ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) https://doi.org/10.17559/TV-20240502001515
Subject review

Historical Development and Recent Advances in FACTS Technology for Transient Stability in Power Systems

Filip RELIĆ*, Hrvoje GLAVAŠ, Ivica PETROVIĆ, Marinko STOJKOV

Abstract: This paper investigates the advances in Flexible AC Transmission System (FACTS) technology and its application in enhancing transient stability in power systems. FACTS devices are becoming increasingly popular due to their ability to improve power system performance by controlling power flow, voltage, and stability. Various FACTS technologies are reviewed, including Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Static Synchronous Series Compensator (SSSC), among others. The impact of these technologies on power system stability is examined and a comprehensive analysis of their effectiveness in mitigating transient stability issues is provided. Recommendations for future research in the field of FACTS technology for improving the reliability and stability of power systems are given in the conclusion.

Keywords: FACTS; SSSC; STATCOM; SV; transient stability

1 INTRODUCTION

Integrating renewable energy sources into the electrical grid is one of the challenges that arise from the world's transition to cleaner and more sustainable energy sources. As more wind and solar power are used as renewable energy sources (RES), the electrical grid will face significant challenges regarding system stability. Renewable energy is different from traditional power sources because it can be intermittent and variable, so the grid must be able to handle sudden changes in supply of electricity. Furthermore, the inertia of power systems additionally decreases as more and more converter-interfaced generation (CIG) units are connected to the power system [1]. The intermittent nature of RES requires a re-evaluation of grid control strategies and methods, as current traditional communication and control strategies are better suited to handle traditional power systems. Optimal integration of RES requires the grid to be flexible and that it can adapt to fast changes in electricity generation. In a system with reduced inertia, after a disturbance, larger rotor angle instability occurs that requires a greater restoring force to return the system to equilibrium. Managing this could strain synchronous generators in the system, potentially resulting in significant instability issues. Renewable energy sources are often located far away from load centers, which places additional stability strain on the power system. Modern electrical grids are going to have to maintain stability and reliability despite displaced centers of electricity production and supply fluctuations. As penetration of distributed generation in the power system increases, these challenges are going to become more prominent. Large renewable energy like photovoltaic (PV) systems located in remote areas may overload the transmission system that connects them to load centers [2]. As PV installation in the transmission grid becomes more frequent, additional research is done in field of general performance analysis with high-penetration PV systems [3], and further regarding transient stability [4, 5]. Researchers in [3] observed that system inertia and frequency regulation is reduced as conventional generation is replaced by PV. It was shown in [4] that large-scale PV systems, that increase PV penetration levels from 20% to 50%, while replacing conventional synchronous machines, have decreased voltage stability. The study in [5] investigated dynamic performance of the system with a varying level of PV penetration, namely small-signal stability, voltage stability, and time-domain contingency assessments. Eigenvalue analysis revealed that PV systems had a negligible impact on overall small-signal stability of the system. Conversely, voltage stability and transient stability analysis indicated that a distributed approach could enhance system stability compared to centralized PV farms. A simulation of a test system with high penetration of PV for transient stability analysis was done in [6] and the low-voltage ride-through (LVRT) characteristics are examined. It was shown that high penetration of PV lowers transient stability under a large disturbance. Tripping of low voltage protection designed to safeguard PV inverters, during a voltage sag in the system, can potentially lead to a cascading fault since disconnecting PV systems during a fault can exacerbate the drop in system voltage. There is a need for additional research to identify optimal LVRT characteristic for PV systems and develop control schemes that enhance system stability under large disturbances. Additional analysis [7] for dynamic behaviour of synchronous generations with high penetration of PV was done by numerical simulation. Research in the field leads to the conclusion that high penetration of renewable sources will need a solution regarding system stability [2]. Fast control of system parameters like node voltage and phase angle, line reactance/current and shunt impedance can increase system flexibility [8]. Fast development of power electronics [9, 10] and extensive research in the field of Flexible AC transmission systems (FACTS) give an option for increased controllability of system parameters [11, 12].

2 POWER SYSTEM STABILITY

Power system stability is defined as the ability of the power system to maintain synchronism and equilibrium under normal operating conditions and to remain in equilibrium after a disturbance [13]. In [13], power system stability was classified into three broad categories rotor angle stability, voltage stability and frequency stability, Fig. 1.

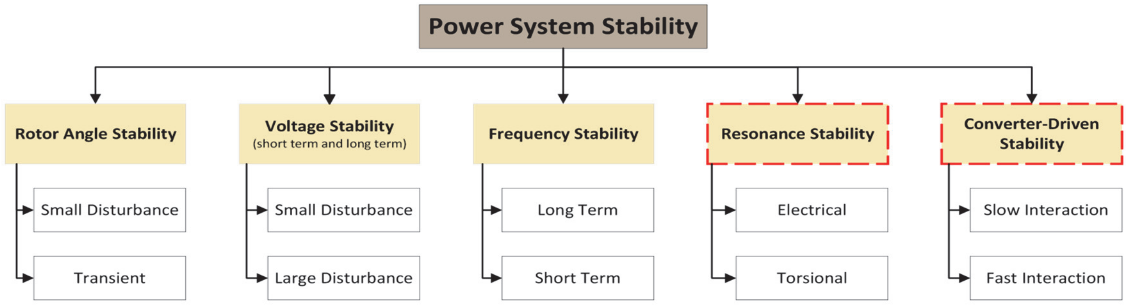

Figure 1 Power system stability classification

Rotor angle stability refers to the ability of a synchronous machine to remain in synchronism after a disturbance. This stability relies on the system's capability to sustain equilibrium between the electromagnetic and mechanical torques of each synchronous machine. Instability that may develop is manifested as escalating angular swings in certain generators, potentially causing them to lose synchronization with other generators in the system. Voltage stability refers to the ability of a system to maintain a predefined voltage range at all system buses after a disturbance. Voltage stability relies on the system's capability to sustain equilibrium between electricity supply and demand. Instability that may develop is manifested as a gradual decline or increase in voltages at certain buses. Voltage instability could potentially lead to consequences such as load shedding in a specific area, or the activation of protective systems causing the tripping of transmission lines and other components, ultimately resulting in cascading outages [14]. These two broad categories can be additionally divided into four subcategories based on the physical process and time frame. Time frame refers to transient and long-term effects. When a disturbance happens, it can cause two types of effects: transient and long-term. Transient effects are fast and severe, and they happen right after a large disturbance. Long-term effects are slow and moderate, and they happen over time after a small or gradual disturbance. Physical processes refer to rotor or voltage dynamics. Rotor dynamics is concerned with electromechanical oscillations of a machine due to torque-angle variations, while voltage dynamics is concerned with voltage variations due to reactive power changes. Lastly, frequency stability refers to the ability of a power system to maintain a steady operational frequency value following a large disturbance that causes a substantial imbalance between power generation and load. This imbalance, if not resolved quickly, can lead to frequency swings that can result in tripping of generators or loads.

Power system stability definitions and classifications had to be updated because of recent developments in CIG technologies that are becoming more prevalent in electrical power systems [15]. CIG devices have a fast response to changes in system parameters, which is the reason that systems dynamics is affected in new ways compared to traditional power generation technologies. Designing grid-connected power converters used by CIG requires ensuring proper operation under various grid voltage conditions. This involves designing control algorithms that guarantee robust and safe performance, especially in abnormal grid conditions. Resonant controllers on the stationary reference frame present an effective alternative to current controllers based on the double synchronous reference frame, particularly for regulating currents during unbalanced and distorted grid conditions. Additionally, alternative solutions like hysteresis current controllers, direct power control methods, and model-based predictive control can be employed for grid-connected power converters, with hysteresis-based approaches standing out for their robustness and quick dynamic response [16]. Due to their increased use, two new stability categories were introduced in [15].

Converter-driven stability was defined because CIG is usually interfaced with the grid by a voltage source converter (VSC) and it is expected that in the near future, more than 50% of the generated power may be converter-interfaced [17]. CIG relies on control loops with rapid response times, including the Phase-Locked Loop (PLL) and inner-current control loop. Consequently, the extensive timescale associated with CIG controls can lead to interactions with both the electromechanical dynamics of machines and the electromagnetic transients of the power system. This interaction may give rise to unstable power system oscillations across a broad frequency range, posing a novel challenge for system operators. Converter-driven stability can be divided into slow-interaction and fast-interaction stability, depending on the frequency of the phenomena in question.

Resonance stability refers to sub-synchronous resonance (SSR) and can be divided into torsional resonance and electrical resonance. Resonance happens when oscillations of energy between two points increase due to insufficient energy dissipation, which in turn causes an increase in system parameters like voltage, current or torque. SSR was first defined in [18], as a condition where the power system exchanges significant energy with a turbine-generator at a frequency below synchronous frequency (50 Hz or 60 Hz). Research on SSR began in the 1930s because a series-compensated line caused a turbine-generator shaft failure because of neglected torsional oscillations [19].

3 FACTS TECHNOLOGY

FACTS devices are a class of power electronic devices used to regulate system parameters such as voltage, frequency and phase angle in electrical power systems

[20], improving the stability and reliability of the grid. Power electronics refers to the processing of electrical power with electronic devices, such as insulated-gate bipolar transistors (IGBT), gate turn-off (GTO) thyristors and integrated gate-commutated thyristor (IGCT) [21]. Typically, FACTS devices are installed in high-voltage electrical power systems to address power quality issues or alleviate congestion in areas of the transmission network [22, 23]. Integrating RES into existing power grids presents several technical challenges. The variability of power generation introduces uncertainties and potential risks to system reliability. Additionally, insufficient transmission capacity hinders the delivery of large amounts of power generated by RES from remote areas to load centers. While constructing new transmission lines is an obvious solution to enhance capacity, these projects are often lengthy and expensive due to long construction times and stringent environmental approvals as they require significant land areas. To address some of these challenges, FACTS devices are designed to regulate power flow over long distances, as RES are frequently positioned far from load centers. Controllability of system parameters inherently allows for higher integration of RES in the grid [24]. This can be particularly important when load centers are geographically far away from RES, as these systems can have significant line losses and stability issues. The feasibility of using FACTS depends on several technical, environmental and financial factors. All three must be carefully considered before deciding to implement them in a power system. FACTS devices are usually installed to optimize existing transmission system assets (instead of installing costly and environmentally problematic transmission lines). Papers [25, 26] have shown that installing them in off-shore wind farms can enhance power quality and improve terminal voltage and power fluctuations. It is worth noting that in [27] a proof of concept showed that an uncontrolled rectifier can be used in an off-shore wind farm with a high voltage DC (HVDC) link as a cost-saving measure, which could eliminate the need for off-shore FACTS controllers. As the complexity of the power system increases, coordination between multiple controllers is going to become a key issue for transmission system operators. Optimal reclosing and SVC coordination improves transient stability in multi-machine power systems under various fault conditions compared to conventional reclosing and SVC methods [28, 29].

FACTS devices can be categorized into four categories based on type of connection and two based on operating principle. FACTS devices can have a series, shunt, series-series and series-shunt connection to the power system [30], as seen in Fig. 2. Thyristor-controlled FACTS devices and VSC-based FACTS devices are both used to enhance the controllability and efficiency of transmission systems, but they differ in their underlying technologies and characteristics. VSC-based FACTS devices may use other types of semiconductor switching devices such as gate turn-off thyristors or gate commutated thyristors, but IGBTs provide several advantages. Thyristors are typically slower in response compared to IGBTs, which makes the control capability of thyristor-based FACTS devices limited to a certain extent. Based on research in [31], it was demonstrated that IGBT-based rectifiers operate at higher switching frequencies using Pulse Width Modulation (PWM), while thyristor-based rectifiers function at lower frequencies using the phase-shifting method. Simulation results demonstrated that implementing IGBT-based rectification systems results in fewer power quality issues and reduced losses, but reduced reliability and higher costs compared to thyristor-based systems. Furthermore, VSC-based FACTS devices: are more modular and scalable, allowing for easier expansion or modification of the system. In summary, the main difference is underlying technology, which is reflected in their control capabilities, dynamic performance, and modularity. Thyristor-controlled FACTS devices may have limitations in speed, but come ahead in cost, while VSC-based FACTS devices leverage better control capability and dynamic performance but for a higher cost and reduced reliability.

The most notable series-connected FACTS device is the Static Synchronous Series Compensator (SSSC), which directly injects variable voltage in quadrature with the current into the connected line. The most notable shunt-connected devices are the Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM). Both devices have seen wide installation in today's power systems. The interline power flow controller (IPFC) [33] and the unified power flow controller (UPFC) [34] represent the series-series and series-shunt devices, respectively. Shunt-connected devices are better at reactive power compensation and voltage control [35-41], while series-connected devices are more suitable for active power flow control and increasing transient stability [42-44]. Furthermore, shunt-connected devices improve transmission capacity indirectly by providing local reactive power compensation, meaning that less reactive power has to be transferred by the grid. On the other hand, series-connected devices modify line reactance and directly improve transmission capacity [45, 46]. Series-connected devices were shown to help with reducing or postponing the need for new transmission lines, which have significant environmental and geographical constraints [47].

	Thyristor-controlled	VSC-based
Series	Thyristor-Controlled Series Compensator (TCSC) Thyristor-Controlled Voltage Limiter (TCVL)	Static Synchronous Series Compensator (SSSC) Interphase Power Controller (IPC) **Series-series:** Interline Power Flow Controller (IPFC)
Shunt	Thyristor-Switched Capacitor (TSC) Thyristor-Controlled Reactor (TCR) Thyristor-Controlled Breaking Resistor (TCBR)	**Series-shunt:** Unified Power Flow Controller (UPFC) Static Synchronous Compensator (STATCOM)

Figure 2 FACTS classification with examples [32]

Based on operating principle, FACTS devices can be categorized into thyristor-controlled and VSC-based FACTS devices. Thyristor-controlled devices like the SVC operate as a controlled reactive admittance, while VSC-based devices like the STATCOM operate as a synchronous voltage source [48].

3.1 Historical Development and First Applications

One of the first FACTS devices installed was an SVC, which was first demonstrated in 1974 and 1975 by General Electric and Westinghouse, respectively [20]. The SVC provides dynamic shunt compensation by adjusting the firing angle of a thyristor circuit that controls the total reactance a reactor or capacitor bank provides into the grid. Today, the majority of installed static var compensation is by ABB [49, 50]. According to the data presented in Fig. 3, the installation of FACTS devices experiences a steady increase, reflecting the growing energy demand [51]. Furthermore, it can be concluded from steeper rise in installed power in recent years in Fig. 3 that more transmission-level FACTS projects are being developed. As transmission system operators gain more experience with these technologies, less resistance to their implementation is expected. It is further expected that with the growth of renewable sources in the power system, the installation of FACTS technology will follow an upward trend. The increasing complexity of the power system necessitates a demand for more precise and improved controllability. A pioneering paper on reactive power compensation with thyristor-controlled capacitors [52] paved the way for further research in the following decade [53-56].

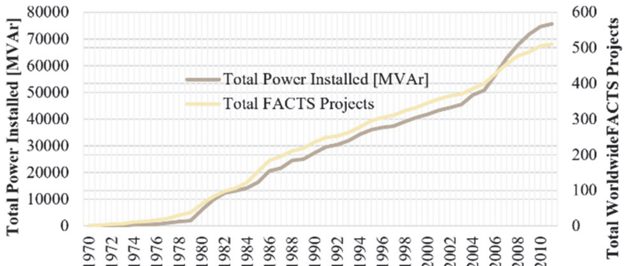

Figure 3 Historical installation of SVC and STATCOM devices [76]

Furthermore, Fig. 4 shows that the North American region has had the most experience with FACTS technology, which is supported by the fact that the US and Canada's large geographical area warrants significant investment in grid stability [57]. Examining the percentage values depicted in Fig. 4, it is evident that the North American region exhibits a substantial level of familiarity and engagement FACTS technology.

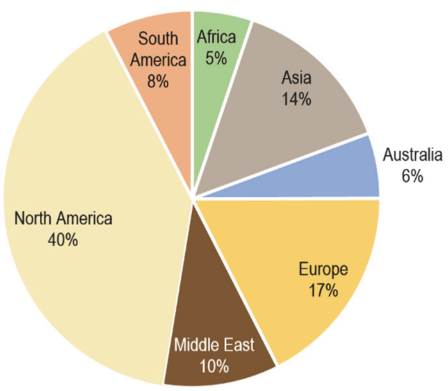

Figure 4 Historical installation of SVC and STATCOM devices [76].

The geographical distribution illustrated in Fig. 5 includes data from an additional manufacturer of FACTS technology (besides ABB, which was provided to the authors directly), providing a more accurate representation of the distribution. However, a comprehensive understanding of this scenario necessitates consideration of additional factors, specifically, the overall electricity consumption within the region. To address this limitation and offer a more nuanced perspective, we propose the introduction of a novel metric: the FACTS Penetration Index (FPI).

This index, when appropriately scaled for the total electricity consumption of a region [58], aims to provide a more accurate reflection of the actual impact and integration of FACTS devices within the regional power infrastructure. By factoring in the corresponding electricity consumption, the FACTS Penetration Index strives to offer a more refined evaluation of the influence of FACTS technology across diverse regions. This nuanced approach is essential for researchers and policymakers seeking a comprehensive understanding of the intricacies associated with the implementation and success of FACTS devices in different geographical contexts.

FPI can be formulated by considering the ratio of the installed FACTS capacity to the total electricity consumption within a given region. The formula for FACTS Penetration Index can be expressed as (1):

$$\text{FPI}=\frac{\text{Installed FACT Scapacity}}{\text{Total Energy Consumption}} \tag{1}$$

Fig. 6 shows total installed capacity by region and with provided FPI for each region. The Australian region is allocating substantial investments to FACTS technology, driven in part by the growing integration of renewable energy sources [59].

STATCOM is a second-generation FACTS device that showed promising control of reactive power, albeit for a steeper price [60]. First installed in 1980 by Kansai Electric Power Co. as a prototype, it showed sufficient protection against system faults which merited a plan for further commercial application [61]. 1991 saw the first commercial use of STATCOM in Japan's Inuyama station with the reactive power output of ±80 MVAr [62]. SVC and STATCOM were initially created to enhance the power quality in electric power systems that use electric arc furnaces (EAF), as these furnaces produce random and substantial fluctuations in both real and reactive power, which can result in voltage drops and significant voltage variations in brief time intervals [63]. The SSSC was first simulated and installed in Spanish transmission grid in 2015 in order to control power flow and reduce line loading caused by high penetration of RES [64-66]. The third generation of FACTS, known as the Unified Power Flow Controller (UPFC), is created by integrating the STATCOM and the SSSC into a single system that uses a common control system. The UPFC has a distinctive capability to control the flow of real and reactive power independently. In 1998, American Electric Power's Inez substation was selected as the site for the first utility demonstration of a UPFC [67]. By 2018, 6 UPFC have been installed worldwide, 2 of which have been decommissioned [68]. Research on improvement of UPFC is still ongoing to provide similar system parameter controllability and reliability, but at a reduced cost [69]. Although UPFC offers technical benefits over SVC, STATCOM and SSSC, its cost poses a challenge for numerous transmission system operators when it comes to installation. In the following chapters, a concise summary will be provided of the technologies currently in use and familiar to transmission system operators.

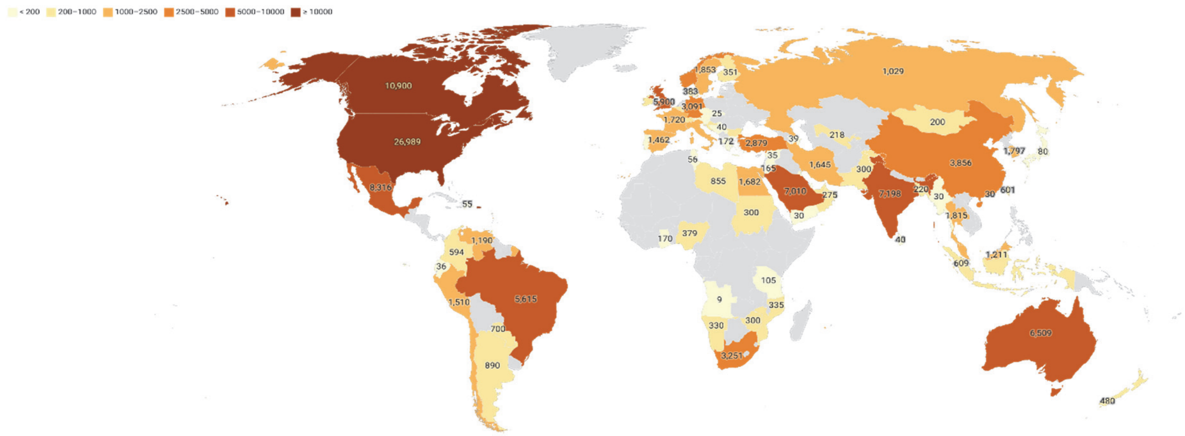

Figure 5 FACTS installation by country from 1970s to 2023, expressed in MVAr

3.2 Static VAR Compensators (SVC)

SVC is composed of a thyristor-controlled or a thyristor-switched reactor (TCR/TSR), a thyristor-switched capacitor (TSC) and filters. The TCR generates harmonics, which is why filters are needed [8]. The primary advantage of using SVCs to enhance transient stability is the quick and precise control they provide over bus voltage by changing the equivalent susceptance of TCR, which is a function of the thyristor trigger angle. This control can be especially useful during low-voltage situations that often arise during faults, as it can improve power transfer and prevent local generators from accelerating too much [70]. At present, the most commonly employed technology for minimizing the adverse impacts of EAF on the power system is SVC [71].

3.3 Static Synchronous Compensators (STATCOM)

STATCOM's operating principle is based on producing a controlled internal voltage. The internal voltage uses grid voltage as a reference and adjusts its amplitude, while maintaining a phase angle of $\pm\pi/2$. Amplitude higher or lower than grid amplitude makes the STATCOM behave as a source or sink of reactive power, respectively [72]. STATCOM is more effective than SVC in improving transient stability of wind farms because it has a faster response time and can provide the needed reactive power during a fault [73-75], but at a higher cost. An additional advantage of STATCOM over SVC is that it does not generate higher-order harmonics. According to data provided by ABB [76] regarding global STATCOM installation, the primary reason for more than 70% of installed devices was because of flicker mitigation. The increased penetration of renewables in recent years has led to a greater use of STATCOMs for enhancing grid stability [77-79].

3.4 Static Synchronous Series Compensators (SSSC)

The SSSC, a device based on a voltage source converter like the STATCOM, is connected in series with a transmission line. Its main functions are to regulate voltage, provide reactive power support, and reduce power system oscillations by injecting or absorbing reactive power. Additionally, the SSSC can adjust the impedance of the line, thus enabling control of power flow and reducing the possibility of congestion. The SSSC is recognized for its capability to quickly respond to changes in system parameters and offer damping support during transients. It can function alone or work in tandem with other FACTS devices to achieve more extensive power system control [43-80]. Further success in improving transient stability was shown in [81]. The effectiveness of SSSC and STATCOM in improving power system stability differs based on the specific scenario. In terms of improving the first swing stability limit, STATCOM is more effective than SSSC. However, when it comes to improving damping in subsequent swings, SSSC is found to be more effective [82]. In [83], different aspects of research on SSSC are shown.

4 RECENT DEVELOPMENTS AND FUTURE DIRECTIONS IN FACTS TECHNOLOGY

Initially, SVCs were used mainly for addressing flicker issues in electric arc furnaces, but their usage is now expanding within utilities due to growing concerns over system stability caused by the reduced system inertia resulting from the higher integration of renewable energy sources [84-85]. Research in [86] conducted a cost-benefit analysis on SVCs in relation to dynamic economic dispatch. By incorporating stability concerns into the calculations, extended analysis could provide further insight into the viability of installing SVCs, which is a factor that often dissuades system operators from considering their use. Advanced models are being researched to represent real systems more accurately in the context of SVC modelling for transient analysis [87, 88]. Furthermore, the control system is being improved in ongoing research aimed at enhancing the low voltage ride through (LVRT) capability of wind farms through the use of SVC [89-91]. The location and size of SVC has been a persistent challenge since its initial installation. However, it has been demonstrated that cost-effectiveness in terms of transient stability necessitates additional research [92-95].

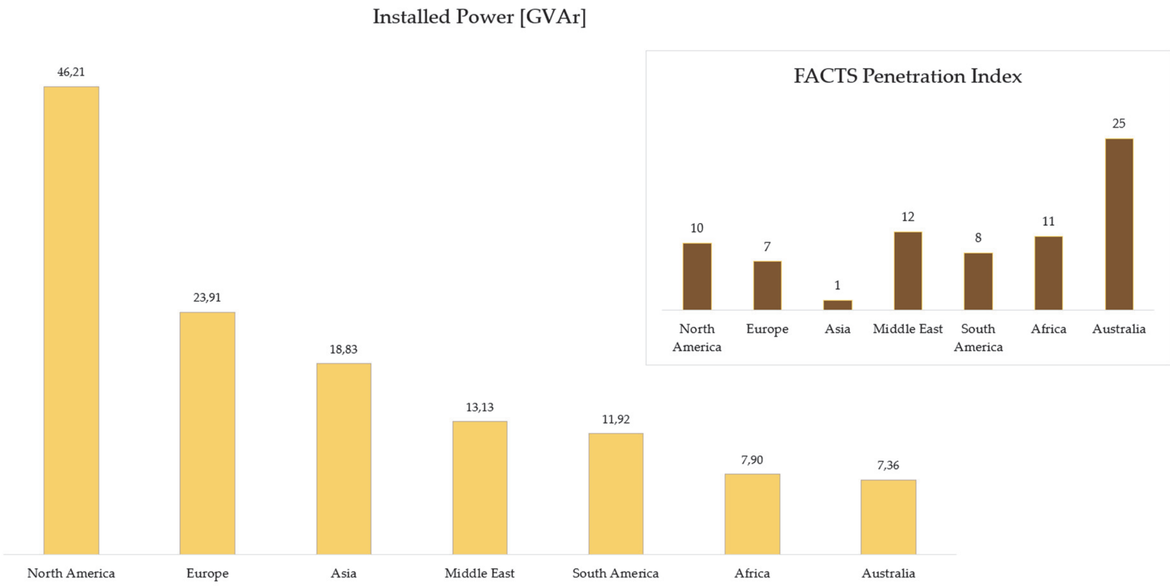

Figure 6 FACTS installation by region, compared to regional FPI.

Novel approaches to STATCOM control are being explored that incorporate considerations for transient behaviour [96, 97], and there is ongoing progress in refining control strategies that utilize neural networks [98]. Due to the decreasing initial cost of battery energy storage systems (BESS), there is an increasing consideration for using more STATCOMs with BESS to manage power system transients [99]. Although BESS has demonstrated superior post-fault voltage restoration performance compared to STATCOM individually [100-102], a hybrid solution combining both devices has been shown to yield even greater benefits for transient response [103-108]. In recent years, there has been growing consideration and testing of PV inverters as a means of supporting transient stability, driven by increasingly stringent grid codes and the desire to maximize the potential of already installed PV systems [109-113].

The current focus of SSSC research is on developing novel control algorithms aimed at enhancing transient stability [114-116]. Additionally, modular implementation is being explored and field tested as a means of overcoming the challenges that have traditionally hindered the widespread adoption of conventional FACTS devices [117-119].

5 CONCLUSIONS

SVCs are mainly used for reactive power compensation and voltage control, while SSSCs are primarily used for active power flow control and improving transient stability. STATCOMs, on the other hand, offer a balance of both reactive and active power control capabilities, making them suitable for a wider range of applications. While SVCs are a more mature and cost-effective technology, STATCOMs and SSSCs offer faster response times and improved performance, making them a preferred choice for modern power systems with high penetration of renewable energy sources. Although there are many benefits to using FACTS devices, not all are easily quantifiable. Furthermore, the cost of these devices is quite significant and must be weighed against their expected advantages. One of the reasons for the limited adoption of FACTS devices is the lack of evidence of their profitability as many factors must be taken into account to accurately predict installation profitability. It is also challenging to obtain information regarding the total capital needed for the installation and operation of FACTS devices. FACTS devices can prevent potential system failures, which could have severe consequences for other economic sectors. They can also help prevent widespread blackouts, and the opportunity cost of not using them in such situations must be considered. The high cost and potential losses, as well as issues such as appropriate sizing and settings, location, and availability, are major considerations in deploying FACTS controllers. Despite the long history of development, proven technology, and extensive benefits, FACTS controllers are still not widely used due to their higher perceived costs compared to conventional alternatives. It can be concluded that future research in the field of FACTS technology must focus on improving transient stability and cost-effectiveness through advanced control strategies and integration with renewable energy sources, thereby optimizing the utilization of pre-existing installed devices. Standardized cost-effectiveness metrics can be developed to evaluate different FACTS technologies based on objective and consistent criteria, enabling accurate comparisons and informed decision-making regarding implementation in the power system.

6 REFERENCES

[1] Tielens, P. & Van Hertem, D. (2016). The relevance of inertia in power systems. *Renewable and Sustainable EnergyReviews, 55*, 999-1009. https://doi.org/10.1016/j.rser.2015.11.016

[2] Shah, R., Mithulananthan, N., Bansal, R. C., & Ramachandaramurthy, V. K. (2015). A review of key power system stability challenges for large-scale PV integration.

Renewable and Sustainable Energy Reviews, 41, 1423-1436. https://doi.org/10.1016/j.rser.2014.09.027

[3] Achilles, S., Schramm, S., & Bebic, J. (2008). *Transmission system performance analysis for high-penetration photovoltaics (No. NREL/SR-581-42300).* National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/924641

[4] Eftekharnejad, S., Vittal, V., Heydt, G. T., Keel, B., & Loehr, J. (2013). Impact of increased penetration of photovoltaic generation on power systems. *IEEE Transactions on Power Systems, 28*(2), 893-901. https://doi.org/10.1109/TPWRS.2012.2216294

[5] Tamimi, B., Cañizares, C., & Bhattacharya, K. (2013). System stability impact of large-scale and distributed solar photovoltaic generation: The case of Ontario, Canada. *IEEE Transactions on Sustainable Energy, 4*(3), 680-688. https://doi.org/10.1109/TSTE.2012.2235151

[6] Viet, N. H. & Yokoyama, A. (2010). Impact of fault ride-through characteristics of high-penetration photovoltaic generation on transient stability. *2010 International Conference on Power System Technology: Technological Innovations Making Power Grid Smarter, POWERCON2010*, 1-7. https://doi.org/10.1109/POWERCON.2010.5666558

[7] Yagami, M. & Tamura, J. (2012). Impact of high-penetration photovoltaic on synchronous generator stability. *Proceedings - 2012 20th International Conference on Electrical Machines, ICEM 2012*, 2092-2097. https://doi.org/10.1109/ICElMach.2012.6350171

[8] Padiyar, K. R. (2009). *FACTS: Controllers in Power Transmission and Distribution*. Anshan Publishers.

[9] Zeng, R., Chen, L., Xu, X., Liu, Q., Gao, X., Li, Z., & Wen, J. (2019). Integrated gate commutated thyristor-based modular multilevel converters: A promising solution for high-voltage dc applications. *IEEE Industrial Electronics Magazine, 13*(2), 4-16. https://doi.org/10.1109/MIE.2019.2906952

[10] Vobecky, J., Vobecky, J., Lazar, J., Simms, R., Kelley, A., Danzl, S., & Burkhart, B. (2021). Recent progress in silicon devices for ultra-high power applications. *2021 IEEE International Electron Devices Meeting (IEDM)*, 36.4.1-36.4.4. https://doi.org/10.1109/IEDM19574.2021.9720569

[11] Damor, K., Agrawal, V., Patel, D. M., & Patel, H. G. (2014). Improving power system transient stability by using FACTS devices. *International Journal of Engineering Research & Technology, 3*(7), 1-5.

[12] Sahu, P. R., Lenka, R. K., Khadanga, R. K., Hota, P. K., Panda, S., & Ustun, T. S. (2022). Power system stability improvement of FACTS controller and PSS design: A time-delay approach. *Sustainability (Switzerland), 14*(21), 14649. https://doi.org/10.3390/su142114649

[13] Andersson, C., Solem, J. E., & Eliasson, B. (2004). Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. *IEEE Transactions on Power Systems, 19*(3), 1387-1401. https://doi.org/10.1109/TPWRS.2004.825981.

[14] Provči, I., Stojkov, M., Marić, P. & Đuračić, I. (2023). A New Protection System Design of Active MV Distribution Network. *Tehnički vjesnik, 30*(1), 131-137. https://doi.org/10.17559/TV-20220509091610

[15] Hatziargyriou, N., Ajjarapu, V., Andersson, G., Antonova, A., Canizares, C., Hill, D. J., & Van Cutsem, T. (2021). Definition and classification of power system stability - Revisited & extended. *IEEE Transactions on Power Systems, 36*(4), 3271-3281. https://doi.org/10.1109/TPWRS.2020.3041774

[16] Teodorescu, R., Liserre, M., & Rodriguez, P. (2007). Control of grid converters under grid faults. *Grid Converters for Photovoltaic and Wind Power Systems*., 237-287. https://doi.org/10.1002/9780470667057.ch10.

[17] Kroposki, B., Johnson, B., Zhang, Y., Gevorgian, V., Denholm, P., Hodge, B., & Hannegan, B. (2017). Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy. *IEEE Power and Energy Magazine*, *15*(2), 61-73. https://doi.org/10.1109/mpe.2016.2637122

[18] Terms, Definitions and symbols for Subsynchronous Oscillations IEEE Subsynchronous Resonance Working Group of the System Dynamic Performance Subcommittee Power System Engineering Committee. (1985). *IEEE Power Engineering Review*, *PER-5*(6), 37. https://doi.org/10.1109/mper.1985.5526631

[19] Reader's guide to subsynchronous resonance. (1992). *IEEE Transactions on Power Systems*, *7*(1), 150-157. https://doi.org/10.1109/59.141698

[20] Hingorani, N. G. & Gyugyi, L. (2000). *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*. Wiley-IEEE Press.

[21] Erickson, R. W. & Maksimovic, D. (2001). *Fundamentals of Power Electronics*. Springer Science & Business Media. https://doi.org/10.1007/b100747

[22] Nguyen, T. T. & Mohammadi, F. (2020). Optimal placement of TCSC for congestion management and power loss reduction using Multi-Objective Genetic Algorithm. *Sustainability*, *12*(7), 2813. https://doi.org/10.3390/su12072813

[23] Subramaniyan, V. & Gomathi, V. (2023). A Soft Computing-Based Analysis of Congestion Management in Transmission Systems. *Tehnički vjesnik, 30*(1), 274-281. https://doi.org/10.17559/TV-20220222072630

[24] Zhang, X., Shi, D., Wang, Z., Zeng, B., Wang, X., Tomsovic, K., & Jin, Y. (2018). Optimal allocation of series FACTS devices under high penetration of wind power within a market environment. *IEEE Transactions on Power Systems*, *33*(6), 6206-6217. https://doi.org/10.1109/tpwrs.2018.2834502

[25] Sekhar, K., Kushwaha, S. K. S., Karthik, D. R., Reddy, V. M., & Reddy, B. M. (2017). Transient stability analysis of large scale grid integration of offshore wind and marine current farm connected to grid using STATCOM. *2017 Innovations in Power and Advanced Computing Technologies (i-PACT)*. https://doi.org/10.1109/ipact.2017.8244893

[26] Kumar, B. N. P. & Reddy, D. S. (2015). Power Quality Enhancement of Integrated Grid Connected Off-Shore Wind Farm and Marine Current Farm using Statcom. *Indian Journal of Science and Technology*, *8*(29). https://doi.org/10.17485/ijst/2015/v8i29/70749

[27] Blasco-Gimenez, R., Añó-Villalba, S., Rodriguez, J., Pena, R., Cardenas, R., Bernal, S., & Morant, F. (2009). Fault analysis of uncontrolled rectifier HVDC links for the connection of off-shore wind farms. *2009 35th Annual Conference of IEEE Industrial Electronics*, 468-473. https://doi.org/10.1109/IECON.2009.5414967

[28] Movahedi, A., Niasar, A. H., & Gharehpetian, G. (2019). Designing SSSC, TCSC, and STATCOM controllers using AVURPSO, GSA, and GA for transient stability Improvement of a multi-machine power system with PV and wind farms. *International Journal of Electrical Power & Energy Systems, 106*, 455-466. https://doi.org/10.1016/j.ijepes.2018.10.019

[29] Sadi, M. A. H. & Ali, M. H. (2014). Combined operation of SVC and optimal reclosing of circuit breakers for power system transient stability enhancement. *Electric Power Systems Research*, *106*, 241-248. https://doi.org/10.1016/j.epsr.2013.09.001

[30] Murali, D., Rajaram, M., & Reka, N. (2010). Comparison of FACTS devices for power system stability enhancement. *International Journal of Computer Applications, 8*(4), 30-35. https://doi.org/10.5120/1198-1701

[31] Naseri, F. & Samet, H. (2015). A comparison study of high power IGBT-based and thyristor-based AC to DC converters

in medium power DC arc furnace plants. *2015 9th International Conference on Compatibility and Power Electronics (CPE)*, 14-19. https://doi.org/10.1109/CPE.2015.7231042

[32] Albatsh, F. M., Mekhilef, S., Ahmad, S., Mokhlis, H., & Hassan, M. A. (2015). Enhancing power transfer capability through flexible AC Transmission system devices: A review. *Frontiers of Information Technology & Electronic Engineering, 16*(8), 658-678. https://doi.org/10.1631/fitee.1500019

[33] Gyugyi, L., Sen, K. K., & Schauder, C. D. (1999). The interline power flow controller concept: A new approach to power flow management in transmission systems. *IEEE Transactions on Power Delivery, 14*(3), 1115–1123. https://doi.org/10.1109/61.772382

[34] Eremia, M., Liu, C. C., & Edris, A. A. (2016). Unified power flow controller (UPFC). *Advanced Solutions in Power Systems: HVDC, FACTS, and Artificial Intelligence*, 559-628. Wiley. https://doi.org/10.1002/9781119175391.ch10

[35] Qi, J., Zhao, W., & Bian, X. (2020). Comparative study of SVC and STATCOM reactive power compensation for prosumer microgrids with DFIG-Based wind farm integration. *IEEE Access, 8*, 209878-209885. https://doi.org/10.1109/ACCESS.2020.3033058

[36] Ismail, B., Wahab, N. I. A., Othman, M. L., Radzi, M. A. M., Vijyakumar, K. N., & Naain, M. N. M. (2020). A comprehensive review on optimal location and sizing of reactive power compensation using Hybrid-Based approaches for power loss reduction, voltage stability improvement, voltage profile enhancement and loadability enhancement. *IEEE Access, 8*, 222733-222765. https://doi.org/10.1109/ACCESS.2020.3043297

[37] Igbinovia, F. O., Fandi, G., Švec, J., Müller, Z., & Tlusty, J. (2015). Comparative review of reactive power compensation technologies. *2015 16th International Scientific Conference on Electric Power Engineering (EPE)*, 2-7. https://doi.org/10.1109/EPE.2015.7161066

[38] Dixon, J., Moran, L., Rodriguez, J., & Domke, R. (2005). Reactive Power Compensation Technologies: State-of-the-Art Review. *Proceedings of the IEEE, 93*(12), 2144-2164. https://doi.org/10.1109/jproc.2005.859937

[39] Zhou, X., Wei, K., Ma, Y., & Gao, Z. (2018). A Review of Reactive Power Compensation Devices. *2018 IEEE International Conference on Mechatronics and Automation*. https://doi.org/10.1109/icma.2018.8484519

[40] Wang, Y., Chen, H., & Zhou, R. (2000). A nonlinear controller design for SVC to improve power system voltage stability. *International Journal of Electrical Power & Energy Systems, 22*(7), 463-470. https://doi.org/10.1016/s0142-0615(00)00023-5

[41] Garrido, C., Téllez, A. A., & Ortiz, L. (2022). Linear Voltage Stability Indicator (LVSI) for optimal placement of SVC devices to improve the voltage stability margin in transmission systems. *Electronics, 12*(1), 43. https://doi.org/10.3390/electronics12010043

[42] Movahedi, A., Niasar, A. H., & Gharehpetian, G. B. (2019b). LVRT improvement and transient stability enhancement of power systems based on renewable energy resources using the coordination of SSSC and PSSs controllers. *IET Renewable Power Generation, 13*(11), 1849-1860. https://doi.org/10.1049/iet-rpg.2018.6010

[43] Castro, Ayres, H., Da Costa, V., & Da Silva, L. (2007). Impacts of the SSSC control modes on small-signal and transient stability of a power system. *Electric Power Systems Research, 77*(1), 1-9. https://doi.org/10.1016/j.epsr.2006.01.003

[44] Wibawa, B. C., Prastiantono, A., Aryani, D. R., Setiabudy, R., & Husnayain, F. (2019). Transient stability improvement by FACTS devices: A Comparison between STATCOM and SSSC in an extra high voltage transmission system. *IOP Conference Series Materials Science and Engineering, 673*(1), 012068. https://doi.org/10.1088/1757-899x/673/1/012068

[45] Sreejith, S., Rangarajan, S. S., Ambili, M., Sujyothi, P., & Nithya, V. G. (2014). Enhancing the power transfer capability in a power system network using series connected FACTS devices for increased renewable penetration. *2014 International Conference on Advances in Electrical Engineering (ICAEE)*, 1-6. https://doi.org/10.1109/ICAEE.2014.6838509

[46] Bisht, K., Kumar, D., & Bedi, K. S. (2020). Enhancement of Power Transfer Capacity and Transmission Efficiency using SSSC. *International Journal of Engineering and Advanced Technology, 9*(3), 2846-2850. https://doi.org/10.35940/ijeat.c5999.029320

[47] Rauhala, T., Jyrinsalo, J., & Kuisti, H. (2010). Enhancing the transmission capability using FACTS: The Finnish experience. *9th IET International Conference on AC and DC Power Transmission (ACDC 2010),* 1-5. https://doi.org/10.1049/cp.2010.0968

[48] Singh, B., Verma, K., Mishra, P. A., Maheshwari, R., & Srivastava, U. (2012). Introduction to FACTS Controllers: A Technological Literature Survey. *International Journal of Automation and Power Engineering, 1*(9), 193-234.

[49] Gandoman, F. H., Ahmadi, A., Sharaf, A. M., Siano, P., Pou, J., Hredzak, B., & Agelidis, V. G. (2018). Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems. *Renewable and Sustainable Energy Reviews, 82*, 502-514. https://doi.org/10.1016/j.rser.2017.09.062

[50] Manoj, S., Puttaswamy, P. S., & Vikas, V. (2011). Importance of Facts Controllers in Power Systems. *International Journal of Advanced Engineering Technology, 2*(3), 207-212.

[51] Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y. (2022). Review and outlook on the international renewable energy development. *Energy and Built Environment*, *3*(2), 139-157. https://doi.org/10.1016/j.enbenv.2020.12.002

[52] Frank, H. & Landstrom, B. (1971). Power factor correction with thyristor-controlled capacitors. *ASEA journal, 44*(6), 180-184.

[53] Achenbach, H., Hanke, W., & Hochstetter, W. (1977). Controllable static Reactive-Power compensators in electrical supply system. *IFAC Proceedings Volumes, 10*(10), 917-925. https://doi.org/10.1016/s1474-6670(17)66723-5

[54] Dmowski, A., Stańkowski, K., Zajac, R., & Fabijański, P. (1977). Thyristor Controller for induction smelting furnace. *IFAC Proceedings Volumes, 10*(10), 961-971. https://doi.org/10.1016/s1474-6670(17)66727-2

[55] Gyugyi, L. (1979). Reactive power generation and control by Thyristor circuits. *IEEE Transactions on Industry Applications, IA-15*(5), 521-532. https://doi.org/10.1109/tia.1979.4503701

[56] Bibliography on Reactive Power and Voltage Control IEEE VAR Management Working Group Report. (1987). *IEEE Transactions on Power Systems, 2*(2), 361-370. https://doi.org/10.1109/tpwrs.1987.4335134

[57] Bilodeau, H., Babaei, S., Bisewski, B., Burroughs, J., Drover, C., Fenn, J., Fardanesh, B., Tozer, B., Shperling, B., & Zanchette, P. (2016). Making old new again: HVDC and FACTS in the northeastern United States and Canada. *IEEE Power and Energy Magazine, 14*(2), 42-56. https://doi.org/10.1109/mpe.2015.2501198

[58] U.S. Energy Information Administration. (n.d.). *International*. Retrieved December 10, 2023, from https://www.eia.gov/international/data/world/electricity

[59] Australian Government. (n.d.). *Energy data*. Retrieved December 10, 2023, from https://www.energy.gov.au/energy-data

[60] Tina, G. M., Maione, G., Licciardello, S., & Stefanelli, D. (2021). Comparative Technical-Economical Analysis of transient stability improvements in a power system. *Applied Sciences, 11*(23), 11359. https://doi.org/10.3390/app112311359

[61] Sumi, Y., Harumoto, Y., Hasegawa, T., Yano, M., Ikeda, K., & Matsuura, T. (1981). New static VAR control using Force-Commutated inverters. *IEEE Transactions on Power Apparatus and Systems, PAS-100*(9), 4216-4224. https://doi.org/10.1109/tpas.1981.316973

[62] Matsuno, K., Iyoda, I., & Oue, Y. (2003). An experience of FACTS development 1980s and 1990s. *IEEE PES Transmission and Distribution Conference and Exhibition*. https://doi.org/10.1109/tdc.2002.1177681

[63] Kashani, M. G., Babaei, S., & Bhattacharya, S. (2013). SVC and STATCOM application in Electric Arc Furnace efficiency improvement. *2013 4th IEEE International Symposium on Power Electronics for Distributed Generation Systems, PEDG 2013 - Conference Proceedings*. https://doi.org/10.1109/pedg.2013.6785641

[64] Alvira, D., Torre, M., Bola, J., Burdalo, U., Marquez, M., Rodriguez, M., & Alvarez, S. (2010). The use of a static synchronous series compensator (SSSC) for power flow control in the 220 kV Spanish transmission network. *CIGRE (Session 43)*, B4-107.

[65] Hernandez, A., Eguia, P., Torres, E., & Rodriguez, M. A. (2011). Dynamic simulation of a SSSC for power flow control during transmission network contingencies. *2011 IEEE PES Trondheim PowerTech,* 1-6. https://doi.org/10.1109/ptc.2011.6019227

[66] Vidal, R., Angel, M., Sautua, A. H., Iglesias, E. T., & Lopez, P. E. (2013). Real 200kVA static synchronous series compensator test bench for control strategy verification and validation using Matlab. *2013 IEEE Grenoble Conference*, 1-6. https://doi.org/10.1109/ptc.2013.6652452

[67] Renz, B. A., Keri, A., Mehraban, A. S., Schauder, C., Stacey, E., Kovalsky, L., Gyugyi, L., & Edris, A. (1999). AEP unified power flow controller performance. *IEEE Transactions on Power Delivery, 14*(4), 1374-1381. https://doi.org/10.1109/61.796231

[68] Nilsson, S., Xu, S., Lei, B., Deng, Z., & Andersen, B. (2020). Application examples of UPFC and its variants. *CIGRE green books*, 1-61. https://doi.org/10.1007/978-3-319-71926-9_15-2

[69] Yuan, Z., de Haan, S. W. H., & Ferreira, B. (2010). DPFC design procedure: A case study using the KEPCO UPFC as an example. *The 2010 International Power Electronics Conference-ECCE ASIA*, 2696-2702. https://doi.org/10.1109/IPEC.2010.5542343

[70] Kaur, T. & Kakran, S. (2012). Transient stability improvement of long transmission line system by using SVC. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 1*(4), 217-227.

[71] Čerňan, M., Müller, Z., Tlustý, J., & Valouch, V. (2021). An improved SVC control for electric arc furnace voltage flicker mitigation. *International Journal of Electrical Power & Energy Systems, 129*, 106831. https://doi.org/10.1016/j.ijepes.2021.106831

[72] Rao, P., Crow, M., & Yang, Z. (2000). STATCOM Control for power system voltage control applications. *IEEE Transactions on Power Delivery*, *15*(4), 1311-1317. https://doi.org/10.1109/61.891520

[73] Singh, R., Singh, A. K., & Singh, A. K. (2012). Transient Stability Improvement of a FSIG Based Grid Connected wind Farm with the help of a SVC and aSTATCOM: A Comparison. *International Journal of Computer and Electrical Engineering*, 55-59. https://doi.org/10.7763/ijcee.2012.v4.451

[74] Hemeida, M. G., Rezk, H., & Hamada, M. M. (2017). A comprehensive comparison of STATCOM versus SVC-based fuzzy controller for stability improvement of wind farm connected to multi-machine power system. *Electrical Engineering, 100*(2), 935-951. https://doi.org/10.1007/s00202-017-0559-6

[75] Khan, B. & Kassas, M. (2019, February). FSIG-based wind power plant transient stability margin improvement, a STATCOM/SVC Comparison. *2019 IEEE Texas Power and Energy Conference (TPEC)*, 1-6. https://doi.org/10.1109/tpec.2019.8662129

[76] ABB. (n.d.). *HVDC Light & SVC Light reference list*. Retrieved from https://new.abb.com/docs/default-source/ewea-doc/hvdc-light-and-svc.pdf

[77] Ruhul Wara, M. & Rahim, A. H. M. A. (2020). STATCOM in Power Systems: A Review. *International Journal of Power Electronics Controllers and Converters, 6*(2), 39-51.

[78] Yachida, T., Okuyama, R., Morishima, N., Ashizaki, Y., & Itaya, Y. (2022). Design and installation of STATCOM system for wind and photovoltaic power plant. *2022 International Power Electronics Conference (IPEC-Himeji 2022- ECCE Asia)*. https://doi.org/10.23919/ipec-himeji2022-ecce53331.2022.9807021

[79] Mitsubishi Electric. (2023, March 28). *Mitsubishi Electric receives order for ±700MVA STATCOM aimed at stabilizing power grid in Northeast Japan*.Retrieved December 10, 2023, from https://www.mitsubishielectric.com/news/2023/0328.html

[80] De Dieu Nguimfack-Ndongmo, J., Kenné, G., Kuate-Fochie, R., Cheukem, A., Fotsin, H. B., & Lamnabhi-Lagarrigue, F. (2014). A simplified nonlinear controller for transient stability enhancement of multimachine power systems using SSSC device. *International Journal of Electrical Power & Energy Systems, 54*, 650-657. https://doi.org/10.1016/j.ijepes.2013.08.019

[81] Aslam, W., Xu, Y., Siddique, A., & Albatsh, F. M. (2018, May). Implementation of series facts devices SSSC and TCSC to improve power system stability. *2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA),* 2291-2297. https://doi.org/10.1109/iciea.2018.8398092

[82] Haque, M. (2006). Damping improvement by FACTS devices: A comparison between STATCOM and SSSC. *Electric Power Systems Research, 76*(9-10), 865-872. https://doi.org/10.1016/j.epsr.2005.11.001

[83] Ordóñez, C. A., Gómez-Expósito, A., & Maza-Ortega, J. M. (2021). Series Compensation of Transmission Systems: A Literature survey. *Energies, 14*(6), 1717. https://doi.org/10.3390/en14061717

[84] Sesok, A. & Pavic, I. (2022). Transient stability improvement of Croatian power system using FACTS. *2022 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia),* 51-55. https://doi.org/10.1109/isgtasia54193.2022.10003484

[85] Bu, W., Ding, Z., Feng, S., Cai, X., Zhang, Y., Yu, X., & Huang, W. (2024). Research on Control Strategy of High-Speed Grid-Connected FESS (Flywheel Energy Storage System) Based on Dual-PWM Converter. *Tehnički vjesnik, 31*(1), 178-184. https://doi.org/10.17559/TV-20230803000849

[86] Sreejith, S. & Simon, S. P. (2014). Cost benefit analysis on SVC and UPFC in a dynamic economic dispatch problem. *International Journal of Energy Sector Management, 8*(3), 395-428. https://doi.org/10.1108/ijesm-05-2013-0010

[87] Bannykh, P., Chusovitin, P., & Pazderin, A. (2017). A novel modeling approach of SVC for three-phase transient stability simulator. *2017 9th International Conference on Information Technology and Electrical Engineering (ICITEE)*, 1-6. https://doi.org/10.1109/iciteed.2017.8250509

[88] Zhu, Y., Zhang, X., & Dai, R. (2021). Power System Transient Analysis via Circuit Simulator: A Case Study of SVC. *2021 IEEE Kansas Power and Energy Conference (KPEC)*, 1-6. https://doi.org/10.1109/kpec51835.2021.9446258

[89] Karami, M. M. & Itami, A. (2017). Implementation of SVC based on grey theory and fuzzy logic to improve LVRT capability of wind distributed generations. *Turkish Journal of Electrical Engineering & Computer Sciences, 25*(1), 422-433. https://doi.org/10.3906/elk-1410-153

[90] Rezaie, H. & Kazemi-Rahbar, M. H. (2019). Enhancing voltage stability and LVRT capability of a wind-integrated power system using a fuzzy-based SVC. *Engineering Science and Technology an International Journal, 22*(3), 827-839. https://doi.org/10.1016/j.jestch.2018.12.018

[91] Dayo, S. A., Memon, S. H., Uqaili, M. A., & Memon, Z. A. (2021). LVRT Enhancement of a Grid-tied PMSG-based Wind Farm using Static VAR Compensator. *Engineering Technology & Applied Science Research, 11*(3), 7146-7151. https://doi.org/10.48084/etasr.4147

[92] Gitizadeh, M., Pilehvar, M. S., & Mardaneh, M. (2013). A new method for SVC placement considering FSS limit and SVC investment cost. *International Journal of Electrical Power & Energy Systems, 53*, 900-908. https://doi.org/10.1016/j.ijepes.2013.06.009

[93] Gitizadeh, M., Ghavidel, S., & Aghaei, J. (2014). Using SVC to economically improve transient stability in long transmission lines. *IETE Journal of Research, 60*(4), 319-327. https://doi.org/10.1080/03772063.2014.961571

[94] Huang, W. & Sun, K. (2018). Optimization of SVC settings to improve post-fault voltage recovery and angular stability. *Journal of Modern Power Systems and Clean Energy, 7*(3), 491-499. https://doi.org/10.1007/s40565-018-0479-0

[95] Aydin, F. & Gumus, B. (2021). Determining optimal SVC location for voltage stability using Multi-Criteria Decision making based solution: Analytic Hierarchy Process (AHP) approach. *IEEE Access, 9*, 143166-143180. https://doi.org/10.1109/access.2021.3121196

[96] Wang, P., Wang, Y., Jiang, N., & Gu, W. (2020). A comprehensive improved coordinated control strategy for a STATCOM integrated HVDC system with enhanced steady/transient state behaviors. *International Journal of Electrical Power & Energy Systems, 121*, 106091. https://doi.org/10.1016/j.ijepes.2020.106091

[97] Vetoshkin, L. & Muller, Z. (2021). Dynamic stability improvement of power system by means of STATCOM with virtual inertia. *IEEE Access, 9*, 116105-116114. https://doi.org/10.1109/access.2021.3106236

[98] Karami, A. & Galougahi, K. M. (2019). Improvement in power system transient stability by using STATCOM and neural networks. *Electrical Engineering, 101*(1), 19-33. https://doi.org/10.1007/s00202-019-00753-5

[99] Chakraborty, A., Musunuri, S. K., Srivastava, A. K., & Kondabathini, A. K. (2012). Integrating STATCOM and battery Energy Storage System for power system transient stability: A Review and application. *Advances in Power Electronics, 2012*(1), 1-12. https://doi.org/10.1155/2012/676010

[100]Rabbi, A. E., Arif, S., & Aziz, T. (2019). Performance comparison of STATCOM and BESS for restoring voltage under post fault scenario. *2019 IEEE region 10 symposium (TENSYMP)*, 435-440. https://doi.org/10.1109/tensymp46218.2019.8971165

[101]Hasan, A. K., Haque, M. H., & Aziz, S. M. (2020). Improvement of Transient Stability Limit Using Battery Energy Storage Systems and STATCOM. *2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 1-6. https://doi.org/10.1109/pedes49360.2020.9379549

[102]Ahmed, F., Tasnim, S., & Aura, S. R. (2022). A comparative study of the influence of BESS and STATCOM on Post-Fault voltage recovery in microgrid. *European Journal of Electrical Engineering and Computer Science, 6*(4), 35-43. https://doi.org/10.24018/ejece.2022.6.4.449

[103]Tu, G., Li, Y., & Xiang, J. (2019). Analysis, Control and Optimal Placement of Static Synchronous Compensator with/without Battery Energy Storage. *Energies, 12*(24), 4715. https://doi.org/10.3390/en12244715

[104]Bharadwaj, A., Maiti, S., Dhal, N., & Chakraborty, S. (2019). Control and sizing of modular multilevel converter-based STATCOM with hybrid energy storage system for large-scale integration of wind farms with the grid. *Electrical Engineering, 101*(3), 743-757. https://doi.org/10.1007/s00202-019-00817-6

[105]Yamin, Z., Naz, M. N., Naveed, I., Imtiaz, S., & ur Rehman, S. (2020). Improved stability control of islanded wind powered microgrid reinforced by STATCOM, battery storage system and pitch angle control. *2020 IEEE 23rd International Multitopic Conference (INMIC),* 1-6. https://doi.org/10.1109/INMIC50486.2020.9318119

[106]Prasanna, V. & Ravi, G. (2021). An Enhanced STATCOM Model based on Hybrid Energy Storage System For SmartGrid. *2021 Innovations in Power and Advanced Computing Technologies (i-PACT),* 1-6. https://doi.org/10.1109/i-PACT52855.2021.9696662

[107]Chakraborty, S., Mukhopadhyay, S., & Biswas, S. (2022). Coordination of D-STATCOM & SVC for Dynamic VAR Compensation and Voltage Stabilization of an AC Grid Interconnected to a DC Microgrid. *IEEE Transactions on Industry Applications, 58*(1), 634-644. https://doi.org/10.1109/tia.2021.3123264

[108]Bhukya, S., Bharadwaj, A., Babu, N. P., & Mallesham, G. (2022). Control and Performance Analysis of Multifunctional Two Level STATCOM fed with Battery Storage System. *2022 Second International Conference on Power, Control and Computing Technologies (ICPC2T),* 1-6. https://doi.org/10.1109/ICPC2T53885.2022.9777063

[109]Varma, R. K., Siavashi, E. M., Mohan, S., & Vanderheide, T. (2019). First in Canada, night and day field demonstration of a new photovoltaic Solar-Based Flexible AC Transmission System (FACTS) device PV-STATCOM for stabilizing critical induction motor. *IEEE Access, 7*, 149479-149492. https://doi.org/10.1109/access.2019.2935161

[110]Varma, R. K., Siavashi, E., Mohan, S., & McMichael-Dennis, J. (2021). Grid support benefits of solar PV systems as STATCOM (PV-STATCOM) through Converter Control: Grid Integration Challenges of Solar PV Power Systems. *IEEE Electrification Magazine, 9*(2), 50-61. https://doi.org/10.1109/mele.2021.3070937

[111]Kumar, R., Diwania, S., Khetrapal, P., Singh, S., & Badoni, M. (2021). Multimachine stability enhancement with hybrid PSO-BFOA based PV-STATCOM. *Sustainable Computing Informatics and Systems, 32*, 100615. https://doi.org/10.1016/j.suscom.2021.100615

[112]Varma, R. K. & Akbari, M. (2020). Simultaneous fast frequency control and power oscillation damping by utilizing PV solar system as PV-STATCOM. *IEEE Transactions on Sustainable Energy, 11*(1), 415-425. https://doi.org/10.1109/tste.2019.2892943

[113]Sidhu, T., Varma, R., Gangadharan, P., Albasri, F., & Ortiz, G. (2005). Performance of distance relays on Shunt—FACTS compensated transmission lines. *IEEE Transactions on Power Delivery*, *20*(3), 1837-1845. https://doi.org/10.1109/tpwrd.2005.848641

[114]Abdalla, A. A., Ahmad, S. S., Elamin, I. M., & Mahdi, M. A. (2019). Application of optimization algorithms for the improvement of the transient stability of SMIB integrated with SSSC controller. *2019 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE)*, 1-6. https://doi.org/10.1109/ICCCEEE46830.2019.9071137

[115]Dahat, S. A. & Dhabale, A. (2022). Co-ordinated control of combination of SSSC and SVC for enhancement of power system voltage stability. *2022 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE)*, 1-6.

https://doi.org/10.1109/PESGRE52268.2022.9715881
[116]Abazari, S. & Ghaedi, S. (2023). Transient stability increase of multi-machine power system by using SSSC and DFIG control with TEF technique and super twisting differentiator. *ISA Transactions, 136*, 390-399. https://doi.org/10.1016/j.isatra.2022.11.008
[117]Hincapie, S., Ordonez, C. A., Patino, M., & Duque, A. (2021). Test Case: Modular SSSC and LCC-based HVDC Link Technical Synergies. *The 17th International Conference on AC and DC Power Transmission,* 210-215. IET. https://doi.org/10.1049/icp.2021.2471
[118]Hojsak, I. & Longoria, M. (2022). Improving Transfer Capability Without Series Compensation Challenges: Utilizing M-SSSC Technology to Provide Series Compensation while Avoiding Sub-Synchronous Resonance Risk. *IEEE Power and Energy Magazine, 20*(2), 74-82. https://doi.org/10.1109/mpe.2022.3153775
[119]Xenos, P., Krommydas, K. F., Karavas, C. S. G., Melissaris, D., Plakas, K. A., Dikaiakos, C. N., & Moraitis, I. (2022). A Modular Static Synchronous Series Compensator Offering Improved Scalability and Replicability Properties. *2022 2nd International Conference on Energy Transition in the Mediterranean Area (SyNERGY MED)*, 1-6. https://doi.org/10.1109/SyNERGYMED55767.2022.9941398

Contact information:

Filip RELIĆ, PhD candidate
(Corresponding author)
Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, University of Osijek
Kneza Trpimira 2B, 31000 Osijek, Croatia
E-mail: filip.relic92@gmail.com

Hrvoje GLAVAŠ, Full professor, PhD
Faculty of Electrical Engineering,Computer Science and Information Technology Osijek, University of Osijek,
Kneza Trpimira 2B, 31000 Osijek, Croatia
E-mail: hrvoje.glavas@ferit.hr

Ivica PETROVIĆ, Associate professor, PhD
Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, University of Osijek
Kneza Trpimira 2B, 31000 Osijek, Croatia
E-mail: ivica.petrovic@hops.hr

Marinko STOJKOV, Full professor, PhD
University of Slavonski Brod,
Mechanical Engineering Faculty in Slavonski Brod,
Trg Ivane Brlić Mažuranić 2, 35000 Slavonski Brod, Croatia
E-mail: mstojkov@unisb.hr