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Design of Embedded and Decentralized DC and AC Power Source Solutions for Each ICT Load Within a Unified Chassis Architecture

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***Abstract*: Telecommunications technologies and equipment, including 5G infrastructure, OLTs, Transmission DWDM, IP/MPLS (CISCO, Juniper) systems, and IGW equipment, typically rely on standalone DC power systems at core sites, exchanges, MSC sites, BSC sites, long-distance sites, and microwave sites. As technology advances, there is an increasing need to implement decentralized DC systems at the equipment level, coupled with backup energy solutions in the form of BB's either Sealed, Flooded or lithium-ion battery type systems. This decentralized approach not only mitigates the risks associated with a single point of failure but also improves the resilience and efficiency of telecommunications infrastructure. Furthermore, it improves resource utilization, accelerates the deployment of new technologies, and offers cost savings by enhancing overall system performance and reducing the dependency on large, centralized backup power solutions. This paper aims to explore the integration of small power plants and UPS systems directly embedded within telecommunications equipment, eliminating the risk of single point failures.**

***Keywords*: Huawei's OptiX OSN 1800 Multi-Service OTN Platform, CISCO Pre Agg, DC Rectifier System, Uninterruptable Power Supply, Lithium-Ion batteries.**

1. Introduction

New developments in telecommunications have provided revolutionary impacts within many societies of the modern world in terms of communications, sharing information and even in conducting business [1], [2]. 5G, Fiber to Home, DWDM, IGW and other similar technologies have dramatically changed the telecom industry [3], [4]. But there are increasing requirements for dependable, efficient, and low-cost power supply solutions [5]. Traditionally, the independent centralized DC power systems have been the key components of the telecommunications power network for the basic, exchange and remote stations [6]. However, these systems are not without their problems such as; having single points of failure, resource wastage and high operating expenses [7].

Telecommunication systems have gained more importance with the advancement of technology and therefore require sound power solutions for uninterrupted and scalable power systems [8]. One of the main issues of traditional power systems is their centralization, which does not meet the flexibility and openness characteristics of modern networks, especially in distributed networks [9]. The increasing utilization of new generations of networks, such as 5G networks that allow low latency, high mobile broadband, and massive machine type connections, makes the need for more effective and self-sustaining power systems even more important [10]. In the same way, the dependence on DWDM technology for high-capacity data transmission and the sophisticated routing systems based on IP/MPLS also testify to the significance of energy infrastructure for providing network dependability [11].

This research examines if and how decentralized DC power systems and UPS can be integrated into telecommunication equipment. In this way, lithium-ion battery system and advanced rectifier technology of the equipment like OLTs, transmission systems, and 5G base stations can eliminate many of the challenges related to the standalone systems [12]. All these decentralized solutions have various benefits, which include increased reliability, lower costs, space efficiency, and minimal dependence on external power supply [8], [13].

The purpose of this research is to explore the design, implementation, and benefits of decentralized power systems tailored to the unique needs of telecommunications networks. By analyzing current practices, identifying inefficiencies, and presenting an alternative self-powered equipment model, this paper aims to provide actionable insights for telecommunications operators and technology developers.

2. Literature Review

The need for energy-efficient and environmentally friendly telecommunication structures has been on the rise hence advancing literature on renewable energy-based power supply systems. This literature explores existing research on RE systems for the operation of telecommunication networks with the view of determining the practicality, efficacy and sustainability of the energy systems. Niranjan Rao Deevela et al. (2023) conducted a review on renewable energy-based

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hybrid systems for telecom towers focusing on the impact of decreasing the use of fossil fuel and greenhouse gas emission. The study also presents practical examples of hybrid systems implementation with the use of solar, wind, fuel cells, and microturbines. Although very extensive, the review mainly emphasizes the applicability of technology without going into many specifics of the economics or the large-scale applicability of the technology.

Similarly, Md. Sanwar Hossain et al. (2020) have also studied the techno-economic analysis of solar photovoltaic (PV) and biomass-based hybrid power system for off-grid cellular base stations [14]. From their study, they concluded that these systems provide reliable and sustainable energy solutions with a quality of service. Although simulations revealed that they are efficient in terms of network throughput and energy efficiency, the study fails to expound on the practical real-world impacts and stability. In another work, challenges of energy efficiency in telecommunications were discussed in a more general manner by Chinedu Alex Ezeigweneme et al. (2024) [15]. Their work brings out the energy intensity of the sector, which uses 2-3% of the world's electricity and recommends integration of renewable energy as a way of reducing the effects on the environment. Despite the fact that the paper offers important strategic advices, it would be helpful for it to support its guidance with real life case studies [15].

Other contributions by Hossain et al. (2020) also present a grid-tied solar PV and battery system for wireless networks with a 54.8% decrease in grid energy use. In addition, the work also highlights the need to balance the load among collocated base stations as a way of improving energy sustainability [16]. However, this approach seems quite promising; however, its application in large networks as well as in different geographic regions has not been tested. Le Xie et al. (2021) approach the issue from a broader energy perspective, discussing the challenges of transitioning to carbon-neutral electricity and mobility. Although relevant, their study does not directly address telecommunications networks, limiting its specific applicability in this field [17].

M. Javidsharifi et al. (2021) present an optimization model for designing photovoltaic-battery systems tailored to cellular networks. By applying the model to various solar availability scenarios, they provide a robust framework for balancing cost and power autonomy [18]. However, their focus on PV systems alone leaves questions about the potential benefits of hybrid renewable energy solutions. Abu Jahid et al. (2020) expand on this theme with a techno-economic analysis of power supply solutions for LTE base stations. Their findings demonstrate significant energy savings and environmental benefits through techniques like cell zooming and green traffic steering [19]. While effective, the study's reliance on simulations and its narrow geographical focus may limit the generalizability of its results.

Mohammed H. Alsharif et al. (2022) offer an optimization analysis of solar power systems for mobile communications, demonstrating profound economic and ecological benefits. Their study ensures reductions in greenhouse gas emissions and positions solar energy as a viable solution for remote network deployments [20]. However, the emphasis on solar energy alone overlooks opportunities for hybrid systems that might enhance efficiency and reliability further. Together, these studies underline the transformative potential of renewable energy systems in telecommunications. Despite this progress, gaps remain in the practical implementation of these systems, particularly regarding their scalability, cost efficiency, and adaptability to diverse operational environments. Future research should address these challenges to facilitate broader adoption and ensure sustainable energy solutions for the telecommunications industry.

In a paper published by M. Javidsharifi, et al. in 2021, they develop an optimization model for photovoltaic-battery systems targeted at cellular networks. By using the model across different levels of solar availability they presented a strong foundation for cost and power autonomy. But they are not clear on the impact of combined PV systems and other hybrid renewable energy systems. Abu Jahid et al. (2020) further discuss this concept with a techno-economic analysis of power supply solutions for Long Term Evolution base stations. These techniques studied by them show major energy efficiency and environmental improvements including cell zooming and green traffic steering. Despite this, the study might be restricted by its use of simulations and a relatively small geographic scope.

Mohammed H. Alsharif et al. (2022) provide an optimization analysis for mobile communication solar power systems that has far-reaching economic and environmental implications. Their study guarantees emission cuts of greenhouse gases and places solar energy in the best place for remote network scenarios. However, it fails to capture other possibilities of combining different systems which could even improve the effectiveness and robustness of the system even further. In combination, these works suggest that renewable energy systems can significantly revolutionize telecommunications. However, there are still some gaps in the application of these systems in practice, especially as concerns their applicability, cost, and versatility in different working conditions. Future research should address the above challenges with a view of expanding the horizon of adoption and making energy solutions sustainable for the telecommunication industry.

3. Methodology

The method of this research is based on examining the integration of decentralised DC power systems and UPS solutions as a part of telecommunication equipment. The research design includes theoretical explanation, system observation, designed experiments, and practical experiments to guarantee that the proposed systems' applicability and advantages can be fully understood by the research.

To start with, the research involves a conceptual examination of the current telecommunication power infrastructure, more specifically, the shortcomings of a standalone DC system and external UPS configuration. Major operational issues are pointed out such as the existence of single sources of failure, unoptimised usage of resources, and high expenses connected with centralised systems. Based on this analysis, a novel architecture for embedded power system design is proposed for the telecommunications equipment like OLTs, FTTH and DWDM systems.

A survey technique is used to evaluate the existing system configurations in the operational telecommunication networks. The information is obtained from several locations such as exchanges, data centers, and mobile base stations employing real-time monitoring. They quantify the parameters like power use, redundancy efficiency and thermal control. This empirical data will be used in this research to compare the performance of the current systems with the decentralized models proposed in this research.

The study consists of the development and evaluation of prototype embedded power systems. These prototypes contain such elements as lithium-ion batteries, rectifier modules, and full-wave converters installed in telecommunication equipment. Performance tests are performed in controlled environments to assess their dependability, and functional autonomy when subjected to different loads. The results of the analysis of the efficiency, reliability, and space utilization of the proposed systems are compared with the characteristics of traditional standalone power systems.

The research design also includes a review of field installations and case studies from renewable energy and power systems industries. Visits to leading R&D facilities, such as Delta, GE, and Schneider Electric, provide insights into best practices and scalable implementations of decentralized power systems. These industry benchmarks help validate the practicality and scalability of the proposed designs.

The evaluation of the proposed systems is conducted using a set of defined metrics. These include energy efficiency, measured by power utilization rates and energy loss reduction; reliability, assessed by system uptime and resilience during power disruptions; cost-effectiveness, analyzed through comparisons of installation and maintenance costs; and environmental impact, measured by reductions in carbon emissions and dependency on fossil fuel-based backup systems.

Data analysis is performed using statistical and comparative methods to ensure the validity and reliability of the findings. The results are further validated through peer benchmarking and expert consultations. The study concludes with recommendations for implementing decentralized power solutions and outlines future directions for enhancing scalability and performance in telecommunications networks.

The research design also involves assessing field installations and case studies of renewable energy and power systems industries. The assessment of leading R&D facilities, including Delta, GE, and Schneider Electric, reveals the experience and global scalable implementations of decentralized power systems. Such industry benchmarks are used here to establish the feasibility and applicability of the proposed designs.

The performance of the proposed systems is assessed based on a set of metrics that has been developed. These are in the form of power utilization rates and energy loss, system uptime and reliability during power outages, installation and maintenance costs and carbon emissions and use of back-up power such as diesel.

Statistical and comparative methods are used for data analysis to maintain the accuracy or credibility of the results. The findings are also supported by peer benchmarking and consultation with academic experts. Recommendations for the deployment of decentralized power solutions are provided in the final section of the study along with future research directions to improve the scalability and performance of telecommunication networks.

4. Results

A. Understanding Business Needs in Telecommunications Networks

The research underscores the importance of a convergence between network design and business needs such as data needs and future expansion trends. Choosing the right network topology (LAN, WAN, or VPN) makes the network run effectively and be easily changed if necessary. The following are the important aspects of planning and installing networks as presented in Table 1.

B. Performance of PON Systems

In the analysis of Passive Optical Network (PON) systems, two key components were recognized namely, the Optical Line Terminal (OLT) and the Optical Network Terminal (ONT). Incorporating distributed power supplies into these components increased the level of autonomy of external DC systems. The traffic flow management and signal combining functions of OLTs also showed performance, and ONTs enhanced data delivery and users' connections. A comparison of the traditional and embedded power systems for PON is presented in Table 2.

Fig. 1 provides a visual representation of a typical PON architecture, illustrating the relationship between OLTs, passive optical splitters, and ONTs at the user end. Integrating decentralized power sources into these components enhanced

Table 1
Considerations for network planning and installation

Factor	Description
Scalability	Ability to grow or shrink based on organizational needs
Security	Implementation of robust measures like encryption and firewalls
Reliability	Deployment of redundant systems to mitigate risks of downtime

Table 2
Comparison of traditional and embedded power systems in PON

Parameter	Traditional System	Embedded System
Power Dependency	External DC source	Self-contained with converters
Traffic Management	Centralized	Decentralized
Resilience	Limited redundancy	Enhanced operational stability

Table 3
Comparison of power solutions for MEC in 5G networks

Power Solution	Backup Time	Dependency	Scalability
External UPS/Inverter	15-30 minutes	High on centralized sources	Limited
Embedded AC-to-DC Converter	Continuous	Self-contained	High

Table 4
Key differences between self-based and standalone systems

Parameter	Standalone System	Embedded System
Resources Utilization	Separate systems	Integrated with equipment
Energy Efficiency	Higher consumption	Optimized
Thermal Management	Limited	Superior due to segregation

independence from external DC systems.

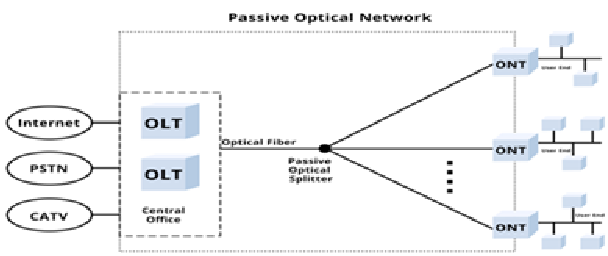

Fig. 1. Architecture of a passive optical network (PON) depicting OLTs, splitters, and ONTs

C. *Advancements in 5G Networks*

The 5G networks facilitate improved mobile broadband, lowest possible latency, and many M2M connections. 5G has multiple layers such as physical layer, MAC layer and RLC layer to make sure that the data is delivered properly, as shown in Fig. 2. But dependence on UPS and inverters from outside for MEC has its drawbacks. Some decentralized AC-to-DC converters showed possibilities to improve reliability, as presented in Table 3. As shown in Fig. 1, 5G network comprises of layers of hierarchy and has interfaces with power system.

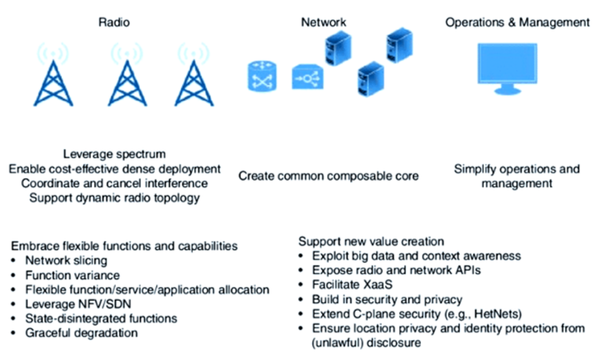

Fig. 2. Overview of radio, network, and operations: strategies for enhancing radio deployment, network connectivity, and operational efficiency

D. *Efficiency of DWDM Technology*

The analysis of DWDM systems showed that using rectifier-based embedded designs instead of traditional dual AC/DC sources reduces power consumption and space. These improvements are especially important for data centers as they work under N+N redundancy concepts.

E. *Effects of CISCO IP/MPLS Pre-Aggregation Routers*

Some of the CISCO routers and switches were known to draw very high power and benefited from the decentralized DC systems as it lessened the cooling requirements for the equipment. Using power autonomy from the embedded systems, operational cost was cut while scalability was improved, as illustrated in Fig. 3.

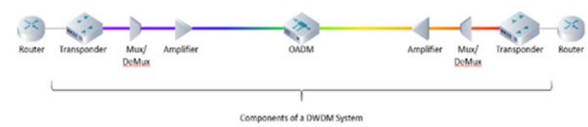

Fig. 3. Components of a DWDM system: A visual representation of the key elements in dense wavelength division multiplexing

F. *Comparing Self-Based with Standalone Systems*

Comparison of self-based power supply strategies with standalone solutions identified several benefits of integrated concepts in the investigated study, as depicted in Table 4. These were issues such as reduced space occupancy, low thermal calls and low energy demands.

5. Discussion

The results of this study are helpful for understanding the importance of including decentralized DC power systems in telecommunication infrastructure. As the telecommunications environment continues to change due to new technologies such as 5G, DWDM the problems posed by old power systems become unsustainable [21]. The analysis of the differences between the traditional and embedded power supply systems in Passive Optical Networks (PON) showed that the decentralized systems do not only minimize the dependence on the external DC sources but also increase the reliability of the networks operation [22]. This supports the view of Niranjan Rao Deevela et al. (2023) on the need to adopt hybrid systems for minimization of greenhouse gas emissions and the use of fossil energy sources by adoption of renewable energy sources [4].

Furthermore, the assessment of the 5G networks exposed some of the drawbacks of the external UPS systems. The high dependence on the centralized sources has been found to limit the scope and variety in a big way, as seen in the outcomes [23, 24]. The integration of embedded AC-to-DC converters corresponds with the conclusion made by Hossain et al. (2020) that grid-tied solar PV systems are beneficial in increasing energy sustainability while decreasing reliance on outside energy resources [25]. These ideas are not unique to Microsoft, similar trends are being experienced in the telecommunications industry where deployment of renewable energy solutions is increasingly becoming mandatory to cater for the growing data requirements as well as efficiency in operations [26].

The findings of the study show that Lithium-Ion Battery systems and superior rectifier technology bring significant enhancements in energy utilisation efficiency. The observed lower thermal demands and reduced space occupancy are in agreement with M. Javidsharifi et al. (2021) who found that improved photovoltaic-battery systems could improve power autonomy and reduce operational costs [18, 27]. This co-ordination between power systems not only enhances efficiency but it also helps to expand the telecommunication networks which is more and more important in the period of rapid development of technology and growing need for telecommunication networks [28], [29].

Moreover, the analysis of DWDM technology shows that efficient power usage is a critical factor in data centers. The transition from conventional two-source parallel AC/DC to the rectifier integrated solution is consistent with Mohammed H. Alsharif et al. (2022) that explained the efficiency, cost, and environmental advantages of solar power systems and hence, the call for an integrated approach to power management in telecommunication [30]. With data centers growing and constantly requiring far more energy, decentralized power solutions become a viable solution to provide energy and at the same time meet the sustainable development objectives [31].

However, there are still some issues which must be resolved to advance the usage of decentralized power systems. The literature suggests that there is a lack of integration of these systems on how they may be scaled up and implemented across different operation settings [32]. For instance, even though the reviewed studies offer a solid theoretical background, they are frequently weak on practical experience and viability data. The integration of such systems is not only a technical problem, but it also requires the development of the legal norms and policies that would enable the shift toward distributed energy systems [33].

However, this research also highlights the need to find out more about the economic effects of decentralization. Although the capital investment may be an issue for some operators, the operational cost of managing the facility together with the potential of improving energy efficiency offers the basis for investment [34]. Thus, cost-effective assessment that will factor in the costs of implementing these systems and the consequent benefits to be accrued in the future will help in convincing the stakeholders [35].

Future research on decentralized power systems is crucial to understanding their performance across different geographic and operational contexts. Holistic field studies are necessary to verify the practicality and adaptability of proposed solutions, encompassing diverse environments like urban and rural deployments. The integration of decentralized DC power systems can make telecommunications infrastructure more reliable and efficient, mitigating risks associated with single points of failure [36].

Introducing renewable energy resources in telecommunications networks can satisfy green aspirations and strengthen environmental profiles of telecom companies. This transition to decentralized power solutions can lead to considerable cost savings in the long term, making telecommunications companies more competitive in a crowded market [37]. Policy frameworks and regulations should be considered as incentives for the adoption of decentralized systems, as they can reduce entry barriers for investors and drive a new sustainable model in the telcos' power source.

Further study is needed on the scalability of decentralized power systems, as understanding how these systems can be efficiently implemented in various geographies and operations will be key. Case studies on successful implementations are best avenues for future research to uncover insights to help set industry best practices and standards.

Decentralized power systems could serve as a buffer for disruptions, ensuring energy security and resilience within the telecommunications industry. Self-sustaining, resilient energy infrastructures created for the telecommunications industries would ensure operation during times of crisis, ultimately securing the network of modern society.

6. Conclusion

In summary, this research provides compelling evidence for the integration of decentralized DC power systems within telecommunications networks. The findings advocate for a transition toward more efficient, reliable, and sustainable energy solutions to address the pressing issues associated with traditional centralized systems. This study aligns with existing literature and emphasizes the need for further research aimed at improving scalability and performance in telecommunications infrastructure. Future efforts should concentrate on creating comprehensive frameworks for implementing decentralized systems, investigating hybrid energy solutions, and encouraging collaboration among industry stakeholders to promote the adoption of innovative power solutions. Ultimately, this holistic approach aims to establish a more resilient and sustainable telecommunications landscape that meets the evolving demands of today’s society while paving the way for advancements in technology and connectivity.

A. Future Trends

Surrendering ownership of power management to each technology department would improve performance and accelerate project delivery. Additionally, reducing reliance on centralized system architectures would enhance network reliability.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper. Due to non-financial interest membership of organizations and scientific societies that undertake advocacy work.

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telecommunication industries.

Author Contribution Statement

My Role: Direct involvement in dimensions, conceptualization, and outline creation.

I personally measured all the current system architecture (DC Rectifier, Inverter, UPS & Converter) system utilization across the network using real-time monitoring tools, collecting data at various points to assess the possibility of this integration.

Facilitators: Provided support through resources, oversight, and strategic input to allow me visits to Multiple World well-known R&D (Delta, GE, Schneider Electric, ABB, Eaton System).

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