Flexible AC Transmission Systems Technologies

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The advancements in power electronics have shown considerable improvement in satisfying the need for voltage stability and power quality improvement by introducing Flexible AC Transmission Systems (FACTS) technology. The main functions of these devices are reactive power compensation, voltage control, and power flow control to enhance better power quality in modern power systems.

optimization   FACTS technologies   distributed generators

1. Introduction

The first generation of FACTS devices were mechanically controlled capacitors, inductors, and phase-shifting transformers with mechanical on-load tap changers [1]. The second generation was developed such that thyristor valves replace the mechanical switches. This gave a significant improvement in the speed of the devices. The third generation was designed using voltage source converter (VSC) based devices [1]. These devices provide multiple and total control of the power system parameters [2]. To further extend the application of FACTS devices to a distribution network, there are custom power (CP) devices similar to FACTS devices, except that they are used only in distribution networks. An example is the distributed synchronous static compensators D-STATCOM [3]. The modification of FACTS to CP to be used in distributed networks can be considered as the foundation for the fourth generation of FACTS technologies. This advancement expands the application of FACTS controllers from being used only in transmission networks to deregulated CPPS networks.

2. Benefits of FACTS Technology in Power System

FACTS devices are used in power systems for economic and technical benefits. Most existing power systems are old and operate under full capacity due, amongst other things, to infrastructure or components worn-out. Building a new power grid or replacing existing components will be an expensive venture; FACTS devices are, therefore, used to optimize the system performance capacity at a lower cost. Furthermore, in a deregulated power system network and competitive market, FACTS devices can be used to maximize consumers' social welfare and utility's profit in the face of imbalance cost due to RES uncertainty [4][5]. Moreover, when optimally placed, FACTS devices can reduce congestion, curtailment and price volatility [6][7].

Research has shown that FACTS technologies can be used to tackle many power system quality and reliability challenges such as: optimizing line power transfer capacity and loadability [8][9][10]; limiting short circuit currents [11];

enhancing power system transient stability state and system security [12][13][14]; compensate reactive power and load for optimal performance [15]; reducing sub-synchronous resonance and enhancing system damping [16][17]; and improving voltage stability and general power system quality [18][19].

3. Classification of FACTS Controllers

According to Rath et al. [6], FACTS controllers can be divided into four categories according to how they are connected: shunt controllers, series controllers, series-series controllers, and series-shunt controllers.

3.1. Series Controllers

Series Controllers inject voltage in series with the line. They are used to reduce the transfer reactance of a power line and hence increase transmission line capacity and improve system stability. Examples of series controllers are Thyristor Controlled Series Compensator (TCSC) and Static Synchronous Series Compensator (SSSC) [20]. **Figure 1** shows the structure and form of TCSC designed with two-directional thyristors.
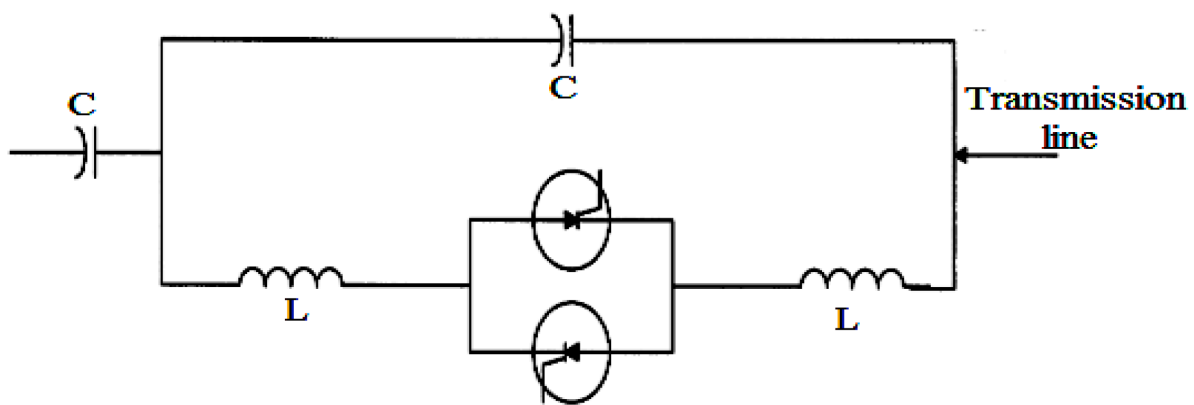

Figure 1. Schematic diagram of TCSC [21].

While the TCSC can be modelled as a series impedance, the SSSC is a series voltage source [20]. **Figure 2** shows the Schematic diagram of SSSC designed based on solid-state voltage source converter and series connected to a transmission line through a transformer.
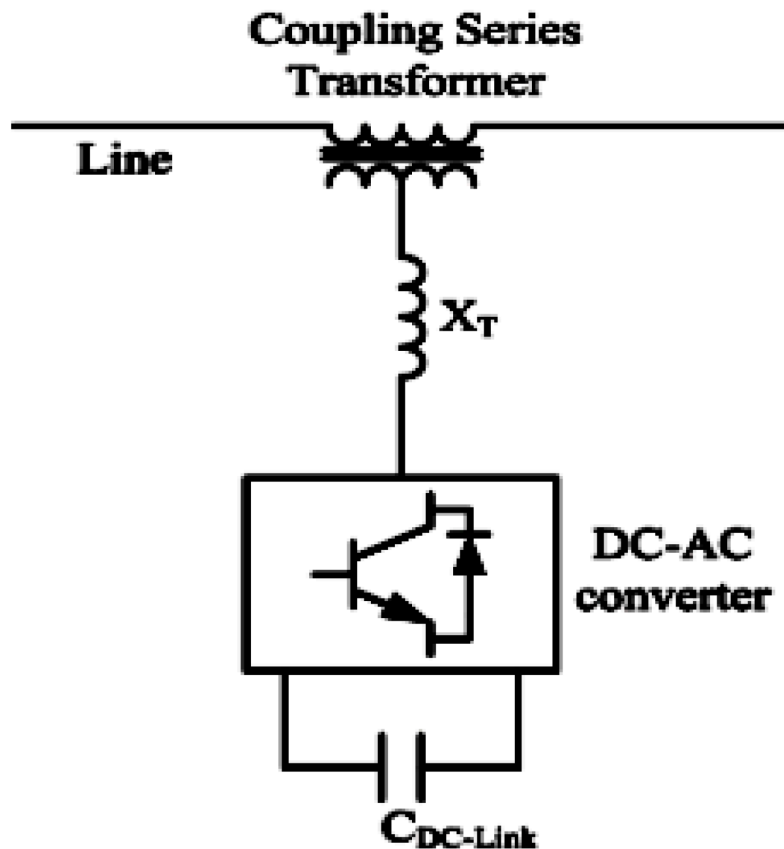
Figure 2. Schematic diagram of SSSC [21].

3.2. Shunt Controllers

Shunt controllers are mainly used in high voltage systems to improve voltage profiles by supplying reactive power as they inject current into the system at the point of connection. The shunt controller only provides or absorbs variable reactive power when the injected current is in the 900 phase with the line voltage. Any other phase relationship will also control real power as well. Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are such controllers [22].

The SVC is designed with Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactor (TCR) or Thyristor Switched Reactor (TSR), as shown in **Figure 3**. The TSR is used to absorb reactive power, while the TSC is used to supply reactive power [23].
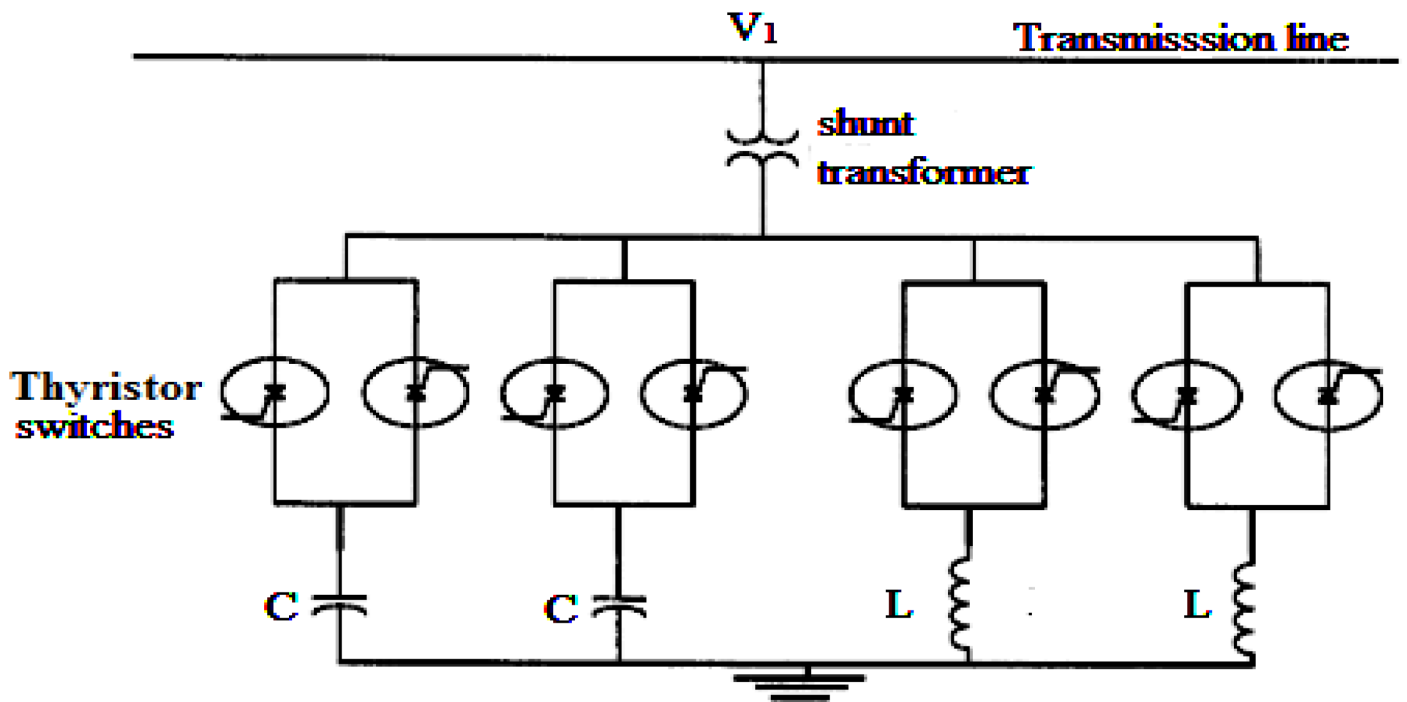
Figure 3. Static Var Compensator [21].

STATCOM is an advanced SVC designed with a VSC which has a Gate turn off thyristor and d.c capacitor linked with a transformer connected to a transmission line, as shown in **Figure 4**. The conversion of dc input voltage into ac outputs to compensate for the real and reactive power of the system is performed by STATCOM [23].
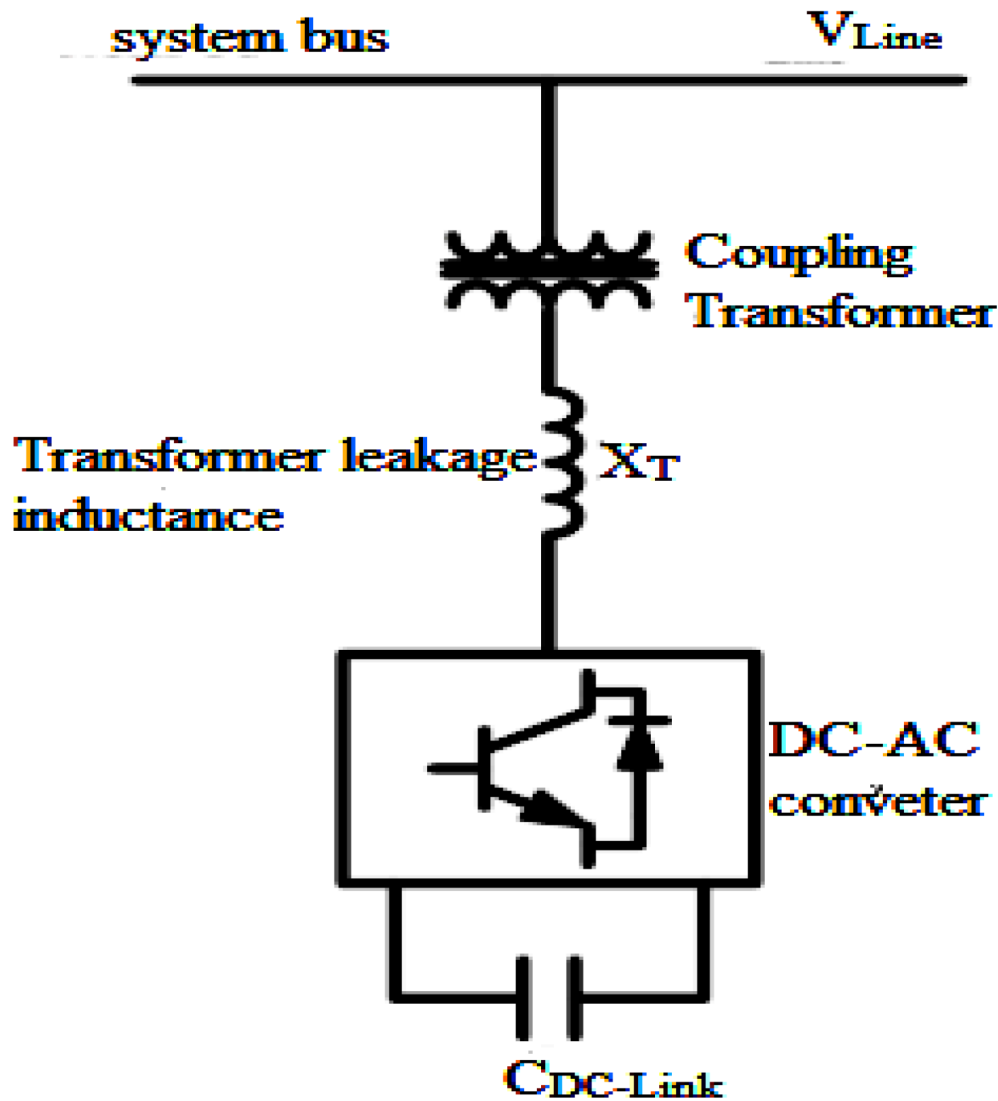
Figure 4. Schematic diagram of STATCOM [21].

3.3. Combined Series-Series Controllers

This is a combination of separate series controllers, which are coordinately controlled, in more than one transmission line system. It could also be a unified controller, in which series controllers provide independent series reactive compensation for each line and also transfer real power among the lines through the power link. Interline Power Flow Controller (IPFC) [22].

IPFC has two series converters connected to two different transmission lines, as shown in **Figure 5**. It provides a very good power flow control for more than one transmission line, with each of the two SSSC giving series power addition for its own transmission line. The two converters are joined through a DC capacitor and attached to the AC network through transformers directly connected. By this, it not only provides reactive power addition, but also any of the converters can be manipulated to inject real power to the dc joint from its own Transmission line.
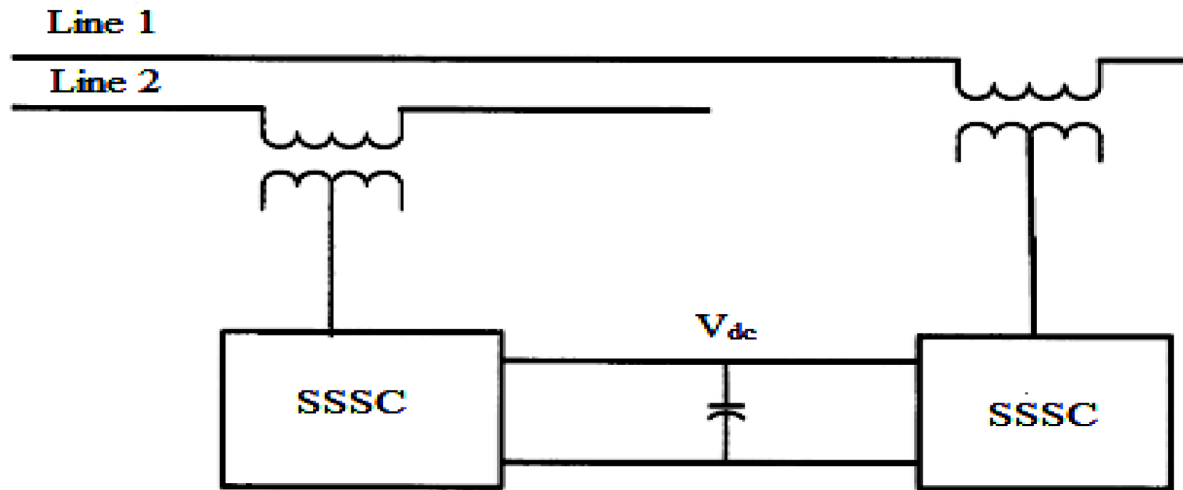
Figure 5. Schematic diagram of IPFC.

3.4. Combined Series-Shunt Controllers

These controllers have combined shunt and series controllers, which have sophisticated control. A real power exchange can occur through their shared DC link when the shunt and series controllers are jointly used. The Unified power flow controller (UPFC) is a series-shunt controller. It is considered one of the most versatile and powerful FACTS devices in the power system today [24]. It is primarily used for flexible control of powers for better voltage stability. It allows concurrent or independent control of these parameters with transfer from one control scheme to another in real-time. **Figure 6** depicts the schematic diagram of UPFC.
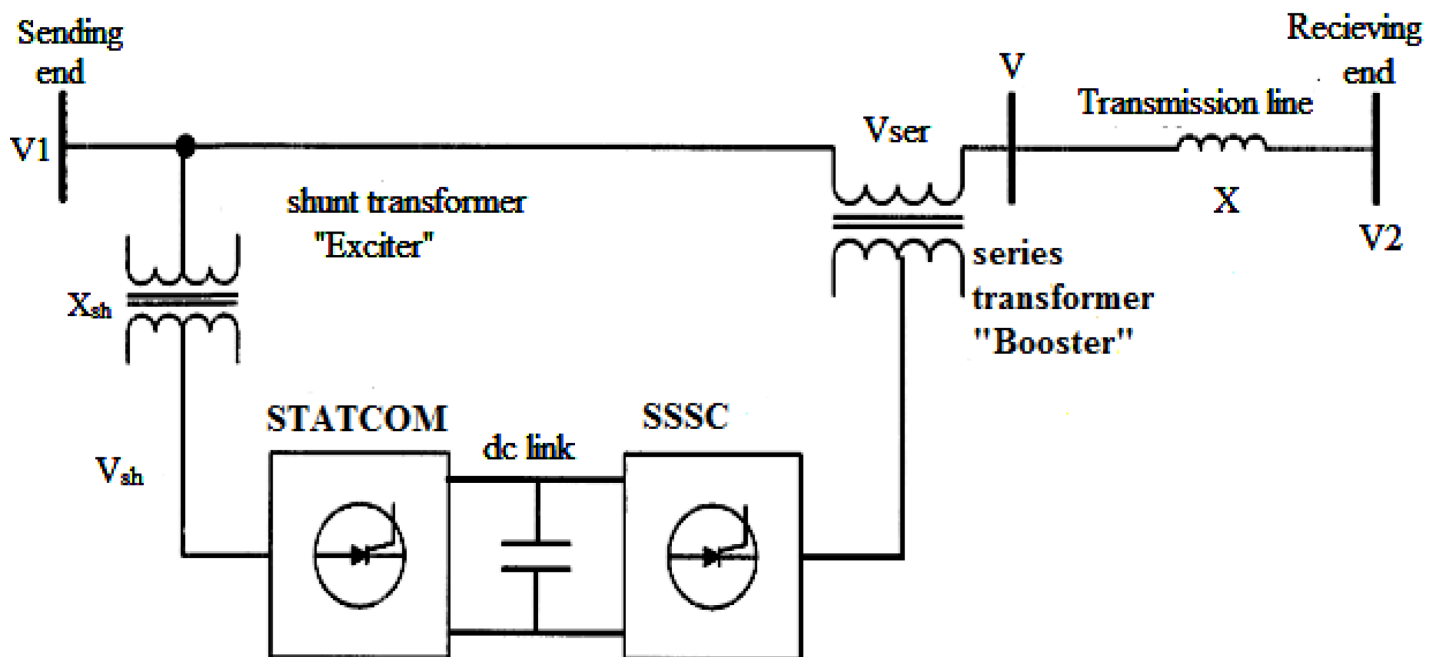

Figure 6. Schematic diagram of UPFC [25].

UPFC, as shown in **Figure 6**, is designed using STATCOM and SSSC linked together with a d.c. The converters are connected to the line with transformers. The unique combination of this device allows for flexibility of operation when connected to a power system network.

The dynamic flow controller (DFC) is a hybrid device combining a Phase Shifting Transformer (PST) and switched series compensator, such as TSC and TSR, as shown in **Figure 7**.
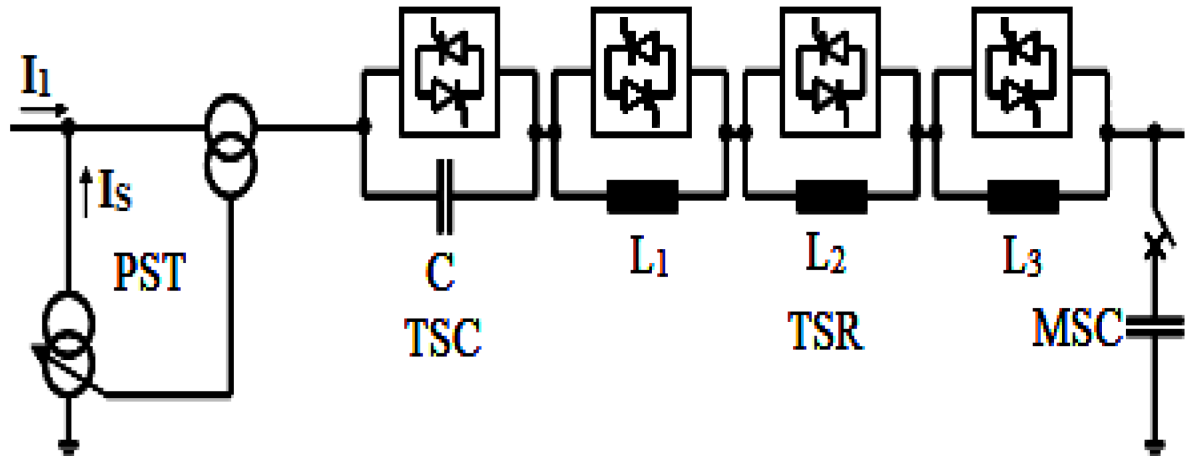

Figure 7. Schematic diagram of DFC [20].

3.5. The Merit of the Voltage Source Converter Based FACTS over Thyristor Controlled Devices

- They consist of voltage source converters designed with an insulated-gate bipolar transistor or integrated gate-commutated thyristor, making them capable of controlling their output voltage;
- With the voltage source converters, there is no risk of shunt or series resonant with the inductive line impedance that may initiate sub-synchronous oscillation;
- They can control their output voltage over the whole VA rating independent of the AC system parameters;
- They exchange controllable real power with AC system.

Figure 8 depicts an overview of major FACTS devices classified according to their connection and different generations.
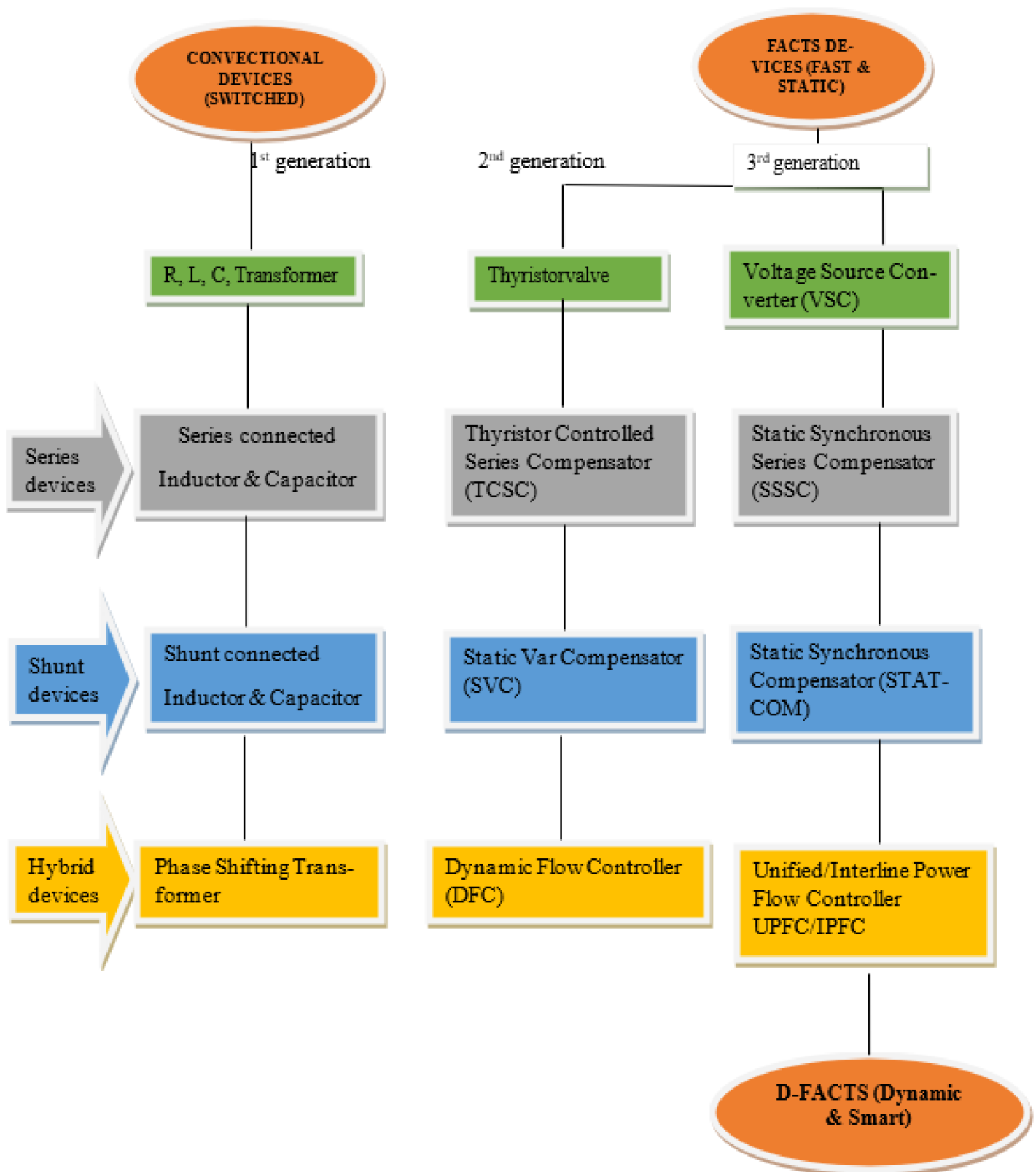
Figure 8. Overview of major FACTS devices.

3.6. Distribution-FACTS Controllers

D-FACTS technologies are advanced FACTS controllers mainly deployed in distribution networks. Due to the increasing introduction of DGs to the power grid, D-FACTS are becoming more promising than convectional FACTS devices, gaining more recent traction in power grid deployment [26]. D-FACTS devices are smaller and, hence, less complex and cheaper than traditional FACTS devices [27]. Beyond the merit of flexibility and cost-effectiveness, D-FACTS controllers are suitable for easy configuration with the sensing and communication system of the modern smart grid for advanced functionality. Therefore, D-FACTS devices are considered an alternative solution to the limitations of traditional FACTS devices.

The similarity of D-FACTS devices to other convection FACTS devices extends beyond functionality to technical configuration; hence, most D-FACTS devices assumed the name of the specific FACTS controller with a similar configuration. D- STATCOM, for instance, is designed to perform a similar function as STATCOM; therefore, the operational configuration and connection in the power grid are the same. Moreover, D-SSSC is the distribution version of the SSSC controller. Both are connected in series along power lines and provide dynamic control for power quality and security improvement.

Pinheiro et al. [26] demonstrates an application of series VSC in distribution network for effective power flow under variable load disturbances. The study results show VSC as active tool for independent control and transfer of real and reactive powers between distribution feeders. On the other hand, the biggest challenge of using series converter in an electrical power system is its ability to make smart decisions or otherwise be removed and protected in case of a short circuit or power outage [26]. An efficient coordination of voltage and reactive power in an automated distribution system using distribution SVC (D-SVC) alongside DGs was presented by Shaheen et al. [28]. This integrated configuration not only achieved optimum distribution system operation and control, but also minimized losses and reduce emissions [29]. D-FACTS can also be utilized to regulate the oscillatory stability of induction motors or synchronous generator [30].

References

1. Seifi, A.; Gholami, S.; Shabanpour, A. Power Flow Study and Comparison of FACTS: Series (SSSC), Shunt (STATCOM), and Shunt-Series (UPFC). Pacific. J. Sci. Technol. 2010, 11, 129–137.

2. Hingorani, N.G.; Gyugyi, L. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems; IEEE Press: Piscataway, NJ, USA; Wiley: New York, NY, USA, 2000; Volume 148, ISBN 0780334272.

3. Sirjani, R.; Rezaee Jordehi, A. Optimal placement and sizing of distribution static compensator (D-STATCOM) in electric distribution networks: A review. Renew. Sustain. Energy Rev. 2017, 77, 688–694.

4. Dawn, S.; Tiwari, P.K.; Goswami, A.K. An approach for long term economic operations of competitive power market by optimal combined scheduling of wind turbines and FACTS controllers. Energy 2019, 181, 709–723.

5. Yu, Z.; Lusan, D. Optimal placement of FACTs devices in deregulated systems considering line losses. Int. J. Electr. Power Energy Syst. 2004, 26, 813–819.

6. Rath, S.; Sahu, B.P.; Dash, P. Power system operation and control using FACT Devices. Int. J. Eng. Res. Technol. 2012, 1.

7. Samimi, A.; Naderi, P. A New Method for Optimal Placement of TCSC Based on Sensitivity Analysis for Congestion Management. Smart Grid Renew. Energy 2012, 3, 10–16.

8. Singh, S.; Pujan Jaiswal, S. Enhancement of ATC of micro grid by optimal placement of TCSC. Mater. Today Proc. 2019, 34, 787–792.

9. Ersavas, C.; Karatepe, E. Optimum allocation of FACTS devices under load uncertainty based on penalty functions with genetic algorithm. Electr. Eng. 2017, 99, 73–84.

10. Sharma, A.; Jain, S.K. Gravitational search assisted algorithm for TCSC placement for congestion control in deregulated power system. Electr. Power Syst. Res. 2019, 174, 105874.

11. Mahdad, B.; Srairi, K. Application of a combined superconducting fault current limiter and STATCOM to enhancement of power system transient stability. Phys. C Supercond. Its Appl. 2013, 495, 160–168.

12. Khan, I.; Mallick, M.A.; Rafi, M.; Mirza, M.S. Optimal placement of FACTS controller scheme for enhancement of power system security in Indian scenario. J. Electr. Syst. Inf. Technol. 2015, 2, 161–171.

13. Tarafdar Hagh, M.; Alipour, M.; Teimourzadeh, S. Application of HGSO to security based optimal placement and parameter setting of UPFC. Energy Convers. Manag. 2014, 86, 873–885.

14. Kang, T.; Yao, J.; Duong, T.; Yang, S.; Zhu, X. A hybrid approach for power system security enhancement via optimal installation of flexible ac transmission system (FACTS) devices. Energies 2017, 10, 1305.

15. Sode-Yome, A.; Mithulananthan, N.; Lee, K.Y. Reactive Power Loss Sensitivity Approach in Placing FACTS Devices and UPFC; IFAC: New York, NY, USA, 2012; Volume 8.

16. Lund, A.A.; Keerio, M.U.; Koondhar, M.A.; Jamali, M.I.; Tunio, A.Q. Investigation of advanced control for unified power flow controller (UPFC) to improve the performance of power system. J. Appl. Emerg. Sci. 2021, 11, 67.

17. Magaji, N.; Mustafa, M.W. Optimal location and signal selection of UPFC device for damping oscillation. Int. J. Electr. Power Energy Syst. 2011, 33, 1031–1042.

18. Singh, B.; Agrawal, G. Enhancement of voltage profile by incorporation of SVC in power system networks by using optimal load flow method in MATLAB/Simulink environments. Energy Rep. 2018, 4, 418–434.

19. Bakir, H.; Kulaksiz, A.A. Modelling and voltage control of the solar-wind hybrid micro-grid with optimized STATCOM using GA and BFA. Eng. Sci. Technol. Int. J. 2020, 23, 576–584.

20. Zhang, X.-P.; Rehtanz, C.; Bikash, P. Flexible AC Transmission Systems: Modelling and Control; Springer: Berlin/Heidelberg, Germany; New York, NY, USA; Dordrecht, The Netherlands; London, UK, 2012; Volume 148, ISBN 9783642282409.

21. Das, D. Dynamic Control of Grid Power Flow Using Controllable Network Transformers; Georgia Institute of Technology: Atlanta, GA, USA, 2012.

22. Krishna, S.B.C.V.; Sankar, K.S.; Haranath, P.V. Power System Operation and Control Using Fact Devices. In Proceedings of the 17th International Conference on Electricity Distribution, Barcelona, Spain, 12–15 May 2003; pp. 12–15.

23. Sarkar, M. Load Flow Studies With UPFC Power Injection Model; National Institute of Technology Rourkela: Odisha, India, 2013.

24. Gouda, P.K.; Sahoo, A.K.; Hota, P.K. Modeling and simulation of UPFC using PSCAD/EMTDC. Int. J. Phys. Sci. 2012, 7, 5965–5980.

25. Farrag, M.E.E.A. Investigation of Advanced Control for the Unified Power Flow Controller (UPFC); University of Northumbria at Newcastle: Newcastle upon Tyne, UK, 2002.

26. Pinheiro, G.G.; Henrique, C.; Guimar, B.P.B.; Gonzatti, R.B.; Pereira, R.R.; Cesar, W.; Ana, S.; Lambert-torres, G.; Santana-filho, J. Power Flow Control Using Series Voltage Source Converters in Distribution Grids. Energies 2022, 15, 3337.

27. Hamidi, A.; Golshannavaz, S.; Nazarpour, D. D-FACTS cooperation in renewable integrated microgrids: A linear multi-objective approach. IEEE Trans. Sustain. Energy 2017, 10, 355–363.

28. Shaheen, A.M.; Elsayed, A.M.; Ginidi, A.R.; Elattar, E.E.; El-Sehiemy, R.A. Effective Automation of Distribution Systems with Joint Integration of DGs/ SVCs Considering Reconfiguration Capability by Jellyfish Search Algorithm. Curr. Opin. Obstet. Gynecol. 2021, 9, 92053–92069.

29. Shaheen, A.M.; Elsayed, A.M.; El-Sehiemy, R.A.; Ginidi, A.R.; Elattar, E. Optimal management of static volt-ampere-reactive devices and distributed generations with reconfiguration capability in active distribution networks. Int. Trans. Electr. Energy Syst. 2021, 31, e13126.

30. Relic, F.; Maric, P.; Glavas, H.; Petrovic, I. Influence of FACTS device implementation on performance of distribution network with integrated renewable energy sources. Energies 2020, 13, 5516.