Applicability Assessment of Power Electronic Transformer (PET) in Textile Applications

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Abstract: Power electronic transformer (PET) has been the subject of extensive research in recent years due to its potential to replace 50-Hz transformers with advantageous characteristics such as reduced volume and weight, embedded fault protection, enhanced controllability, and bidirectional power flow. However, PET has not yet been successfully developed and implemented to a variety of field applications, making it an active area of research. Informed by this fact, the purpose of this paper is to evaluate the applicability of PET in textile applications while emphasizing the current problems of isolation transformers, such as harmonic effects, bulky size, and passivity, and how PET can solve these problems. PET can be an attractive replacement for the 50-Hz transformer in the above mentioned application by mitigating the drawbacks of the conventional 50-Hz transformer. In addition, challenges and current PET development trends are discussed.

Keywords Power electronic transformer(PET), isolation transformer, textile machineries, dual active bridge converter, power factor correction, fault protection.

1 Introduction

Power electronic transformer (PET) has so far attracted a lot of research interest from different industry and academia throughout the world and has the potential to replace the conventional 50-Hz transformer in many applications such as locomotives, EV charging, smart grid with attractive features of PET such as power quality improvement, bi-directional power flow capability, fault isolation, and improved controllability[1].

However, before the mass adaptation of PET, several issues need to be addressed, such as controller implementation, design optimization, topology selection, functionality testing, cost and size optimization, and so on. It is to be mentioned that, although few PET prototypes are tested worldwide, this concept is yet to be investigated in countries like Australia, New Zealand, Bangladesh, Korea and other countries in the world. The successful development of the PET concept will allow smart power transfer concept in these countries and make the deployment of Micro-grid concept viable. Furthermore, the successful development of PET prototype will bring in significant size and volume reduction benefits to the locomotive and traction industry by eliminating the bulky 50-Hz transformer[2].PET can be a flexible and attractive alternative in these applications due to its significantly reduced size with improved controllability.

Based on the foregoing discussion, the successful development of PET prototype and its functionality testing is an ongoing research topic. Inspired with this fact, this paper aims to investigate the applicability of PET in textile machineries which can be employed for varied applications in textile industry. Currently, the challenge of the isolation transformer in this application is to ensure a highly efficient energy transfer while regulating the voltage supply of the various motors running in the textile industry. The isolation transformer requires to have the following features:

1. Compact design
2. High overload capacity
3. Excellent voltage regulation
4. Trouble free performance
5. Fault isolation capability
6. Reactive power compensation
7. High energy efficiency

Additionally, the negative effects of the harmonics on this system are to be tackled by the isolation transformer which is not achievable with the conventional 50-Hz transformer without auxiliary devices such as STATCOM and SVC[3]–[6]. To ensure a highly efficient energy management in this application, the transformer must not remain a passive element. Interestingly, all these requirements can be well handled by the PET. At present, no efforts have been reported that had addressed the applicability of PET in such applications. However, the application of PET in the above mentioned application is relevant and useful for the future as the adaptation of PET for such application not only ensures a compact design but also ensures several other advantages such as improved power quality with flexible control facilities. The overall aim of this paper is to investigate the applicability of PET in textile machineries applications. To achieve this, a three-stage PET topology consisting of AC/DC, isolated DC/DC and a DC/AC converter is suggested. Furthermore, how the requirement of the target applications can be meet with the PET configurations which includes but not limited to fault isolation capability, power quality enhancement, and improving energy efficiency will be discussed.

This paper is organized as follows. Section II describes the basic configuration of the PET. Section III highlights the drawbacks of the conventional transformer in the textile applications. Section IV discusses the PET configuration in the above mentioned application and how PET can solve the drawbacks of the conventional transformers. Finally, a conclusion is drawn in Section V.

2 PET TOPOLOGY

PET is also known as Solid state transformer (SST) or an intelligent universal transformer (IUT).It replaces the conventional 50/60 Hz transformer by the ability of high frequency isolated ac-ac conversion technique, shown in Figure 1.

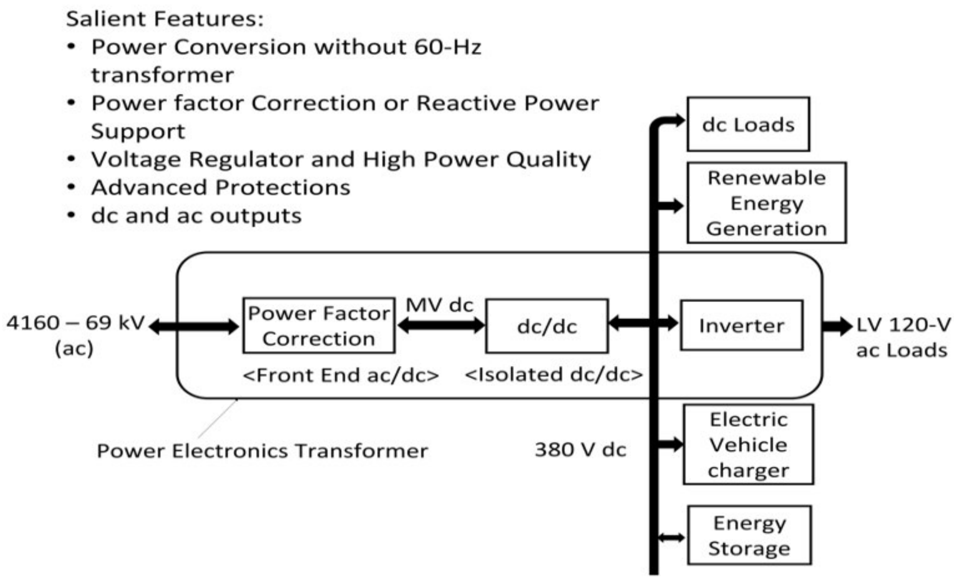

Figure 1: PET Topology with embedded smart features.

Basic operations of a PET's are follows:

1) Change the 50-Hz ac voltage to a high frequency voltage of several kilohertz to tens kilohertz.

2) Step up or down this high frequency voltage by a high frequency transformer.

3) Guide the high-frequency wave back to the 50/60-Hz voltage.

In Figure 1 the possible configuration of a PET is shown, that performs the step 1 in two power conversion stage. There are 3 conversation stage from ac-ac. There is an MV voltage side dc link and a LV dc link. This transformer offers a number of advantages over traditional transformer[7]–[9]. The use of solid state transformer and high frequency PWM enables voltage and current regulation possible. That offers number of benefits like input side voltage control, Voltage sag compensation, LV ride through, output voltage regulation, fault current limiting, and fault isolation. All of those features are not available on the conventional transformer. The availability of dc ports allows it to connect and power dc microgrid.

The concept of PET was about 50 years old but it takes so long to have suitable semiconductor devices like Si IGBT & SiC and topology innovations for realization of PET [4]. PET is essentially an isolated ac-ac converter. It works on both unidirectional or bidirectional and can also have single multiple stages. To support the needed voltage levels, there are two-level or multilevel topology variations. Initially due to the voltage limitation of power devices, multilevel converters such as the cascaded H-bridge converters are preferred for reaching desirable distribution grid voltages without device series connections that are mentationed in this category include the Electric Power Research Institute (EPRI) IUT transformer Asea Brown Boveri (ABB) power electronic traction transformer (PETT) and Future Renewable Electric Energy Delivery and Management's (FREEDM's) Gen-I SST . On the other hand, a 15-kV MOSFET is adequate for a simple and efficient two-level SST implementation when connecting to single-phase 7.2-kV ac grid. The detailed circuit diagram of the PET is shown in Fig. 2. To address the medium voltage and high power of the required distribution grid with the lower rated switching devices multilevel converters are adopted as shown in Fig. 2[10].

PET is not only the replacement of traditional 50-Hz transformer it also offers many smart grid functions[7], [11]. It enables many smart grid architecture such as the SST-enabled hybrid ac and dc microgrids. As PET is a power electronic based device so it can inject and absorb reactive power. It also has the ability to ride through LV sags; therefore, it performs like a DVR [12]. Another feature of the PET is it can decouple the HV and LV grid harmonics. PET can limit the short circuit current and interrupt fault[8], [13].

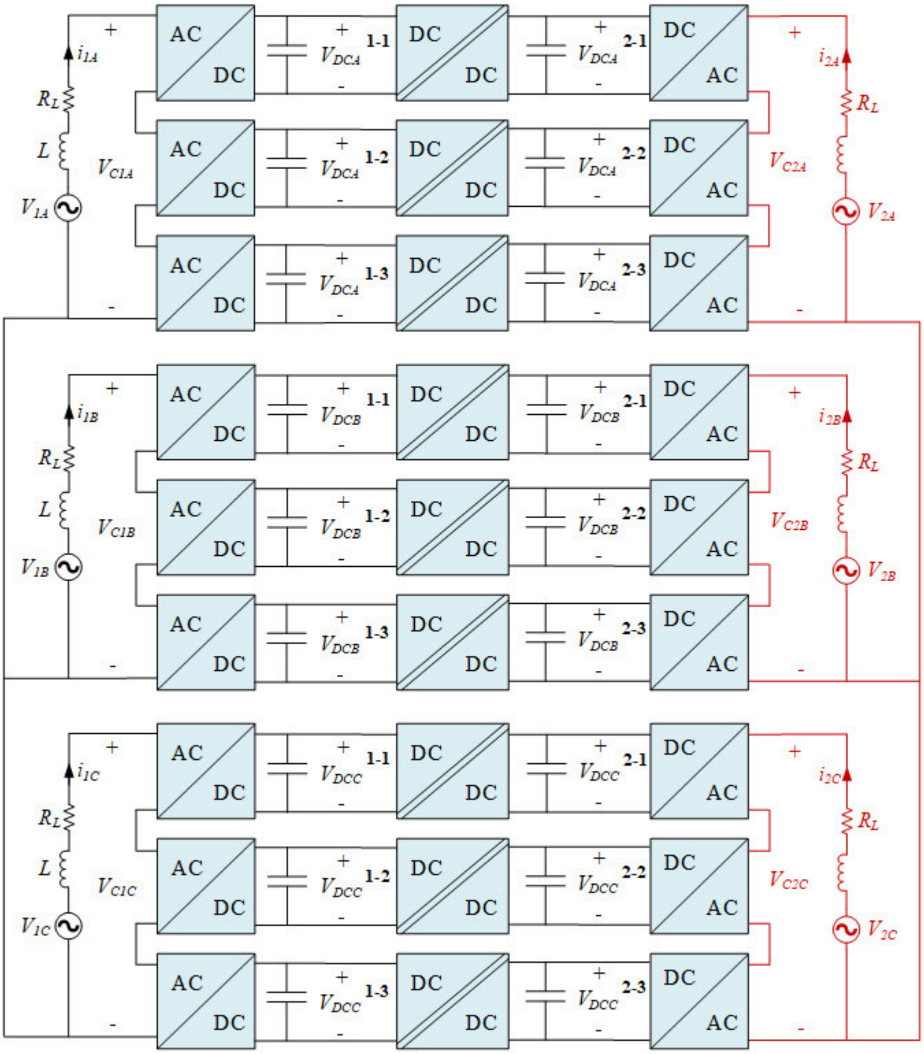

Figure 2: Circuit diagram of the PET topology [10].

3 Applicability and significance in Textile Applications

The successful development of the PET concept can lead to significant advancement in many areas such as traction, locomotives and micro-grids[9]. However, in the context of some countries like Bangladesh, India this concept can find some other interesting and relevant applications, and one such application will be investigated in this paper that is the textile machinery application. The conventional 50-Hz transformer is a bulky and passive device which requires additional components to handle the drawbacks of the 50-Hz transformer such as harmonics effect or higher losses due the system harmonics, bulky size, poor voltage regulation, reactive power support and response to faulty conditions. To solve this problem, a lot of auxiliary devices are required which increases the cost of the overall system. Hence, it is necessary to look for some suitable economically efficient alternative of the conventional 50-Hz transformer with additional control capability. PET is an attractive solution to this problem[13],[14],[15] and can bring significant changes to the present scenario in textile industries in those countries. Specially, in Bangladesh they have a lot of spinning mills where the use of isolation transformer is frequent and cost reduction by replacing the conventional 50-Hz transformer with PET can be a direct benefit to the government and ultimately to the mass people. The PET will not only reduce the cost but also will contribute to the enhancement of the overall efficiency of the system which will provide a significant economic benefits to the society. Additionally, this will change the concept in which the isolation transformer is utilized for this applications. This not only provides a cost-effective solution for the technology but will eventually lead to a reduced production cost for the overall manufacturing process of the spinning mills. It is to be mentioned that, textile industry contributes significantly to the total per capita income and the GDP (Gross Domestic Product) of Bangladesh. The textile industry remains a major strength in Bangladesh export section and a lot of revenue is earned in this sector per year. Thus a cost effective solution for the isolation transformer will bring in significant revolution to the textile industry by lowering the manufacturing cost. This reduced cost can be utilized either to increase the production of the textile sector or for changing the salary infrastructure of the textile workers which will help to maintain a healthy relationship between the workers and the owners of the textile industry.

PET is considered as a highly reliable and highly efficient solution. PET has no moving parts in its configuration which can provide several benefits to the textile applications such as reduced size and less maintenance[16]. This will have less failure chances and hence can have a very rugged performance with long life. All these features can be considered as a perfect match for the textile applications. PET can also satisfy the fast response requirements of the isolation transformer in the textile applications. The conventional transformer for this application is unable to satisfy the fast dynamic response capability with embedded fault protection features. On the other hand, PET can significantly change the scenario of the energy management in textile and spinning mills applications.

Furthermore, PET can include smart communication facilities with the smart grid network and integrate the renewable energy in its configuration [17]. PV arrays can be installed in the spinning mills and this PV energy can be harvested in the industry applications to some degree during the peak hours of need and can reduce the cost of the overall electricity cost for the manufacturing. At present, the peak hour tariff for the industry is huge and contributes to the higher cost of manufacturing for the textile sector. The application of PET with integrated renewable energy facilities will allow the PET to utilize the PV energy in peak hours for reduced manufacturing cost. This facility will not only reduce the cost but also will improve the reliability and lessen the burden on the traditional energy sources from the large consumption of the electricity. It can be noted that the textile sector is a major consumer of electricity sector in South Asian countries e.g Bangladesh, India[18] and supporting this sector with renewable energy in an efficient and smart way using PET is an interesting and effective concept.

The introduction of Power Electronic Transformers (PETs) represents a major technological breakthrough in the energy sector of the textile industry. It is claimed that these transformers may equal, if not exceed, the efficiency levels of the traditional 50-Hz transformers. PETs have a profoundly revolutionary effect on renewable energy as well since they offer an effective means of incorporating sustainable power sources into the industry's power grid[15], [19]. Power quality increases as a direct result of PETs' capacity to support reactive power and their built-in fault isolation capabilities. This improvement is especially helpful for textile machines, which depends on a reliable and high-quality power source to run smoothly and continuously.

Beyond these noteworthy advancements, the textile industry may experience a radical change in power transfer techniques with the implementation of PETs. PETs represent an enormous advance towards economic and operational optimization by enabling a major downscaling of power systems' size and cost. Such innovation is especially important for developing countries, as the textile sector frequently makes up a sizable portion of the national economy. With the introduction of PET technology, nations like Bangladesh are poised for an industrial revolution since it provides a means of overcoming the developmental gap. Less developed countries may leap to the forefront of sustainability and energy efficiency by adopting these cutting-edge methods, which will spur economic growth and environmental stewardship.

The intelligent application of PET technology has the potential to cause a revolution in the power management of textile manufacturing. This is a socio-economic as well as technological transformation, since energy-efficient techniques support wider ecological goals while also making the business more competitive. Such a shift might have far-reaching consequences, putting countries in a position to advance quickly toward a time when industrial strength and environmental responsibility blend together to create a more wealthy and sustainable global community.

4 Proposed Methodology

The power architecture of the textile sector typically uses the traditional transformer, as shown in Figure 3. Electrical isolation, voltage transformation, and regulation are some of its primary duties. To provide extended capability in this standard setup, more devices must be included. These improved features include the use of renewable energy sources, efficient fault isolation, and regulation of reactive power flow. While these extra parts are functionally beneficial, adding them results in increased costs and a larger physical footprint for the power system. There may be significant negative effects on efficiency and utilization of space from this.

The solution that is being described seeks to address and minimize the inherent constraints that are present in a standard 50-Hz transformer system. The argument suggests a paradigm change in favor of the PET configuration, which uses high-frequency isolated transformers to reduce the system's overall size. In addition to allowing for a more compact construction, the high-frequency approach achieves a functional decoupling between the transformer's input and output sides. A high-frequency transformer core is used to complete the decoupling process. Improved fault isolation capabilities, rapid response to transient events, and a notable improvement in power quality are just a few advantages of this strategy.

The adoption of Power Electronic Transformers (PETs) in the textile industry marks a significant departure from traditional power system architectures, revolutionizing the way power is managed and distributed. PETs make auxiliary devices like STATCOMs redundant by integrating their functionalities into a single, more efficient unit. This not only streamlines the power system by eliminating unnecessary complexity but also leads to cost savings and more efficient use of space. The multifaceted nature of PETs proves especially beneficial in advanced power management, significantly reducing the need for extensive componentry previously essential for managing power flows and quality. As a result, the power system becomes more robust, responsive, and adaptable to the dynamic demands of modern manufacturing. Beyond technical improvements, the shift to PETs signals a new era in industrial power management, aligning with the current needs for efficiency and environmental sustainability. PETs act as a catalyst for change, driving the textile industry towards an innovative and sustainable future. This transformative approach is expected to have far-reaching impacts, fostering an operational paradigm that emphasizes reduced environmental impact, increased productivity, and cost-effectiveness, and could set a precedent for global industrial practices focused on sustainable growth and resource conservation.

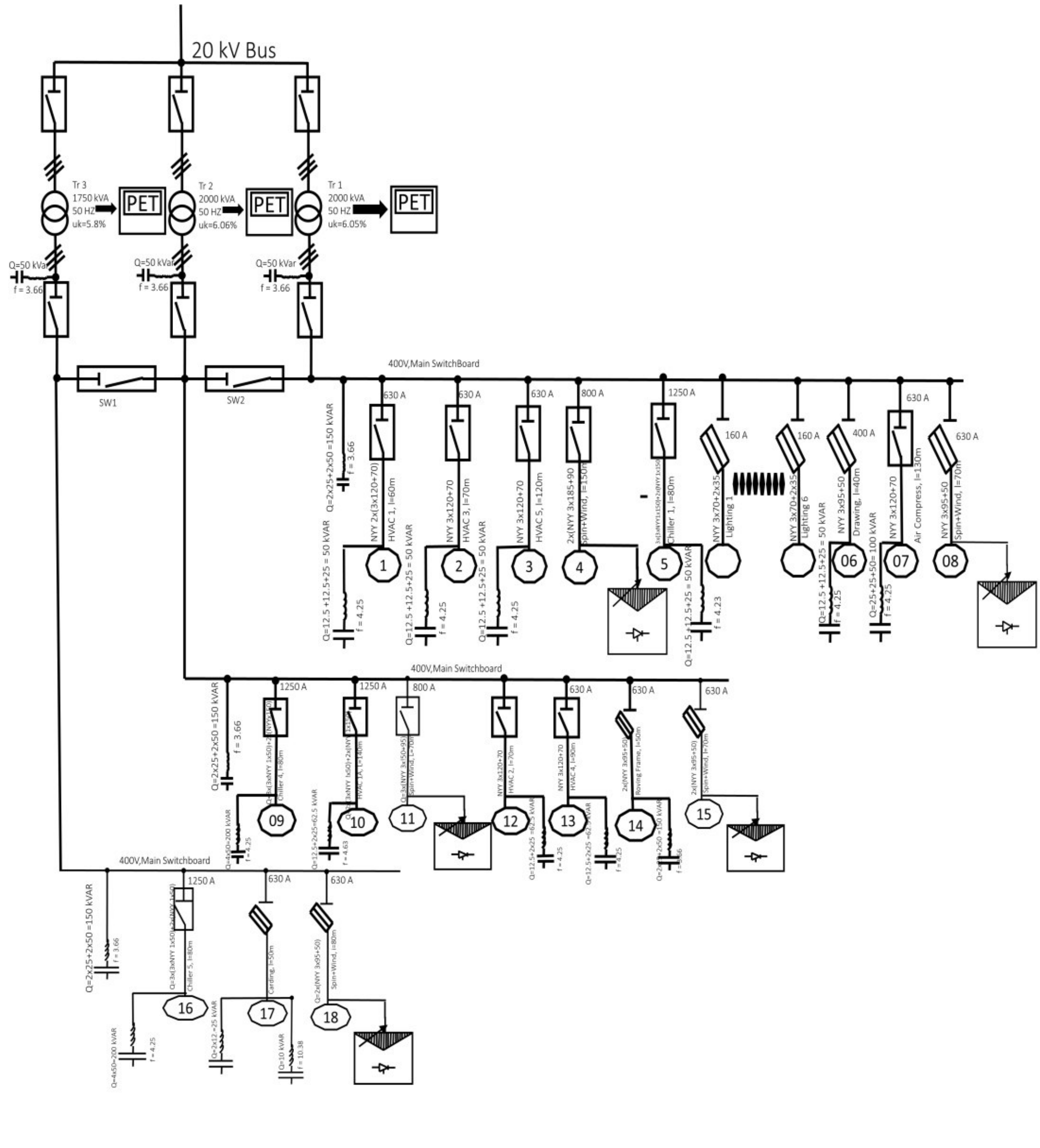

Figure 4: Simplified block diagram showing PET in Textile Machineries application.

Conclusion

The introduction of power electronic transformers (PETs) into the textile sector is an encouraging step toward the development of power management solutions that are both more sophisticated and more efficient. These cutting-edge transformers stand out from the crowd because of their capability to provide intelligent protection systems, significantly reduced physical dimensions, and a discernible improvement in the quality of power delivered to delicate textile gear. However, the road to their widespread adoption is paved with a number of significant barriers that must be overcome. When compared to typical transformers, the upfront expenses associated with PETs are much greater. This presents a financial obstacle that may be enough to dissuade many organizations from adopting PETs, particularly those that operate in industries that are extremely cost-conscious.

Furthermore, power electronic transformers (PET) is a relatively new technology that has not yet been thoroughly tested and adopted by the business community as a whole. Due to the early stages of the technology, there are worries over its reliability and performance over the long run. The complexity that is inherent to PET systems also needs a greater degree of technical competence for operation and maintenance. This necessitates considerable training and has the potential to lead to resistance from workers who are accustomed to traditional systems.

It's possible that integrating PETs into current infrastructures may require significant adjustments, which will drive up costs even further and make the changeover process more difficult. In addition to the practical difficulties, the industry must also deal with the lack of comprehensive standards and regulatory guidelines that are specific to PET technology. These are crucial for assuring safety, compatibility, and uniformity in deployment, but they are not currently in place.

In spite of these obstacles, there is still optimism regarding the use of PETs in the textile sector. In order to overcome these challenges, an integrated approach that includes participation from manufacturers, industry experts, and regulatory agencies is required. Putting money into research and development is absolutely necessary in order to improve technologies and bring down prices. The value of pilot programs that illustrate the use of PETs in operational settings cannot be overstated when it comes to displaying the benefits of these technologies and boosting confidence among potential adopters. The development of definite standards and regulations will be the foundation for the industry's continued progress toward a more secure and efficient integration of PETs as time goes on. PETs have the potential to revolutionize energy management in the textile manufacturing industry if these coordinated efforts are made. This would bring in a new era of efficiency and creativity in the industry.

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