturbances.

Power Quality: IEEE 1547 specifies requirements for power quality parameters, including voltage regulation, harmonic distortion, and voltage flicker, ensuring that DERs do not degrade the quality of electricity supplied to consumers or cause disruptions to sensitive loads.

Interconnection Process: This standard defines the procedures, technical specifications, and documentation requirements for interconnecting DERs to the grid, streamlining the approval process and facilitating timely and cost-effective deployment of distributed generation resources.

Regulatory Compliance: Compliance with IEEE 1547 is often required by regulatory authorities and utility companies as a condition for connecting DERs to the grid. By adhering to these performance standards, DER owners and developers demonstrate their commitment to operating in accordance with industry best practices and regulatory requirements, ensuring a smooth and seamless integration process.

IEEE 1547 is made up of 11 clauses that address various aspects of the interconnection and operation of DERs with electric power systems. These clauses collectively provide a comprehensive framework for the safe, reliable, and efficient integration of distributed energy resources into modern electric power systems, ensuring grid stability, quality of service, and interoperability among different types of DERs. Compliance with IEEE 1547 standards is often required by regulatory authorities and utility companies to ensure the proper interconnection and operation of DERs with the grid.

Clauses 1-4 define the scope, reference, definitions of key terms and concepts as well as specific technical requirements and procedures for the connection of DERs which includes voltage and frequency requirements along with grid support functions. WAGO's DER controllers specifically conform to Clauses 5 and 10 which involve the requirements for the installation, commissioning, and operation of DERs to ensure safe and reliable operation as well as safety requirements. Clause 5 specifically discusses reactive power and voltage/power control with Clause 10 emphasizing safety considerations throughout the interconnection process. This includes provisions for personnel safety, equipment protection, and emergency shutdown procedures.

Clause 6 of IEEE 1547 focuses on establishing operational requirements and standards that DERs must adhere to during their integration with the electric power system. Clauses 7-9 deal primarily with inverters and their operational and protection requirements along with performance testing. Finally, Clause 11 specifies requirements for communication interfaces and control functionalities to facilitate coordination between DERs and grid operators and enable grid support functions.

IEEE 1547 outlines testing procedures and requirements for certifying compliance with the standard. Performance testing may involve assessing the DER's behavior under various operating conditions, including normal operation, grid disturbances, and fault scenarios. Testing may also verify the functionality and effectiveness of protection schemes, communication interfaces, and grid support functions. Compliance with performance testing requirements is essential to demonstrate that DERs can safely and reliably interconnect with electric power systems while meeting specified technical specifications and performance criteria.

There are specific documentation requirements for DER owners to obtain and maintain when seeking to connect their systems with the electric power grid. This includes preparing and submitting documentation such as interconnection agreements, technical specifications, and compliance documentation to utility companies or regulatory authorities. Interconnection agreements outline the terms and conditions for interconnecting DERs with the grid, including technical requirements, operational procedures, and dispute resolution mechanisms. Compliance documentation demonstrates that the DER complies with IEEE 1547 standards and any additional regulatory requirements. Proper documentation ensures transparency, accountability, and legal compliance throughout the interconnection process, facilitating smooth and efficient integration of DERs into the electric power system.

IEEE 1547-2018 Clause 5 Analysis

Within a power system the generation and consumption need to be equivalent. If it is not, the voltage and frequency will not stay constant. As grid generation has become more decentralized with renewable resources, the need for grid operators to control them has grown. IEEE1547 is a standard for defining how these resources will react to disturbances on the grid. The Area EPS needs to have DER resources with a known response to prevent cascading of disturbances into larger issues. Clause 5 of IEEE1547-2018 defines how a DER will react to voltage disturbances. An example of this would be that if the voltage starts to rise, a solar DER can be configured to reduce its power output. This will help bring the voltage back to the nominal level.

Clause 5 defines the characteristics and capabilities for response to voltage variations within the normal operating range for a DER. Over or under production of real or reactive power on the grid will cause the voltage to fluctuate up and down. Clause 5 gives the Area EPS the ability to define how a DER should operate its power output when the connection voltage fluctuates. There are 5 modes of operation that are defined in clause 5. Area EPS operators can use multiple modes in conjunction to achieve the desired response to grid conditions. All modes are subject to the site's capabilities. Priorities and limits are defined by the equipment and the EPS settings.

Section 5.3.2 defines the constant power factor mode. In this mode, the DER will produce a fixed power factor as specified by the Area EPS. As the real power output of the DER changes, the reactive power will change accordingly to maintain a fixed power factor. The WAGO DER controller function block monitors real power output of the DER and adjusts the reactive power setpoint to the DER to keep the power factor constant. An example of this would be in a solar field when a cloud passes and reduces the real power output, the reactive power output would change also to maintain the power factor of the DER output.

Section 5.3.3 defines the voltage-reactive power mode, aka Volt-Var. In this mode, the DER will regulate the reactive power as a function of the connection voltage. The curve can be preset in the function block or the values can be configured and updated by the Area EPS. The function block has the four input points as defined by clause 5.3.3. This function helps with power factor correction on the area grid. Figure 1 is an example of a Volt-Var curve.

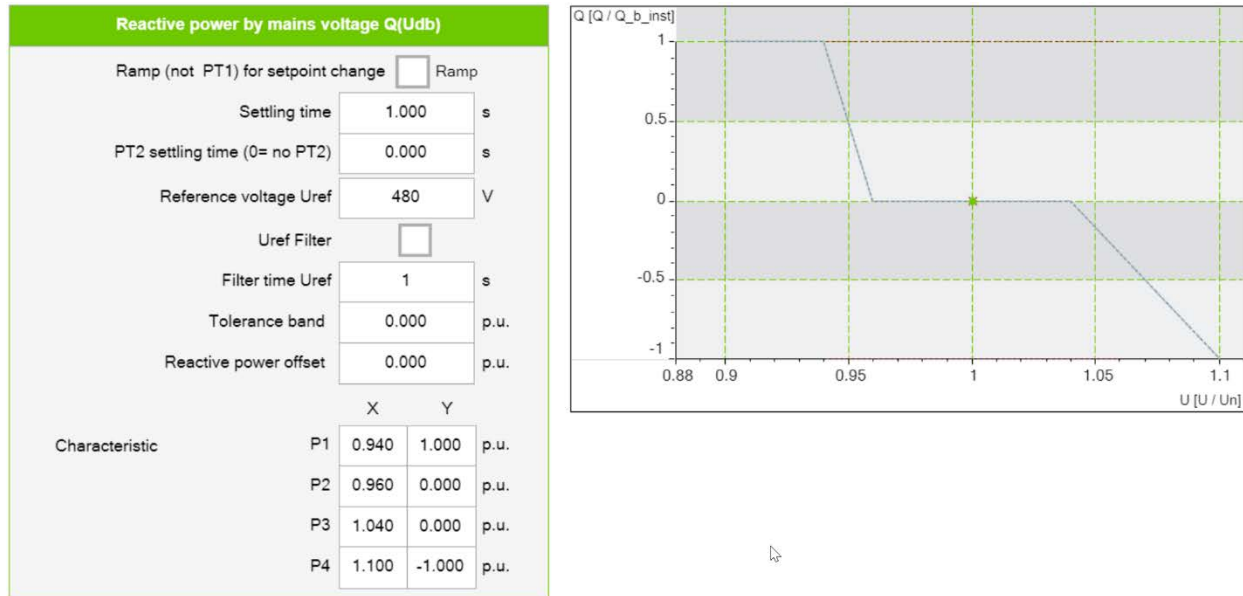


Figure 1: Volt-Var example curve

Section 5.3.4 defines the active power-reactive power mode. In this mode, the DER will control the reactive power output as a function of the active power output of the DER. The characteristic of function can be adjusted by the Area EPS. The curve is defined by up to 10 active power settings and 10 corresponding reactive power settings. Between the defined points, the output is a linear function from point to point. Figure 2 shows an example of a power curve. An example of this would be in a solar field when a cloud passes and reduces the real power output, the reactive power output would change as a function of the defined curve.

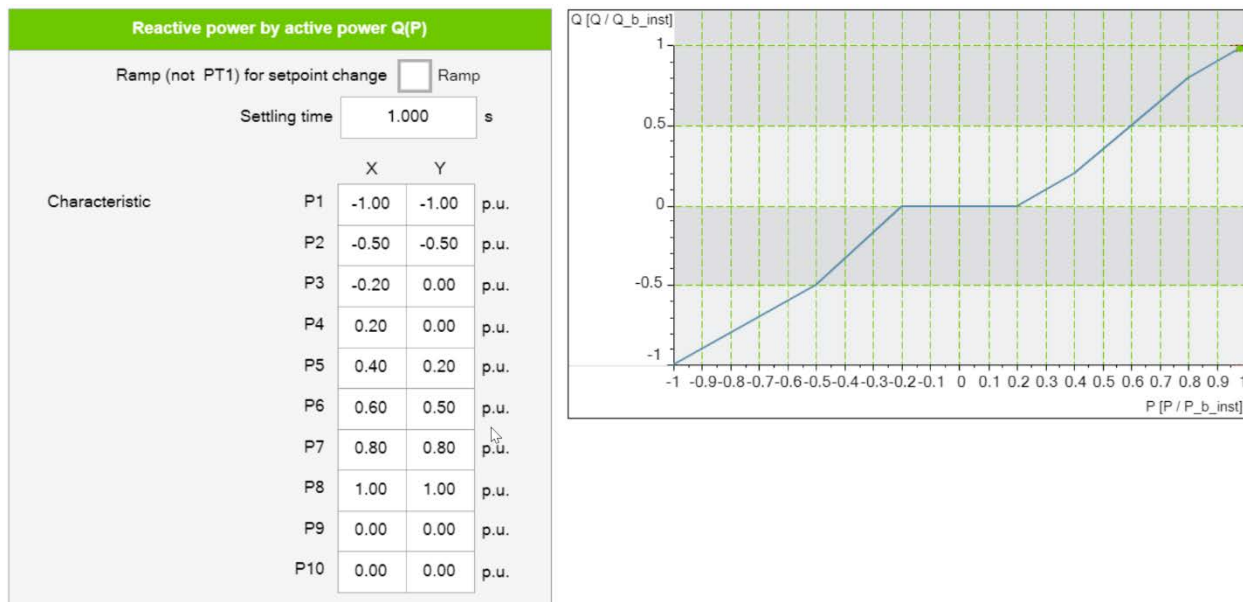


Figure 2: Reactive power as a function of active power Q(P)

Section 5.3.5 defines the constant reactive power mode. In this mode, the DER will control the reactive power to a fixed level defined by the Area EPS. The real power output can change as required by the DER while the reactive power remains constant.

Section 5.4 defines the voltage and active power control mode. In this mode, the DER will control the real power output as a function of the connection voltage. This mode is used by the Area EPS to reduce the power output of the DER when there is an over generation condition. Figure 3 shows an example of power vs voltage mode.

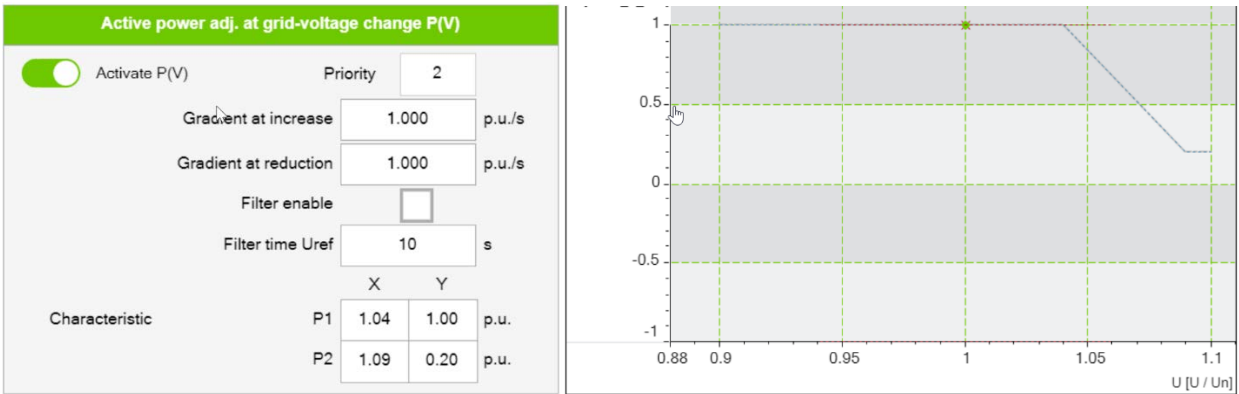


Figure 3: Active Power vs Voltage curve

Within the function block, there is the target calculation that handles the 1547 mode calculations, a ramp function, a PID function for closed loop control and a limiting function.

Schematic Structure of the Power Plant Controller

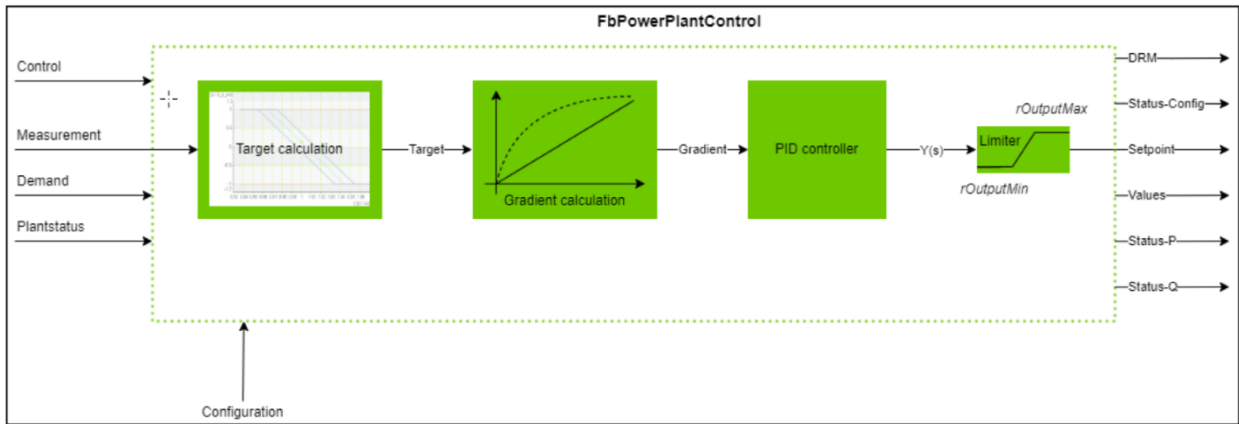


Figure 4: Function block internals

Utilization of IEEE 1547-2018:

There are multiple benefits of this IEEE standard whose main purpose is defining the requirements for interconnection and interoperability of DERs with the associated Electric Power System interfaces. The following list of benefits covers many but not all of the associated benefits:

- 1) For new DER additions: Speeding up the configuration and commissioning time
- 2) For existing (i.e. legacy) DER assets: Allows for custom approaches to integrate legacy DER assets, utilizing these interoperability standards
- 3) Increased power quality on the Area Electric Power System (Area EPS) including:
 - a. Voltage Regulation
 - b. Frequency Regulation
 - c. Active and Reactive Power Control
- 4) Increased reliability and stability on the Area EPS (e.g. “riding through” minor disturbances rather than tripping off-line prematurely)
- 5) Allows for static and remote dynamic adjusting of setpoints to achieve optimal power quality on the Area EPS
- 6) Increased safety by establishing limits of normal and abnormal conditions and when to trip off-line

DER Controller Use Cases (I have the Excel File of this spreadsheet graphic)

Use Case 1: DER Gateway Platform* enabled with WAGO DER Controller Library for IEEE1547-2018 compliance (std use case)

Use Case 2: DER Gateway Platform* enabled with WAGO DER Controller Library for IEEE1547-2018 compliance & Plant Master Controller all-in-one

Use Case 3: DER Gateway Platform - Protocol ONLY Converter

Use Case 4: DER Gateway Platform with Protocol Converter+WAGO DER Controller Library+Advanced Functionality

Use Case	Northbound Communications to Managing Entity DNP3 IEEE2030.5	Southbound Communications to DER SunSpec Modbus Series 700	WAGO Controller DER Controller Library for IEEE1547-2018 compliance	DERs Supported**		Advanced Functionality				Legacy DER Communications									
				Unitary	Multi-DER	Scheduler	Alarm	Mfg Data Logger	Time Sync	Modbus			DNP3	IEC61850	Ethernet/IP	CANbus	Others		
										TCP	RTU	Sunspec Modbus							
1	yes	later	yes	yes*	yes	yes	yes, if DER has its own Plant Controller	Optional	Optional	Optional	Optional	yes	optional	yes	optional	optional	optional	optional	optional
2	yes	later	yes	yes*	yes	yes	yes, Plant Controller inside of WAGO Controller	Optional	Optional	Optional	Optional	yes	optional	yes	optional	optional	optional	optional	optional
3	yes	later	yes	yes*	no	yes***	yes, if DER has its own Plant Controller	n/a	n/a	n/a	n/a	yes	optional	yes	optional	optional	optional	optional	optional
4	yes	later	yes	yes*	yes	yes	yes, if DER has its own Plant Controller	Optional	Optional	Optional	Optional	yes	optional	yes	optional	optional	optional	optional	optional

*WAGO Controllers: CC100, PFC100, PFC200, PFC300, Edge Controller, TP600

**Different plant DER configurations shown in Fig 2 of the IEEE1547-2018 std (p. 18)

***IEEE1547-2018 library by others

IEEE 1547 Assessment

Overall, many benefits of the IEEE1547-2018 standard have been highlighted including establishing the northbound and southbound communications, normal and abnormal voltage, frequency and active/reactive power limits with associated time delays (“ride through”) and trip limits. The 11 clauses of this standard have been covered as well as a detailed description of Clause 5 which covers normal operation.

Multiple use cases have been described from very simple to more complex use cases such as all-in-one DER Controller/Gateway plus Plant Controller functionality with advanced functionality.

Volt/VAR, Active/Reactive power curves and an overview of the DER Controller function block have been provided to show the dynamic behavior required for a stable electrical distribution grid.

Synopsis

There are multiple trends for DER integration according to this interconnection and interoperability standard, IEEE1547. As we have experienced over multiple years, these standards are in a constant state of flux and improving over time as the market needs and technical requirements are better defined. For example, at the time of writing this whitepaper, the IEEE1547-2018 standard has been updated to IEEE1547-2022 and is going through the adoption phase.

In addition, more states, provinces, corporations, and municipalities have established firm carbon reduction goals (with laws and/or executive orders, in some cases) which require a faster-paced implementation of renewable energy, including battery energy storage systems. Another trend is the expanding role and convergence of the supply side DERs in-front-of-the-meter with behind-the-meter (3rd party owned) DERs within facilities, together with handling of the loads within facilities [e.g. Grid-Interactive Efficient Buildings (GEB)]. Over the coming years, we will see utilities and aggregators take on a greater role managing third-party DER assets with the creation of ancillary services markets for which the utility/aggregator and asset owner will be compensated, accordingly. The rapidly expanding EV infrastructure will create additional challenges and market opportunities for multiple entities participating in this rapidly evolving new energy landscape.

The IEEE1547-2018 standard is quite complex and often involves DER capital equipment and T&D infrastructure which is worth millions of dollars. In addition, personnel safety and cybersecurity impacts occur with the improper use of this technology. Damage to capital equipment can take many months or more to repair or replace, causing lengthy outages with substantial financial impacts. Due to the seriousness of these concerns, it is very important to engage with qualified personnel regarding the design and implementation of this DER technology such as professional engineers, trade association professionals and Nationally Recognized Testing Laboratories (NRTL).

WAGO's DER Controller offers multiple benefits including:

- 1) Ease of Use: Minimal PLC programming required to support multiple geographies (speeds time-to-market); recognizing that qualified system integrators are in high demand
- 2) Flexibility: (e.g. Multiple communications supported like DNP3, SunSpec Modbus Series 700, Modbus TCP/RTU, IEC61850, CANbus, Ethernet/IP, etc...)
- 3) Ruggedness option: Have wide temp range and ruggedness, especially for un-airconditioned cabinets
- 4) Scalable/Wide range of CPU Horsepower: Some applications are simple, requiring low CPU loading; some applications are more complex requiring higher CPU loading
- 5) Support Multiple Use Cases: From a simple protocol gateway to an all-in-one DER Gateway with plant master controller plus Advanced Functionality
- 6) I/O Capable: Sometimes Digital and Analog I/O are needed for monitoring and/or control (e.g. tripping breaker, 3-phase power measurement, etc...)
- 7) Easily support Advanced Functionality (e.g. alarming, scheduling, logging, etc...)
 - a) Advanced Functionality currently being defined in the IEEE P1547.10 DER Gateway Working Group Subgroup 2 (SG2)
- 8) Cybersecurity: Greater focus on DER cybersecurity is happening globally, so it is important to stay abreast of the latest guidance and standards. Valuable resources to consult are: SunSpec Alliance, IEEE1547.3-2023, ISA/IEC-62443, UL-2941, DOE/NARUC