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Solid-State Transformers: A Game-Changer for Off-Grid and Emergency Power Systems

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***Abstract:** This paper compares Solid-State Transformers with traditional low-frequency transformers to consider their suitability for temporary power infrastructure in emergency response scenarios and remote locations. While current solid-state transformers do not offer significant weight reductions or cost advantages over low-frequency transformers, they provide approximately 20% volume reduction and superior integration capabilities for diverse power sources and loads. Despite higher initial costs and maintenance challenges, solid-state transformers' ability to accommodate renewable energy sources, enable direct DC connections and support distributed operations makes them particularly valuable for future applications in disaster recovery and off-grid power systems. The analysis suggests that as solid-state transformer technology matures and gains industry support, it will become increasingly critical for enhancing the flexibility and resilience of temporary power systems in disaster recovery and remote areas. Future research should focus on optimising power electronic components, particularly filter design, to reduce the solid-state transformer's volume and weight and investigate reliability and maintenance requirements in challenging operational conditions.*

***Keywords:** Solid-State Transformer, Power Infrastructure, Low-Frequency Transformer, Power Grids.*

Abbreviation:
SST: Solid-State Transformers
LFTs: Traditional Low-Frequency Transformers
LAPDS: Lighting and Power Distribution System
SWOT: Strengths, Weaknesses, Opportunities, and Threats
S: Apparent Power
B_mMaximum Flux Density
J: Current Density
A_cMagnetic Core Area
A_w: Window Area
F: Frequency

I. INTRODUCTION

This paper compares Solid-State Transformers (SSTs) with traditional Low-Frequency Transformers (LFTs) to consider their suitability for temporary power infrastructure. Depending on the nature and priorities of the temporary infrastructure, different emphasis will be placed on each Technology's varying features/benefits. For this reason, this paper considers a short-term (less than 12 months) emergency deployment as a context to compare the technologies.

It analyses the size and weight considerations of SSTs, their advantages, and their suitability for various applications.

Magnetic components, such as transformers, are LFTs' most significant and heaviest parts. However, increasing the frequency of operation can decrease the size of transformer cores and windings; this can be considered one of the benefits of SSTs [1] However, higher frequencies also increase core losses and skin effects, necessitating finding the optimum operating point. The transformer's size and weight mainly influence the overall size of LFTs, while SSTs are heavily impacted by the need for additional components like filters [2]. These power electronics components in SST introduce additional size and weight requirements, offsetting some advantages gained from high-frequency switching.

Comparisons between LFTs and SSTs show that SSTs have significantly reduced volume but comparable or slightly lower overall weight. SSTs are somewhat less efficient due to switching losses in power electronics and have higher costs due to increased semiconductor usage. However, LFTs have undergone decades of optimisation, leading to cost reductions and performance improvements. However, SSTs are still in early commercial development and are likely to see performance improvements over time. Emergency operations will increasingly rely on alternative power sources and the integration of renewable energy. So, SSTs offer advantages in the flexible integration of renewable sources, direct connection to charging and DC equipment buses, and modularity for mobile and distributed operations, enhancing flexibility and resilience [2].

This paper aims to analyse the size and weight considerations of SSTs compared to traditional LFTs and evaluate the advantages and suitability for application in temporary power infrastructure, including disaster recovery.

II. LOW-FREQUENCY TRANSFORMER

Traditional low-frequency electromagnetic transformers use the principles of electromagnetic induction to transfer electrical energy between two or more circuits [3]. They consist of primary and secondary coils wound around a magnetic core, enabling electrical energy transfer through magnetic fields [4]. Depending on the ratio of turns on the primary and secondary coils, a step-up or step-down of voltage can be achieved with efficiencies greater than 95% [5].

Figure 1 demonstrates the typical topology of this type of transformer, which has three-phase (delta) windings on the primary and a secondary and a magnetic core in the middle.

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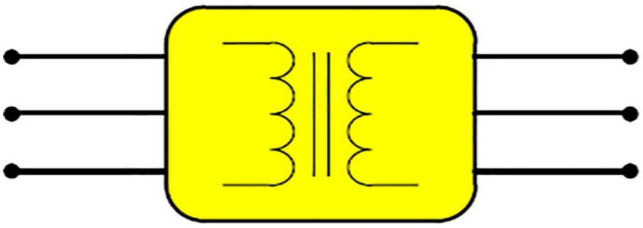


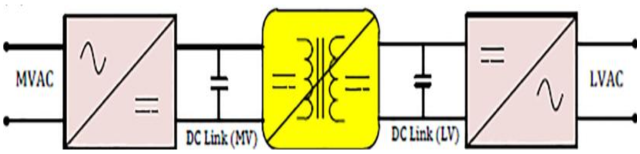
[Fig.1: Topology of Traditional Three-Phase Delta Low-Frequency Transformer] [5]

In a typical power infrastructure, these transformers operate at the same frequency as the supply. 50 Hz, the so-called "European" frequency, is one of the two standard frequencies that govern the electric power supply worldwide, with 60 Hz, the "American" standard frequency, being the other [7]. This operating frequency has implications for the size of the transformer, and the SST is said to outperform the traditional transformer by leveraging the benefits of much higher transformer frequencies.

III. SOLID-STATE TRANSFORMER

Unlike traditional low-frequency transformers (50/60 Hz), SSTs offer versatility in modular construction, bidirectional power flow, and compatibility with AC and DC grids [8]. They provide voltage control and modulation of active and reactive power and eliminate the need for additional equipment or components typically used in conventional electricity grids to control voltage levels and modulate active and reactive power [9].

The configuration of SSTs can be adapted to suit their intended purpose. Figure 2 shows the most versatile configuration: a three-stage topology "with a DC link on both the primary and secondary sides" [6]. A medium voltage AC supply is rectified to a DC voltage, passed across the DC link, converted to a high frequency (tens of kHz) pseudo-AC signal, and stepped up/down across the transformer. The signal is then converted back to DC and passed across the DC link to be inverted to a new AC signal [10].



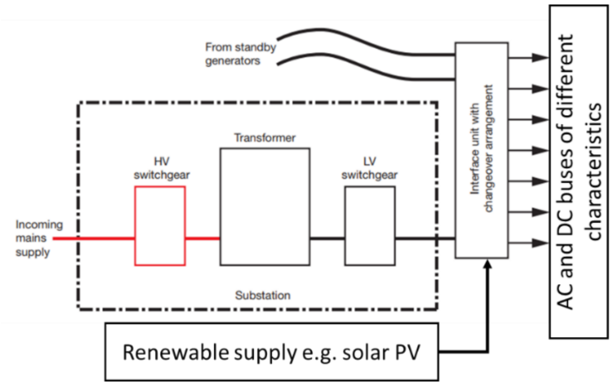
[Fig.2: Topology of Three-Stage Solid-State Transformer]

SSTs address challenges posed by renewable energy sources, distributed generation, distributed storage, and bi-directional power flow in current grid models [11]. They are designed to be more compact, efficient, and flexible than traditional transformers [12]. For example, renewable supplies are typically converted by electrical induction machines and AC/AC converters in combination with a conventional 50/60 Hz transformer and AC/DC rectifiers [13]." However, the SST allows all this in one compact and efficient device [14].

IV. TEMPORARY POWER INFRASTRUCTURE

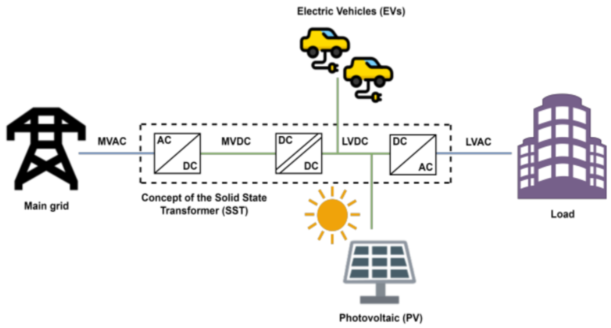
This paper defines the term "Temporary Power Infrastructure" to encompass the systems and equipment required to meet power needs for short-term periods (less than 12 months). This infrastructure refers to construction sites, disaster response, or any scenario requiring a temporary, safe, reliable electricity supply. This paper also considers expeditionary emergency operations.

Supply or generation could be from several sources at differing frequencies, voltages, and types (AC/DC). Depending on the application, the distribution and load requirements may also vary in terms of voltage and frequency. Figure 3 is an adapted version of the power supply schematic from the UK's Emergency Response Engineering Guide: "Electrical Engineering in the Field" [15]. The adapted model presented includes provision for supply from national transmission and distribution infrastructure, plus standby generators [16]. It has been adapted to include the addition of renewable energy supplies, which will become an increasingly common feature in all temporary power infrastructure, including emergency deployments, as the reliability of the main supply is increasingly threatened and the motivation to reduce carbon emissions is increased [17].



[Fig.3: Adapted Power Infrastructure Concept] [15]

Figure 4 illustrates a comprehensive system concept for energy sources and storage, where buses provide varying loads at different points in the SST.



[Fig.4: Concept of Solid-State Transformers Integrating Power Infrastructure] [18]

V. ANALYTICAL FRAMEWORK

An analytical approach systematically compares SSTs with traditional low-frequency transformers [19]. As outlined in Table I, it proposes a bespoke framework in which the factors for consideration have been extracted from the approaches taken by several research papers that evaluate emerging engineering technologies [20].

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Every application will have competing priorities in this framework, and to consider them all for every scenario is beyond the scope of this paper [21]. Instead, this paper focuses on the requirements of temporary power infrastructure for emergency response and remote operations, and the scope of analysis is limited to two of these factors: size and application suitability [22]. These factors have been selected based on priorities for emergency response and remote infrastructure needs, as indicated in several UK engineering and infrastructure guidelines and analysed using a SWOT analysis as shown in Appendix A [23].

Table-I: Analysis Framework for SSTs

Factor	Considerations
Application Suitability	Addressing the requirements of the intended application.
Size	Indicative physical size and weight of equipment required.
Reliability and Safety	Reliability and safety aspects include failure rates, mean time between failures, protection mechanisms, and compliance with safety standards.
Scalability	Scaling with changing demand or requirements and compatibility with existing systems. Adaption to future developments and needs.
Industry Support and Development	Level of industry support and development. Robust support and ongoing advancements can ensure long-term viability and compatibility.
Cost	Initial setup costs, maintenance expenditures, and additional infrastructure requirements. Factors such as lifespan and reliability are used to assess the long-term cost-effectiveness of a product.
Efficiency	Energy efficiency, particularly power consumption, conversion efficiency, and overall energy utilisation.
Environmental Impact	Carbon emissions, waste generation, and the use of hazardous materials.

VI. RESULTS

Appendix A presents a SWOT analysis of SSTs' size and weight factors, detailed in this paper's Analysis section. Based on the analysis of current size and weight benefits alone, there is no extreme case for implementing SSTs in temporary power infrastructure for remote or emergency scenarios. However, when considering how this infrastructure will need to function in the future, the versatility of SSTs presents a much stronger case. Indeed, the analysis suggests that SSTs are a critical component in future temporary power infrastructure for disaster recovery, remote operations, and off-grid applications.

Current research shows that SSTs do not yet demonstrate significant weight reduction or cost savings advantages compared to LFTs, as illustrated in Tables II and III for 500kVA and 1,000kVA units. This comparison, however, is not entirely fair. LFTs represent a mature technology with decades of commercial investment and optimisation, while SSTs are still emerging and primarily exist in research environments rather than industrial applications. Although SSTs offer negligible weight benefits and come at a significantly higher cost, this balance is likely to shift in their favour as the technology develops. The approximately 20% volume reduction already achieved by SSTs suggests positive momentum, indicating that SSTs are on track to compete with LFTs based on these physical characteristics alone, eventually.

Table-II: Characteristics of Two 500kVA Transformers

	SST (AC/AC)	LFT	*% Reduction*
Efficiency (%)	96.3	98.7	-2% (SST is less efficient)
Volume (m^3)	2.67	3.43	-22% (SST is smaller)
Weight (kg)	2600	2590	0%
Cost (1000s USD)	52.7	11.4	+362% (SST is more expensive)

Table-III: Characteristics of Two 1000kVA Transformers

	SST (AC/AC)	LFT	*% Reduction*
Losses (W/kVA)	37.3	13.0	187% (SST has higher losses)
Volume (l/kVA)	2.7	3.4	-21% (SST is smaller)
Weight (kg/kVA)	2.6	2.6	0%
Cost (USD/kVA)	52.7	11.4	362% (SST is more expensive)

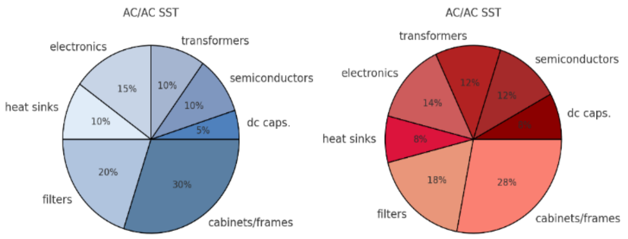
Where the analysis does highlight the benefits of SSTs over LFTs is their suitability to the application, however. While existing deployable power infrastructure, such as the LAPDS, can meet current needs, there is a growing requirement to adapt to future operational demands in remote and emergency scenarios. The LAPDS cannot integrate more than two sources of supply with more than two sources of output [25]. However, on future deployments, power infrastructure will increasingly need to integrate multiple sources of power and energy storage to reduce reliance on unstable supplies and minimise its environmental impact. Furthermore, this infrastructure must supply an increasingly electrified network, particularly as vehicles transition from dependence on fossil fuels. These loads will also become increasingly spatially dispersed, with extended supply chains posing a threat to the force. Anything that can be done to reduce this threat is a key benefit [23].

The ability of SSTs to integrate this network of sources, storage, and load, with varying demand profiles and voltage requirements, is where the benefits of SSTs outweigh those of LFT. The technology is not without risk, however. The current lack of commercial and industrial investment, combined with limited technology availability, means that adopting it now would require organisations to take on the risk of ongoing maintenance and supportability. Depending on their willingness to invest in an emerging yet critical technology, this can be viewed as either a risk or an opportunity for early adopters.

VII. ANALYSIS

A. Size and Weight

In a conventional LFT, the transformer mainly determines the dimensions and mass. Figure 5 demonstrates the usual distribution of contributions to the volume and cost of the components of an STT. It indicates that for an STT, transformers account for a relatively small proportion (approximately 10%) of the device's volume compared to filters and cabinets/frames. The function of cabinets and frames is only to encase all other components; hence, their size can only be diminished if another volumetric feature of the device is lowered [25].



[Fig.5Breakdown of Component Contributions to Volume (Blue) and Cost (Red) of AC/AC SSTs]

B. Magnetic Component Contributions to Size and Weight

Conventional electrical induction machines, AC/AC converters, conventional 50/60 Hz transformers, and AC/DC rectifiers are "physically large and heavy" [2]. Size and weight are key considerations for temporary power infrastructure, particularly when access to the site is restricted or vulnerable, and available space is at a premium. On a construction site, this restriction may be due to the proximity of other infrastructure or, conversely, a considerable distance from existing transportation networks. Access could also be restricted in remote or disaster-stricken areas due to limited logistical resources, challenging terrain, and environmental conditions along supply routes.

Magnetic components are key in voltage conversion systems and are the bulkiest part of high-power converters. For a conventional and high-frequency power supply, the transformer contributes to the size "since it determines about 25% of the overall volume and more than 30% of the overall weight" [26]. Hence, anything that can be done to reduce the size and weight of these components is beneficial [27].

One of the main advantages of an SST compared to a traditional LFT is the much-reduced size and weight of the bulky transformer. Equation (1) shows that as frequency increases, the required size of a transformer core and its windings reduces proportionally [28].

$$\mathrm{A}_w \cdot \mathrm{A}_c \propto \frac{S}{B_m \cdot f \cdot \mathrm{J}} \quad \dots \quad (1)$$

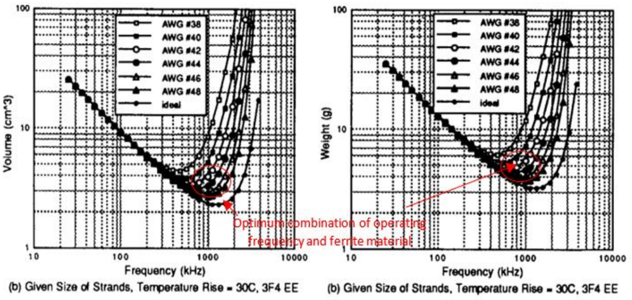
To demonstrate this, Equation 2 shows that the product of the core and window areas can be reduced by 200 for an increase in transformer frequency from 50 Hz (LFT) to 10 kHz (SST).

$$\frac{(\mathrm{A}_w \cdot \mathrm{A}_c)_{50Hz}}{(\mathrm{A}_w \cdot \mathrm{A}_c)_{100kHz}} = \frac{1/50Hz}{1/10kHz} = 200 \quad \dots \quad (2)$$

However, increasing frequency is not a panacea for reducing transformer sizes. Core losses (hysteresis, residual, and eddy current losses) and skin effects on the windings increase with frequency, so a limiting factor on maximum transformer frequency is needed to get optimum results. As Gu and Liu [1] stated, "the size of magnetic components has to be increased after a certain frequency to obtain a high efficiency and a low-temperature rise".

Much work has been done to model these behaviours and find the optimum operating point for any application and transformer configuration. However, Figure 6, extracted from Gu and Liu's "Study of volume and weight vs. frequency for high-frequency transformers," best illustrates the optimum operating frequencies for a range of ferrite core materials to minimise volume and weight. Gu and Liu [1] conclude that "the optimum frequency to obtain the smallest volume and the lowest weight for a transformer depends on the ferrite material and winding technique". As the field of materials science continues to develop ever-better-performing transformer components, this optimum operating point will continue to improve. It should be noted that much of this published research is over 20 years old, and technological developments over this period have likely further tipped the balance in favour of STT performance. However, more contemporary analyses are not readily available.

Biernacki and Czarkowski [29] established crucial modelling techniques for high-frequency transformers that demonstrated the fundamental relationship between operating frequency and core dimensions. Building on this foundation, Guillod and Kolar [30] developed comprehensive scaling laws for medium-frequency transformers, mathematically verifying the inverse relationship between transformer size and operating frequency while critically analysing practical limitations. Their research identified that core losses, thermal constraints, and skin effects create physical boundaries that prevent unlimited miniaturisation despite the theoretical scaling benefits predicted by electromagnetic theory. Both studies emphasised the importance of finding optimal frequency points for specific applications rather than arbitrarily increasing frequency.



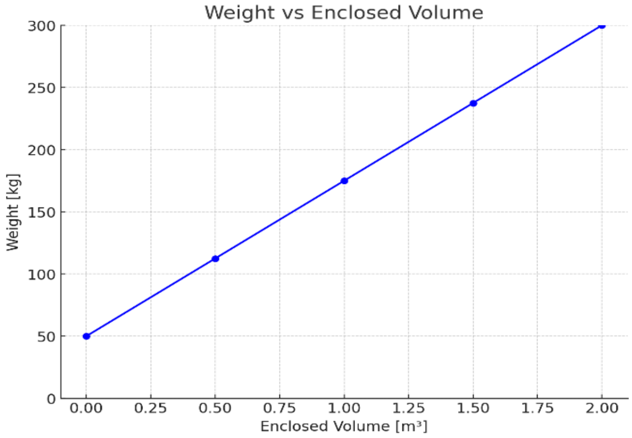
(b) Given Size of Strands, Temperature Rise = 30C, 3F4 EE

(b) Given Size of Strands, Temperature Rise = 30C, 3F4 EE

[Fig.6Plot of Transformer Frequency Against Volume and Weight of the Core] [1]

C. Power Electronics Contributions to Size and Weight

In contrast to LFTs, SSTs require additional power electronics. Where weight and size reductions may have been gained in SSTs through high-frequency switching across the core, they are somewhat replaced by weight and volume requirements from components such as filter capacitors and power transistors. Furthermore, these components also need to be included in housing/cabinets and on frames, thereby reducing the impact of improvements in magnetic material size and weight reductions [31]. Using the empirical data provided by Gu and Liu. An approximately linear relationship between STT weight and volume can be established, as shown in the exact Figure using Python code.



[Fig.7: Dependence of Cabinet Weight on Enclosed Volume of a Solid-State Transformer]

Consideration is given to a hypothetical reduction in the volume of the most significant contributing power-electronic component to retain the weight and volume savings gained through high-frequency switching: the filters (shown in Figure 5). Equation 3 is extracted from Figure 7, and the calculation shows that for a hypothetical 50% reduction in the volume of the filter components, there will be a circa 17.9% reduction in the weight of the STT enclosure. These figures are summarised in Table IV.

$$
\begin{aligned}
&\mathit{Enclosure\ Weight\ Reduction}\ (\%) \\
&= \frac{\mathit{Initial\ Weight}\ -\ \mathit{Reduced\ Weight}}{\mathit{Initial\ Weight}} \mathit{Equals} \\
&= \frac{(50 + 125 \times 100\%) - (50 + 125 \times 75\%)}{(50 + 12 \times 100\%)} \\
&= 17.9\% \quad \dots \quad (3)
\end{aligned}
$$

Table-IV: Summary of Hypothetical Weight and Volume Saving Calculations

Factor	Reduction	Remark
Filter Contribution to Overall Volume	50%	Estimated from Figure 5
Theoretical Reduction in Filter Volume	50%	Hypothetical example
Overall Reduction in STT Volume	25%	50%. 50% = 25%
Projected Reduction in Enclosure Weight	17.9%	Using Equation (3)

The analysis demonstrates that research and development must focus on enhancing the properties of these filters to achieve significant reductions in the overall size and weight of SSTs. Reducing the size and weight of these components would not only recoup the benefits from reducing the size and weight of the magnetic components but also require further reductions in the size and weight of the enclosures.

Huber and Kolar's paper compared the efficiency, volume, weight, and cost of LFT and STT. They noted that whilst LFTs are readily available on the commercial market, no such market exists for SSTs, so their comparison was partly based on a hardware prototype [2]; their findings must be considered in this context. Future commercial research and development will likely improve the performance of SSTs.

The findings of their comparison are summarised in Tables II and III, which compare 500kVA and 1,000kVA units, respectively. Current research shows that SSTs do not yet demonstrate significant weight reduction or cost savings advantages compared to LFTs. This comparison, however, is not entirely fair. LFTs represent a mature technology with decades of commercial investment and optimisation, while SSTs are still emerging and primarily exist in research environments rather than industrial applications. Although SSTs offer negligible weight benefits and come at a significantly higher cost, this balance is likely to shift in their favour as the technology develops. The approximately 20% volume reduction already achieved by SSTs suggests positive momentum, indicating that SSTs are on track to compete with LFTs based on these physical characteristics alone, eventually.

Table II (for a 500 kVA comparison) and Table III (for a 1,000 kVA comparison) show that while the SST has significant volume reductions (c. 22% compared to LFT), there are negligible differences in overall weight. The transformer component is marginally less efficient than LFTs, primarily due to switching losses in the power electronics. [32]. However, if using an LFT where the source or supply is required to be converted to/from AC/DC, additional losses would be associated with these conversions. Hence, the difference in whole-system efficiencies is likely negligible.

Huber and Kolar [2] estimated that SSTs' cost would be significantly higher than LFTs' at circa 362% due to the increased use of semiconductors and power electronics, despite reductions in magnetic core and winding materials. Improvements in the semiconductor field are likely to drive down these costs, but the overall cost of SSTs will depend on fluctuations in the semiconductor market. This analysis does not appear to provide a compelling case for the SST compared to the LFT. However, it should be noted that LFTs have undergone decades of optimisation in design and manufacturing processes to drive costs down; the same is not true for SSTs. Given the same opportunities, the performance characteristics of SSTs are likely to improve manifold relative to LFTs with commercial investment.

D. Application Suitability

Operational requirements must be considered to determine whether LFTs or SSTs are most suitable for temporary power infrastructure in remote or emergency scenarios. Large-scale operations in remote areas, such as disaster recovery or off-grid construction projects, can consume significant amounts of diesel daily, placing a huge logistical burden on planners and resources. This reliance on fossil fuels strains supply chains and contributes to greenhouse gas emissions and environmental degradation [31].

Initiatives such as Project MERCURY have been developed to resolve the issue of fossil fuel dependency primarily through the electrification of operational fleets in remote and emergency scenarios. Project MERCURY also highlights the future of operations in increasingly dispersed and remote locations, rather than centralised bases, focusing on generating power from renewable energy sources [24].

These factors indicate the need for the flexible integration of renewable energy sources to Enable remote or temporary installations and reduce reliance on traditional power grids. Vehicle electrification will require rapid charging DC voltage buses rather than conventional AC supplies. The simple and efficient integration of power supplies will also significantly benefit collaborative projects or international operations. This challenge is due to differences in power standards, such as the 60 Hz supply used in some regions versus the 50 Hz supply used in others [15].

The multi-stage SST topology, as shown in Figure 2, provides a low-voltage DC link. This design will enable direct connections from STTs to vehicle charging buses and DC equipment buses, as well as direct connections for backup generators, renewable energy supplies, and energy storage, eliminating the need for an AC conversion stage. A traditional LFT would require AC conversion stages to integrate these sources and loads, with each stage introducing a new level of inefficiency and additional equipment requirements, with the associated additional logistical burden [33]. By containing all the required equipment in one discreet unit, the SST becomes an optimal choice for remote or temporary installations that require compact and efficient equipment [34]. Furthermore, SSTs are modular and ideal for mobile and distributed operations in challenging environments. They offer improved flexibility and resilience for applications such as disaster recovery, off-grid projects, or remote site operations.

VIII. CONCLUSIONS

This paper analysed the size and weight considerations of SSTs compared to traditional LFTs for use in temporary power infrastructure in remote or emergency scenarios. SSTs offer versatility and adaptability, which are essential for future power requirements in off-grid and disaster recovery applications. While the current size and weight benefits of SSTs may not strongly justify their implementation in temporary power infrastructure, their integration potential is significant. SSTs' ability to integrate multiple power sources and energy storage and accommodate varying demand profiles will become crucial and particularly relevant in remote or emergency operations, where renewable energy integration, reduced reliance on unstable supplies, and minimising environmental impact will become increasingly paramount.

The weight reduction and cost savings results are skewed when comparing SSTs to well-established LFTs. SSTs are still in the research phase, lacking widespread deployment and commercial investment. As technology matures and gains industry support, SSTs will likely become strong competitors to LFTs in terms of size and weight.

Adopting SSTs carries risks for early adopters due to the current lack of commercial and industrial investment, posing challenges for ongoing maintenance and supportability. However, this presents an opportunity for organisations and industries to invest in emerging technology, shaping the future of temporary power infrastructure for remote and emergency applications and positioning themselves as leaders in this field.

The paper emphasises the significance of magnetic components in determining transformer size and weight. SSTs leverage higher frequencies to reduce their size, but finding the optimal operating frequency is crucial for efficiency and compactness.

Finally, this paper acknowledges that many other aspects, such as cost, reliability, safety, environmental impact, and scalability, must be analysed in detail before an informed decision can be made about the adoption of SSTs into temporary power infrastructure for remote or emergency applications.

DECLARATION STATEMENT

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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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APPENDIX-A

SWOT Analysis of Solid-State Transformers

Qualitative SWOT Analysis Comparing Size, Weight, Cost and Application Suitability of SSTs to LFTs

	Positives	Negatives
Internal	**Strengths** ▪ A reduced volume of units (a fifth smaller) reduces the logistical burden. ▪ While slightly less efficient across the transformer, it allows the removal of additional AC/DC conversion elements, thereby increasing the overall system efficiency. ▪ Versatility with AC and DC voltage links provides multiple buses for load requirements, eliminating the need for various rectifiers or inverters and associated losses and equipment. ▪ A direct connection to energy sources, including renewable energy, provides versatility in supply options. ▪ Bidirectional power flow and direct energy storage connection allow efficient energy transfer between storage and loads. ▪ The modular approach enables scalability according to the application's needs.	**Weaknesses** ▪ More than 3.5 times more expensive reduces the appeal of technology and delays investment. ▪ Negligible weight savings reduce the appeal from a logistics perspective. ▪ It is not commercially available on the scale of LFTs, so it may deter investment in technology if it is not perceived as being supported by the industry.
External	**Opportunities** ▪ Material technology improvements to reduce the size of power-electronics components. ▪ The increasing requirement for systems to incorporate multiple energy sources and storage makes this an appealing option. ▪ Military drive to adopt new technologies may attract investment to accelerate technological improvements.	**Threats** ▪ The current lack of commercial availability of units restricts investment in the technology and slows research and development. ▪ The slowdown in integrating renewable energy sources and vehicle electrification undermines the benefits of this technology. ▪ Lack of commercialisation means a perceived lack of support for early adopters of the technology.
