COMMUNICATION NETWORKS

Understanding Fault Managed Power

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INTRODUCTION

The advent of fiber optics and wireless technologies has enabled communications networks to achieve higher bandwidth and lower latency in part by moving the connectivity and computation electronics closer to the end user. This distribution of network electronics increases the number of sites that require power, adding a layer of cost and complexity not experienced in more centralized architectures. Often, the edge device can be powered by tapping directly into the grid when it is in close proximity. But more and more, a single grid tap connects to a centralized power conversion device that in turn.

This remote powering technique has been effective for over two decades. But wireless networks, particularly 5G, are utilizing newer small cell radios that consume considerably more power than previous generations. Moreover, small cell nodes often include 2-3 radios to supplement the coverage and capacity of the macro cell. The result is the need for a distributed power solution that delivers much more power than the remote line powered devices previously used.

In 2020, operators, manufacturers, and industry standards bodies began to investigate the potential for a new distributed power technique that could deliver much more power yet in a safe environment for technicians and the public. Spearheaded by ATIS® and supported by UL & NEC®, a new distributed powering technique called fault managed power was developed. Also known as Class 4 power, fault managed power systems impose no power limit under normal operation, but precisely limit energy transferred under a fault condition to mitigate shock and fire hazard.

The purpose of this paper is to provide a comprehensive overview of fault managed power systems, their key components, the standards implications, benefits, and their potential impact on various sectors.

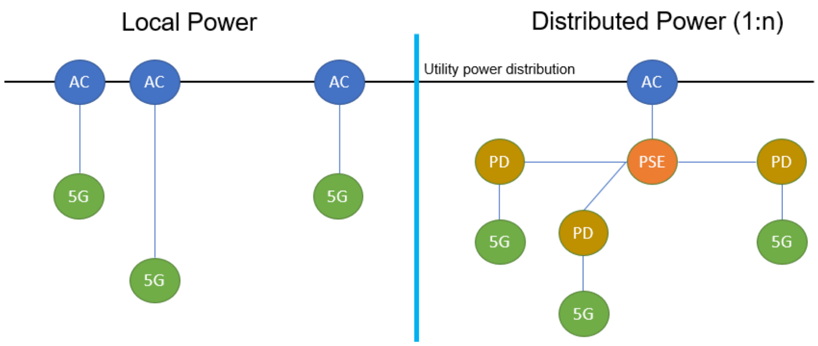
BACKGROUND

In today's rapidly evolving technological landscape, the demand for efficient and safe power distribution systems has become increasingly critical. Businesses and industries are undergoing a digital transformation, adopting digital solutions and smart technologies. Advanced electronic devices, IoT (Internet of Things) devices, artificial intelligence, wireless networks and high-performance computing all require increased power and data processing capabilities.

The demand for cellular data is only growing, and it has reached a tipping point with the rise of 5G connectivity. As operators commence the deployment of 5G wireless services, the need to densify the radio network with small cell technology is increasingly more important.

One of the key challenges operators face is securing power for each of the small cell sites in a cost effective and timely fashion. Distributed powering (remote line powering) has the potential to save operators both time and money for dense small cell deployment by minimizing the number of utility grid tap connections compared to using local power for each small cell node (See Figure 1 below). Typical Distributed Power implementations can realize a 10:1 reduction in the number of commercial AC service connections.

Figure 1. Example of utility connection for local vs distributed power



Traditional line powering using the RFT-V (Remote Feeding Telecommunication - Voltage[1]) standard limited the power to 100W per circuit at ±190VDC which was sufficient to power low power 4G small cell radios with RF power of 5W to 10W. Over the past few years, new 5G spectrum both in mid-band and high band became available to operators that resulted in 5G small cell radios consuming more power (>450W).

RF POWER REFERS TO THE AMOUNT OF POWER CARRIED BY RADIO FREQUENCY (RF) SIGNALS. POWER CONSUMPTION REFERS TO THE AMOUNT OF ELECTRICAL POWER THAT THE SMALL CELL CONSUMES WHILE OPERATING.

In 2020 industry standards bodies spearheaded by ATIS® and supported by UL® & NEC® defined a new distributed powering technique called Fault Managed Power (referred to as Class 4 power in the NEC®). A key feature of fault managed power systems is that there is no power limit imposed under normal operation, but energy transferred under a fault condition is precisely limited to mitigate shock and fire hazard.

As technology continues to evolve, distributed powering is expected to play a crucial role in powering the growing array of networked devices and contributing to the advancement of smart building infrastructure and the IoT ecosystem. With the introduction of fault managed power systems (Class 4 circuits) there is a new tool in the toolbox that could support high power delivery over long distances in a safe manner.

WHAT IS A FAULT MANAGED POWER SYSTEM (FMPS)?

Technological advancements in power distribution system fault management techniques have made it possible to transport electrical power while reducing the risk of human shock and fire hazard.

While adhering to the same source voltage limits defined for RFT-V technology, fault managed power systems make it possible to safely deliver higher levels of power to remote network elements than existing RFT-V powering methods. No power limitation is placed on fault managed power system (FMPS) sources; instead unlike RFT-V systems, FMPS standards impose a limit on the amount of fault energy that can be transferred to a human during a human contact fault event.

A fault managed power system as defined in ATIS® Technical Report (TR) 0600040[2] can operate with a maximum line to line source voltage of 400Vdc. Instead of limiting the power source output to a certain threshold such as in NEC® Class 2 and Class 3 systems, the fault managed power system (or Class 4 circuit) monitors the circuit in real time and limits the power available during a fault event.

Systems that employ fault managed power distribution technology provide for rapid fault detection and power source shut down in the event of human contact under a wide range of line to ground and line to line fault scenarios. Fault managed power systems precisely control and minimize the amount of fault energy that can be transferred to a person during a human contact fault event.

Several safety standards are published to support this new FMPS technology with stringent requirements on human safety in the event of incidental contact with power cables (Hand-to-Hand, Hand-to-Feet). The graphics below show testing performed at the Power Sourcing Equipment or transmitter output terminals according to ATIS® TR 0600040. Additional testing is performed mid-span and at the Powered Device (PD) input terminal.

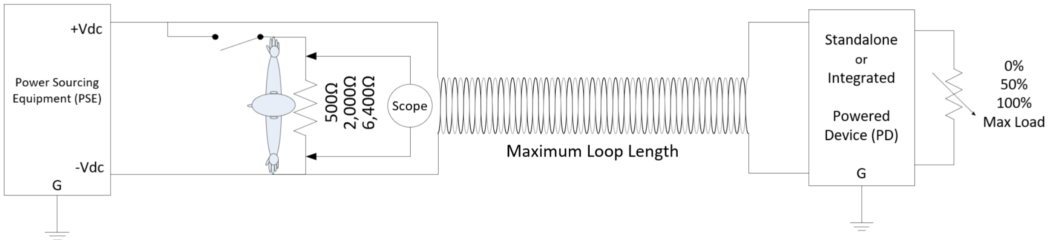


Figure 2. Fault Scenario: Hand-to-Hand (ATIS® TR 0600040)

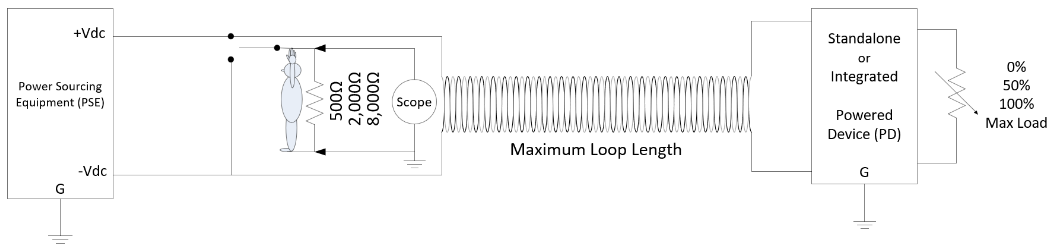


Figure 3. Fault Scenario: Hand-to-Foot (ATIS® TR 0600040)

The human body resistance model presented in the ATIS® TR (Technical Report) ranges from 500 to 8,000 ohms for hand to foot contacts and 500 to 6,400 ohms for hand-to-hand contacts. The upper resistance value is actually touch-voltage dependent as it is associated with a body current value of 25mA which is the IEC DC Zone 2/3 boundary "b line[3]" for durations longer than two seconds. (when a human body presents a resistance value greater than 8kΩ or 6.4kΩ, it cannot draw enough body current to cause ventricular fibrillation). Also, the simulated human contact fault testing is performed at 0%, 50%, and 100% rated load. The ATIS® Technical Report provides system designers and manufacturers with the necessary framework of FMPS performance and fault testing metrics needed to bring system designs to fruition.

System specific power transport cabling requirements must be adhered to in order to ensure proper fault management monitoring and control functionality. Systems are tested with the maximum cable length allowed as specified by the manufacturer to verify that capacitive energy stored in the cable is safely managed under a wide range of fault scenarios.

It is important to note that the requirements for FMPS systems are technology agnostic. In other words, standards such as UL® 1400-1[4] do not define specifically how an FMPS delivers power and limits fault energy via monitoring and control—it defines the actual fault energy limits. Fault managed power systems are relatively new (and only recently standardized), so the technology used for them varies between vendors. However, regardless of the manufacturer, FMPS technology must meet the standards set out by the NEC®, UL and ATIS®.

In the industry, "Fault-Managed Power System" is also referred to as Packet Energy Transfer (PET), Digital Electricity (DE), Pulsed Power, and Smart Transfer Systems. A fault-managed power circuit is also referred to as a Class 4 circuit in the NEC® context.

HOW A FAULT MANAGED POWER SYSTEM WORKS.

Class 4 fault managed power systems (FMPS) are a new classification in the electrical industry that aim to enhance safety and efficiency in power transmission. The standards community is currently working to address these new telecommunications power systems.

Development of the ATIS® TR was done in parallel with the creation of NEC® Article 726, prior to most of the development of UL1400-1. The ATIS® TR is currently under review and is expected to be revised to incorporate feedback from the manufacturing and end user communities. This is a living breathing document that will undoubtedly undergo additional refinement as FMPS technology gains traction.

A Fault managed power distribution circuit is comprised of three main sections. Power Input (PSE), Power Transport, Power Output (PD). PSE is also referred to as a transmitter and PD is also known as a receiver in the context of NEC® Class 4 circuit nomenclature.

In the context of the ATIS® TR, the following definitions apply:

1. Power Sourcing Equipment (PSE) — Telecommunications equipment supplying fault-managed DC power to remotely located powered devices (PDs). The PSE shall provide power and fault management functionality when connected to a PD specifically designed to be used with the PSE. The PSE is connected to a mains utility and typically includes a rectifier (AC to DC) and a DC-to-DC converter.

EnerSys participated in the development of Underwriters Laboratories (UL) FMPS equipment and cable Outlines of Investigation. These two standards serve as the Listing standards for Class 4 equipment and cables. Listing of the equipment and cables is required for all in-building installations.

2. Powered Device (PD) — Telecommunications equipment designed to be paired with a specific PSE design to facilitate the fault management functionality of a fault-managed power system. PD power output is intended to provide non-fault-managed power for remotely located telecommunications equipment (e.g., 48VDC for a 5G small cell radio). A PD can be a stand-alone device or integrated directly into the enclosure of a telecommunications network element.

Below is an illustration how a fault managed power system works using DPX™ distributed power transport as an example::

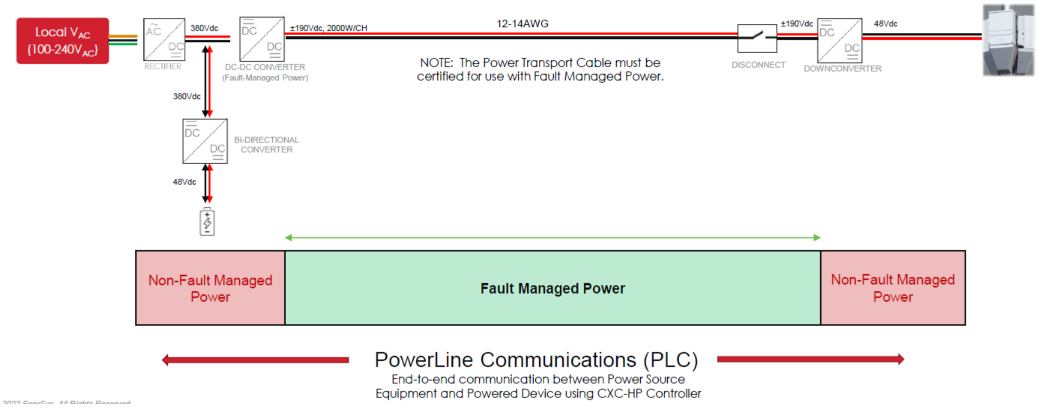


Figure 4. EnerSys Distributed Power Transport (DPX™) System overview

The DPX™ power hub (power source equipment or transmitter) houses the main power conversion equipment to convert the incoming AC voltage to fault managed power distributed over copper cable (Power Transport Cable) to a DPX™ downconverter (powered device or receiver) that in turn converts it to a usable voltage to power the load. The system uses the same source voltage as RFT-V (±190Vdc) but no limit is imposed on transmitted power" per circuit.

The Class 4 transport cable connecting the power source to downconverter can come in different gauge sizes, varying cable lengths, number of pairs, etc., depending on the specific application. Fault managed power technology requires that the PSE, power transport cable and the PD be tested as a complete system to precisely control and manage the amount of fault energy transferred to a person during a human contact fault event. Failure to do so may result in system malfunction and could potentially cause an unsafe condition.

AS A MEMBER OF ATIS' SUSTAINABILITY IN TELECOM: ENERGY AND PROTECTION COMMITTEE (STEP), ENERSYS PLAYED A KEY ROLE IN CREATING THE ATIS STANDARD ATIS-0600040 FAULT MANAGED POWER DISTRIBUTION TECHNOLOGIES –HUMAN CONTACT FAULT ANALYSIS. THEY HELPED DEVELOP THE FAULT MANAGED POWER SYSTEM EQUIPMENT REQUIREMENTS AND TESTING PROTOCOLS AS WELL AS PROVIDED MUCH OF THE TESTING THAT VALIDATED THE REQUIREMENTS. THEIR SUPPORT AND CONTRIBUTION TO ADVANCING THIS IMPORTANT STANDARD WAS SINCERELY APPRECIATED.

ERNIE GALLO, ERICSSON - CHAIR ATIS NETWORK POWER SYSTEMS

Distributed power transport architecture enables operators to deploy their networks faster by eliminating the need to have AC utility power at each of the small cell locations. At the central location, a central power hub converts the incoming AC power to fault managed power and transported over a hybrid or copper cable to a disconnect box and then to a downconverter located up to a mile (1.6km) away. This reduces installation, operating expenses, and provides flexibility related to site selection for the installation of the remote communications equipment.

The system employs intelligent fault detection mechanisms to minimize the amount of fault energy transferred to a person and there are specific cabling requirements to ensure the unmanaged capacitances (i.e., power cable) are accounted for in the overall system to manage the stored energy transferred during fault events.

FAULT-MANAGED POWER: STANDARDS DEVELOPMENT

The development of fault managed power systems (FMPS), or Class 4 power, is causing a buzz in the industry due to its potential to revolutionize the way we manage power transport for various critical infrastructures. The introduction of Class 4 power in electrical circuits marks a significant advancement in enabling safe and efficient power delivery for high-powered devices. Accepted into the 2023 National Electrical Code as Article 726, Class 4 provides a solution for applications that require more power and/or longer distances than what traditional power-limited circuits can offer.

Prior to the NEC® Class 4 power, the primary approach to ensuring safe electrical installations relied on limiting the maximum power and voltage of circuits. Classes 1, 2, and 3 were established to mitigate risks, with Class 2 becoming widely adopted for commercial and residential use, typically used in applications where Power over Ethernet (PoE) technology cannot support the power or distance required by the end devices such as wireless access points, IP (Internet Protocol) cameras, and Voice over IP (VoIP) phones.

NEC® Class 2 can achieve longer distances than PoE due to article 725 in the NEC®. Per Table 1 below, Class 2 circuits are limited to 60Vdc and 100 W/VA per circuit.

TABLE 1. COMPARISON OF NEC® CLASSIFICATION OF CIRCUITS

	Class 1	Class 2	Class 3	Class 4
Max Power (VA)	1000	100	100	No limit, system dependent e.g., 2000W @ 380VDc
Max Voltage (V)	30	60	150	450
Fire/electrical shock risk	Higher	Low	Low	Low

In the outside plant environment, distributed power, also known as remote line power (RLP), has employed RFT-V technology. RFT-V standards limit voltage to 200VDC line to ground and limit power to 100 Watts per circuit. Dual polarity RFT-V systems typically operate at 380VDC conductor to conductor and utilize a high impedance midpoint grounding configuration to minimize line losses and maximize power transmission distance. However, due to line losses, actual power delivered to remotely located loads is typically limited to about 75 watts per circuit.

Much of the work over the past two years has been focused on North American regulatory code and standards development pertaining to fault managed power systems. Spearheaded by ATIS® and supported by UL & NEC®, a new distributed powering technique called Fault Managed Power was developed.

The evolution of Fault Managed Power Standards is depicted in Figure 5 below.

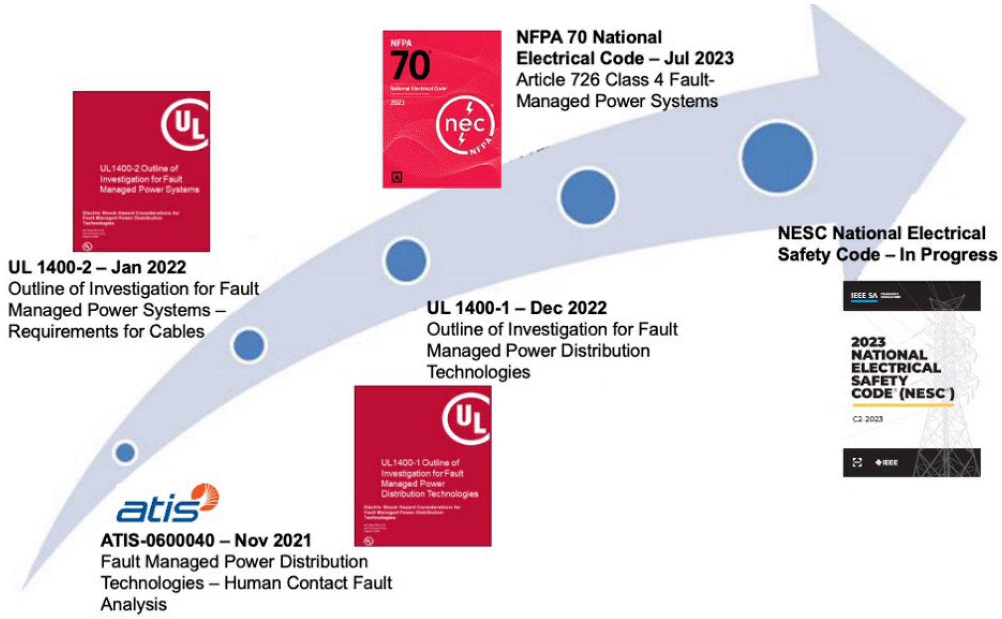


Figure 5. The evolution of Fault Managed Power Standards

Overall, the introduction of FMPS represents a significant step forward in power distribution and safety. It offers improved capabilities for delivering higher power over extended distances, changing the way we power and connect devices in various industries.

WHAT ARE THE BENEFITS OF FAULT MANAGED POWER SYSTEMS?

By adhering to FMPS (Class 4 standards), unlimited power may be transmitted constrained only by source voltage limits and the ampacity constraints of the copper conductor pairs. This allows for more dense cable with less pairs of copper conductors than traditional (RFT-V) line powering solutions. The ATIS® TR limits voltage to 400 VDC line to line, 200 VDC line to ground. NEC® limits voltage to 450 volts, either AC or DC.

With the ability to safely distribute up to 450V without any power limitations, a Class 4 fault managed power system can deliver several thousands of Watts over long distances with the same, or even higher safety features compared to a Class 2 power distribution circuit. Class 4 power systems can deliver about 20 times more power than a Class 2 system or an RFT-V system in the outside plant case. Class 4 transmitted power level is constrained only by source voltage limit and power transport cable length and wire gauge.

SOME KEY ADVANTAGES ARE:

Higher power, longer distance: enabled by larger copper conductors (12/14 AWG versus 22 AWG)

Power demand visibility: With the integration of power line communication (such as the EnerSys DPX™ distributed power system) FMPS technology provides more sustainable solutions as they offer operators complete visibility into the power demand of each connected radio and the remote power cycling of each PD output port for maintenance purposes. Maintenance truck rolls can be reduced by remotely accessing the power device to reset a small cell radio by toggling the power on and off.

Power and Data Convergence: Deployment of hybrid copper-fiber cables, allowing for power and data transmission in the same pathways and spaces as used with Class 2 cabling installations, can reduce project costs associated with cabling, as well as simplify cable management.

Reduced Capex: Like Class 2 circuits, the cabling for the new Class 4 circuits can be installed using a low voltage technician. Electricians are not required to perform the installation. Likewise, conduits or armored cables are not needed (provided the design meet ULs 1400-1 and NEC Article 726 specifications). Distributed powering has the potential to save operators both time and money for dense small cell deployment by minimizing the number of utility grid tap connections.

Improved Safety: Technicians and installers are safer due to the inherent features of Class 4 circuits and equipment.

Back-up: In the future, when back-up power for small cells" is likely to be required to meet the requirements for autonomous vehicles and other new services, upgrading the central power source is much quicker and less expensive than adding a backup power cabinet at each small cell site.

Like all OSP applications, the specifics of the site dictate the solution. Because outdoor small cells are deployed in a myriad of configurations, there is no universal power solution that will address all deployment scenarios. Variations in topography, demographics, and local regulations make it difficult to develop a cookie-cutter power solution for small cell deployment. But provides a new tool in the toolbox that can accelerate routine deployment for small cell and 5G networks.

The power source selection will depend on factors like:

- local grid availability or connection cost and lead time, compared to remote powering;
- site load requirement and need for back-up;
- services availability (continuity) requirements;
- need to share the power infrastructure between operators;
- availability of renewable energy e.g., photovoltaic;
- possible power connection shared with other user such as street Lighting equipment or electric car charging stations, etc;

THE FUTURE OF FAULT MANAGED POWER

The adoption of fault managed power systems holds promising developments and applications for various industries. This technology enables the deployment of applications like "smart" buildings, DC-powered data centers, and high-power LED lighting in a more feasible and cost-effective manner. In the telecommunications industry, the potential benefits of Class 4 could be significant, especially as the 5G expansion continues. As operators commence the deployment of 5G wireless services, the need to densify the radio network with small cell technology is increasingly more important. One of the challenges operators face is securing power for each of the small cell sites in a cost effective and timely fashion.

To get commercial power to the site, the local utility may need to install a new transformer, run a drop cable and possibly install a meter and disconnect. Utility projects can be expensive and time-consuming, perhaps jeopardizing the business case and deployment timelines. Also, the advanced capabilities of today's 5G-ready small cells mean added power requirements. A single small cell node that covers three sectors and multiple frequency bands can require 200 W to 2,000 W of power, depending on the size of the sector(s).

DEVELOPMENT AND IMPLEMENTATION OF FMPS TECHNOLOGY AND SUPPORTING STANDARDS IS ONLY HALF THE BATTLE. ENERSYS IS ALSO ACTIVELY ENGAGED WITH VARIOUS REGULATORY CODE MAKING BODIES TO PAVE THE WAY FOR CODE COMPLIANT INSTALLATION AND OPERATION OF FAULT MANAGED POWERING SYSTEMS ACROSS A WIDE RANGE OF APPLICATIONS AND ENVIRONMENTS.

In the future, when backup power is likely to be required to meet the requirements for autonomous vehicles and other new services, upgrading the central power source in a FMPS distributed power architecture is much quicker and less expensive than adding a backup power cabinet at each small cell site.

FMPS unique properties may offer a viable solution to this problem as it's able to serve large loads over longer distances than previous technologies and can do so without the need for conduits or licensed electricians. This makes FMPS well-suited for deployments of indoor/outdoor distributed antenna systems (DAS), fixed wireless access (FWA) systems, and private networks, which can help provide highspeed access and throughput in large facilities including stadiums, parks, campuses, and hotels.

As fiber-optic networks continue to grow and expand, one of the most critical components of these networks is the ONT or Optical Network Terminal. ONTs are devices that are used to convert optical signals into electrical signals that can be used by customer devices. However, to function correctly, ONTs require a reliable and consistent source of power - without the right power solutions, its value can be greatly diminished. FMPS has great potential to provide more and safe power for devices such as sensors, cameras, wireless access points, Optical LAN, ONTs and other IoT devices over longer distances.

However, the widespread adoption of Class 4 power may take time due to knowledge gaps, scarcity of Class 4 FMPS available on the market, and infrastructure improvements needed for retrofitting. Additionally, the implementation timeline will depend on state-level regulatory revisions and global adoption policies. Nonetheless, as awareness and confidence in Class 4 power grow, its usage is expected to increase in communications deployments and high-budget greenfield constructions.

CONCLUSIONS

Fault managed power is a cutting-edge technology that is opening new doors in the power industry. Its capabilities to manage high power applications at greater distances while maintaining a high level of safety make it a technology to watch out for in the coming years. By addressing the challenges and educating professionals, FMPS Class 4 can be the key to smarter and greener infrastructures.

Powering mission critical infrastructure presents significant challenges that need to be solved. The industry requires a better power solution:

- More power per remote node
- Safe
- Scalable

Adopting a fault managed power solution for small cell deployment empowers mobile network operators with faster deployment, greater reliability, increased control, and improved scalability. These advantages enable operators to seize market opportunities, boost revenue, and stay ahead in the competitive telecommunications landscape.

Following the best practices that have already been established for safe deployment of RFT-V, the transition to FMPS will likely be much faster due to increased level of safety protection built into this technology coupled with a tightly regulated standards bodies such as ATIS®, UL, NEC® and NESC. NESC has in fact recently approved code changes recognizing FMPS for use in the communications space.

As far as the timetable for widescale adoption is concerned, it's still uncertain. However, what's clear is that FMPS has the potential to be a game-changer in how we power critical infrastructure in the future.

Endnotes

1 IEC 60950-21, "Information Technology Equipment – Safety – Part 21: Remote Power Feeding"

2 ATIS® 0600040 2021 Edition, November 2021 Fault Managed Power Distribution Technologies – Human Contact Fault Analysis

3 ATIS® 0600040 2021 Edition, November 2021 Fault Managed Power Distribution Technologies – Human Contact Fault Analysis, Figure 5.1 Fault Current Magnitude – Duration Test Result Graph.

4 UL LLC Outline of Investigation for Fault-Managed Power Systems - Part 1: Safety Requirements

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