SST Development for Next Generation Power Grid Application

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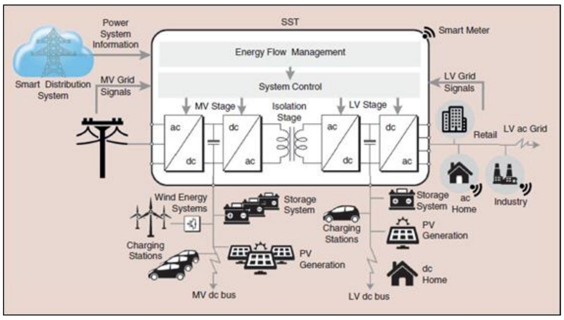
I. Research Background and Objectives

Developed countries are all facing increasing electricity consumption and the carbon emissions reduction issue, so the development and construction of renewable energy have been invested. However, most of the power generation of renewable energy is relatively unstable. In order to meet the high proportion of renewable energy and ensure the safety and reliability of power supply, modern power grids must have the ability of real-time adjustment and be able to monitor the load status at all times. With modern power grids, we can facilitate more intelligent control and operation. In addition, the power system's information technology and industrial automation technology have been adopted, making full use of information and communication technology to integrate power electronics technology to conduct the modernization and optimization of power infrastructure. Ultimately, the goal of reducing energy consumption and improving power quality can be achieved.

Solid-state transformers are one of the indispensable power infrastructures for the realization of smart grids. They can accomplish tasks that traditional transformers cannot handle and accelerate the development of grid resilience and intelligence. The solid-state transformers are based on the power electronics technology. The circuit architecture is composed of three-stage switching power converters, including AC/DC converters, DC/DC converters, and DC/AC converters. Therefore, the solid-state transformers can integrate AC or DC power systems and be directly connected to the grid or distributed energy sources and various loads. The input side of the solid-state transformer can easily realize the control of power factor correction and effectively reduce the harmonics of the grid and the supply burden of the power plant, while the output side can withstand the nonlinear load changes without changing the good characteristics of the input side. Meanwhile, energy storage batteries can be added to the DC terminal of the solid-state transformers to improve the stability of the power supply of the solid-state transformers. Furthermore, with the control and communication functions brought by the application of information and communication technology, it will be possible to make the solid-state transformer a more intelligent device and can effectively improve the power quality of the power grid in the context of a high proportion of renewable energy.



（Source：FELIPE RUIZ ALLENDE, MARCELO A. PEREZ, JOSE R. ESPINOZA,TOMASZ GAJOWIK, SEBASTIAN STYNSKI, and MARIUSZ MALINOWSKI, “Surveying Solid-State Transformer Structures and Controls Providing Highly Efficient and Controllable Power Flow in Distribution Grids”, 56 IEEE INDUSTRIAL ELECTRONICS MAGAZINE MARCH 2020.）

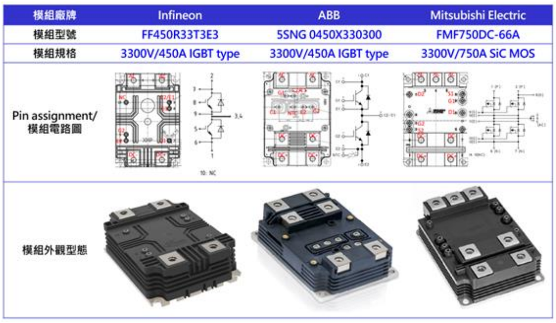
Fig. 1 Operation diagram of solid-state transformer (SST)

The solid-state transformers can achieve tasks that traditional transformers struggle with, such as managing highly variable bidirectional currents between microgrids and main grids, modularization for easy transport and installation, and lighter weight than equivalent traditional transformers (half of the weight of the transitional transformer). Moreover, the use of the solid-state transformer can effectively improve the power quality and energy conversion efficiency and reduce system volume, which is a key system for improving the conversion efficiency of renewable energy,as shown in Fig. 1.

International cases of the solid-state transformer technology applied to distributed power sources, microgrids, energy storage, and electric vehicles have gradually emerged. In the US and Japan markets, solid-state transformers are used as a key equipment for electric vehicle charging infrastructure. In Europe, the US, and Singapore, solid-state transformer technology has been included in the national future development technology strategy projects, which is a development trend worthy of domestic attention. On the other hand, introducing silicon carbide (SiC) components into the development of solid-state transformers is superior to silicon-based components in terms of electric field strength, energy gap, electron saturation drift velocity, carrier mobility, thermal conductivity, and melting point. The operating temperature using SiC is superior to using GaN, so the solid-state transformers using SiC can operate under higher temperatures, faster switching speeds, and lower energy loss and possess the advantages of improving system power density and reducing weight.

II. Research content：

1. **1.** Discussing and organizing the trend of domestic and foreign technical regulations and standards of the solid-state transformers, power grid applications, and benefits. Analyzing the materials of the power semiconductor components used as switching components in the solid-state transformers, including operating voltage, switching frequency, temperature characteristics, conversion efficiency, manufacturing costs, and component reliability comparison. Collecting the scientific research plans and policy objectives of major countries or regions so as to provide references for the future applications of the solid-state transformers in the distribution networks. Organizing the relevant standards listed in the solid-state technology roadmap report of the US Department of Energy (DOE) and adding descriptions and notes to make the relationship between each standard and solid-state transformers clearer. Sorting out the application cases of foreign energy storage systems in actual power distribution systems. For example, Shell, a company in the Netherlands, used solid-state transformers to assist hydrogen production in 2021. CRG, a company in the US, was entrusted by the DOE in 2022 to develop a digital twin technology of the solid-state transformers suitable for power grid applications. Many companies in developed countries such as the US and Japan also applied solid-state transformers to electric vehicle charging infrastructure. Comparing the physical characteristics of different power device semiconductor materials, including silicon carbide (SiC), gallium nitride (GaN), and silicon (Si). The analysis includes operating voltage, switching frequency, temperature characteristics, conversion efficiency, manufacturing costs, and component reliability. Finally, the most suitable power semiconductor component materials for SST. Fig. 2 shows the 3.3kV power modules from major international manufacturers.



模組廠牌	Infineon	ABB	Mitsubishi Electric
模組型號	FF450R33T3E3	5SNG 0450X330300	FMF750DC-66A
模組規格	3300V/450A IGBT type	3300V/450A IGBT type	3300V/750A SiC MOS
Pin assignment/ 模組電路圖			
模組外觀型態			

（Source：drawing by authors）

Fig. 2 3.3kV power semiconductor modules from major international manufacturers

2. Silicon carbide solid-state transformer design and development technology includes simulation verification analysis for the system specification of distribution voltage level 22.8kV, output voltage 380V three-phase AC. Meanwhile, a solid-state transformer using silicon carbide semiconductors is developed. The system specification of the three-stage solid-state transformer is that the rated capacity: ≥5kVA; the rated input voltage: ≥1kV; the switching frequency of the dc/dc converter: ≥100kHz; power conversion efficiency: ≥90%. At the same time, the high-power silicon carbide modules applied to SST with input voltage ≥1kV are used for electric performance, heat transfer, and reliability design. Figs 3-5 show the AC/DC converter, DC/DC converter, and DC/AC inverter used for the solid-state transformer.

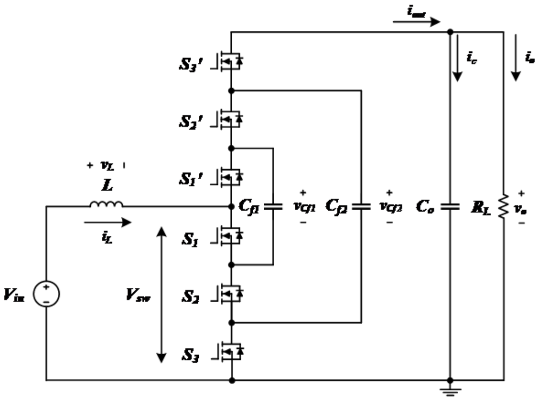


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Fig. 3 Flying capacitor multilevel converter

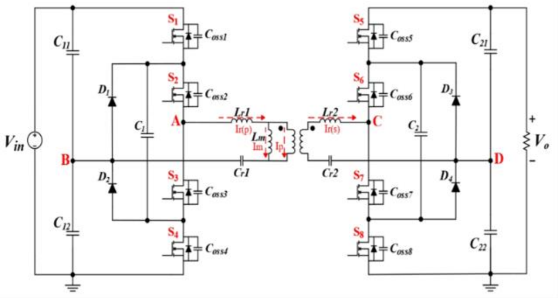

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Fig. 4 Multilevel CLLC resonant converter

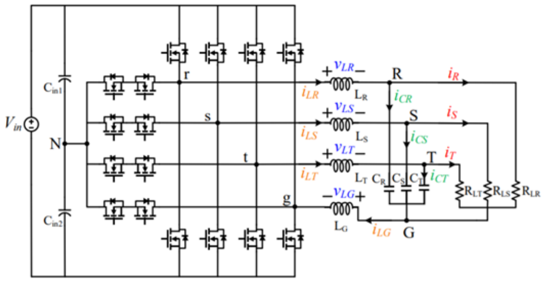

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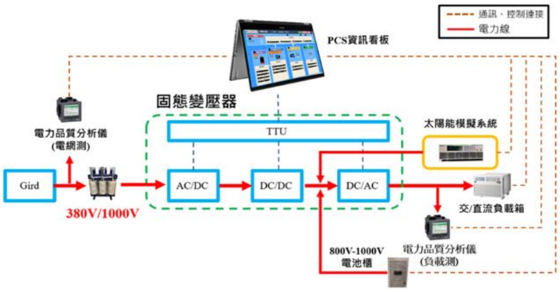
Fig. 5 Three-phase four-leg DC/AC inverter

3. Building a small-scale demonstration system to demonstrate the energy management system, solid-state transformer, energy storage, and AC/DC loads in the context of distributed power generation including mains power and solar power as shown in Fig. 6. Fig. 7 shows the power conditioning system (PCS) information page, which can display the information of the solid-state transformer.



（Source：drawing by authors）

Fig. 6 System hardware architecture diagram

（Source：drawing by authors）

Fig. 7 PCS information page

III. Conclusion

Currently, most of the SST products use Si IGBT components, and the application of SiC components is still in development. However, there is no research of solid-state transformer domestically. In order to accelerate SST technology development, in this project, SiC components are used to build a small scale energy management system, including SST, energy storage, power quality control and information and communication technology in the context of distributed power generation. It is expected that the distribution-level SST can be developed in the future, and can be verified in the microgrid in Taipower to effectively expand the use of distributed energy and renewable energy in the future. At the same time, developing SST technology in a microgrid can accelerate the development of domestic smart grid technology, and achieve the goal of low-carbon environments.