Transient Stability Enhancement Using FACTS Devices in a Distribution System Involving Distributed Generation Systems

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Abstract Distributed generation technologies provide a reliable and cost-effective solution for power generation along with enhanced power quality features compared to the conventional source of generation. The transient stability has gained interest because of the tremendous increase of distribution generation in distribution systems. This paper presents the improvement of transient voltage stability in the distribution system using Flexible AC Transmission Systems (FACT) devices like Static Synchronous Compensator (STATCOM), and Static Var Compensator (SVR) involving distributed generation systems such as Double Fed Induction Generator (DFIG)-based wind turbine system. IEEE standard 399–1997-based system with some modifications has been considered for the study in this paper. Simulation has been carried out using MATLAB SIMULINK software.

Keywords STATCOM · SVC · DFIG · Static and dynamic load · Transient stability

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M. J. B. Reddy et al. (eds.), *Advances in Smart Grid Automation and Industry 4.0*, Lecture Notes in Electrical Engineering 693, https://doi.org/10.1007/978-981-15-7675-1_50

1 Introduction

Electrical distribution system is a part of electrical power system succeeding the transmission system which is committed to deliver electrical energy to end consumers. Generally, electrical distribution system is said to be the electrical system between substation fed by transmission system and consumer end. The purpose of an electrical distribution system is to meet customer's energy demand. The problems in an electrical distribution system are diverse and cover a wide field which involves multiple engineering branches. There are lots of challenging issues in distribution systems. Distributed generation creates problems such as accounting and optimization of reverse power flows. The most important problems are power quality, reliability, protection, and grounding [1]. The most challenging issue here is to find the balance of investment and cost of the modern power distribution networks in relation to solve reliability, protection, and power quality problems of the consumers in the networks [2]. The distribution automation provides a fast method of improving reliability of the distribution system [3]. The Distribution Automation (DA) makes the whole operation more efficient. It reduces operation and maintenance costs across the entire utility. Power system studies form a significant part of electrical engineering which is mainly perturbed with generation and transmission of electrical power as per requirements. The power often changes because of load variation or may be due to disturbances in the system. Because of these factors, the power system stability is considered important. As a power system is subjected to several disturbances in the form of transients, the stability of the power system could be hampered to a greater extent. It is highly essential that the system's stability is restored toward an equilibrium condition for the reliable operation of a power system network [4].

Several methods have been emerged over the years for improving the system stability. Fast fault clearing, reducing reactance of transmission system, series compensation, regulated shunt compensation, and dynamic breaking enhances the system stability [5]. The stability improvement is achieved by reducing the severity of fault and fault duration, by implementing independent pole operation of circuit breakers [6]. The maximum power transfer capability is achieved with the use of series capacitor banks. The several control schemes can be used for improvement of transient stability with simple power electronic converters to FACTS devices [7, 8]. Distributed generation in short often termed as DG refers to power generation using small-scale technologies close to the end user connected to nearby low voltage grid for integrated gradient utilization. As the grid is becoming smart, the increased penetration from green energy-based DG has started to play a vital role in replacing the fossil fuel-based generation. Distributed generation is mostly used in emergency conditions like power failure or power shortage. Using distributed generation technologies, electricity can be generated near to the load, decrease the transmission and distribution losses, and improve reliability. Implementing Decentralized Distribution Generation (DDG) has become the need of the hour [9]. DDG is the implementation of renewable energy resources near to the inaccessible areas. In India, many renewable energy projects are being implemented to electrify rural areas. Here, DFIG-based wind turbine used as the distributed generation. The criterion of low installation and operational cost should be met using optimal design techniques [10].

With the large implementation of distributed generation, some issues may arise. Power flow is bidirectional; voltage profile may change along the network. Voltage transients will arise due to connecting and disconnecting of generators. Power quality and reliability might be affected [11]. The best way to meet customer needs is to implement the decentralized power plants near to load. Implementation of smart PV inverters helps to mitigate power quality issues in distribution systems [12]. The wind farms are made with low cost profile and highly efficient with the help of power electronic converters [13]. The paper explains about the FACTS technology in Sect. 2, description and working of test system in Sect. 3. Section 4 deals about results and conclusion in Sect. 5.

2 Flexible Alternating Current Transmission System (FACTS)

Flexible Alternating Current Transmission System (FACTS) is power electronic devices that can alter the parameters of a line for a stable operation of the grid. With the help of a suitable controller, a FACTS device can provide a dynamic compensation to support the grid and also aid in providing reliable operation of the grid by altering the real and reactive power flows [14].

In a typical AC transmission system, AC power transfer capability is limited by several factors like voltage limit, thermal limit, short circuit current limit, etc. Efficient maximum power which can be transmitted along the transmission line is defined by these factors. Even with the addition of variable impedance devices like capacitors and inductors, a part of energy is stored in these devices as reactive power. Thus, the actual amount of power which is transferred to the load is always less than the apparent power. For ideal transmission in the system, the active power should be equal to the apparent power. This is where flexible AC transmission system plays a role. The FACTS devices are used to provide controllability of high voltage side by introducing capacitive and inductive power in the system. FACTS is required to improve system stability, reliability, and operational flexibility. The series controllers such as Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Capacitor (TCSSC) can be used with shunt controllers such as Static Synchronous Compensator (STATCOM), Static Var Compensator (SVR) [15]. The Unified Power Flow Controller (UPFC) can also be used for voltage improvement in the system.

The robust control of power is made easily possible by the FACTS devices increases the loading capability of the line by overcoming limitations. It increases system security by overcoming the transient stability limit [16]. Provide secure tie line connections. It makes lines to carry more active power by reducing reactive power flows and damps active power oscillations. In industries, these devices help and improve plant productivity in case of dynamically fluctuating disturbances [17].

3 Proposed Work

The Doubly Fed Induction Generator (DFIG)-based wind turbine is considered. Wind farm rating is 4.5 MW (3 × 1.5 MW) with a line voltage of 575 V. The voltage is stepped up to 13.8 kV. In flexible AC transmission systems, solid state devices are often incorporated in the system for improvement of power factor and to overcome the limits of an AC transmission system. These devices are non-linear and inject harmonics in the system. By using the filters, these harmonics can be reduced. The load block is connected to the point of common coupling. Two different kinds of loads are used here. One is a dynamic and motor load, and the other one is a static load. The 13.8 kV is stepped down to 2300 and 480 V. The motor load of 1.68 MW, 0.93 power factor is connected to 2300 V bus and dynamic load of 570 kW, and inductive reactance of 470 kW is connected to 480 V bus. The static loads are also of same rating.

The Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVR) are used as FACTS devices. The rating of both STATCOM and SVC are 3 MVA connected tom 13.8 kV feeder, frequency of 60 Hz. The point of connection is where load, grid, wind turbine, FACTS devices are connected which is termed as point of common coupling. Figures 1 and 2 show the connection of SVC and STATCOM in a developed system. The voltage response at point of common coupling is affected by changes in load and wind power generation [18, 19].

The phase-phase fault is created and connected to 2300 V bus. The fault is created between phase A and phase B. The duration of fault is 0.15 s. The fault starts at 5.00 s and end at 5.15 s. The grid voltage is 69 kV and connected to point of common

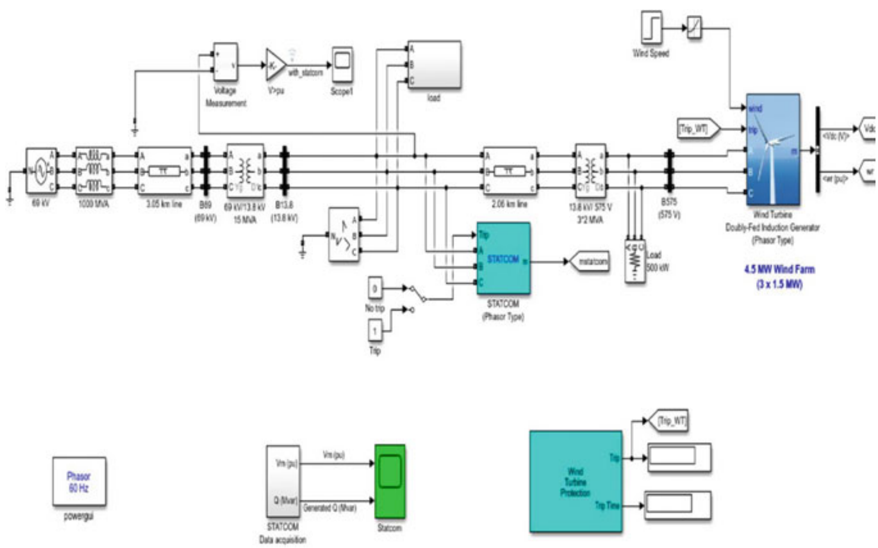

Fig. 1 System with STATCOM

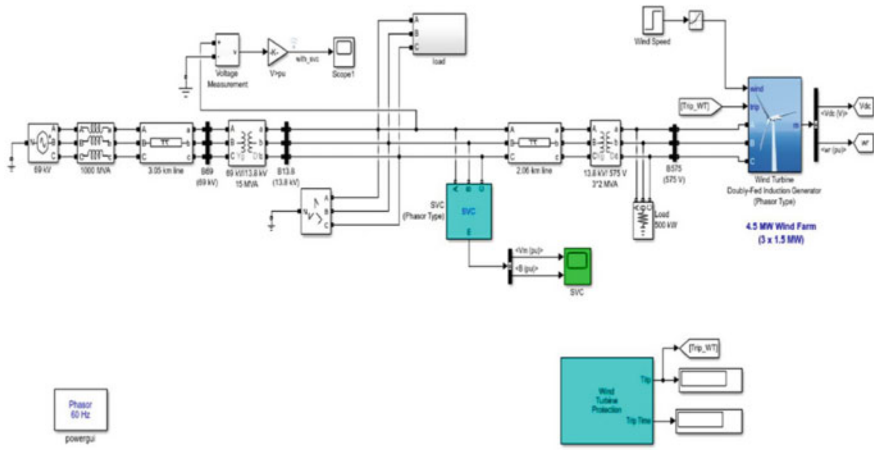

Fig. 2 System with SVC

coupling through a three-phase PI section line of length 3.05 km and step-down transformer which steps down voltage from 69 to 13.8 kV.

Under normal condition, i.e., before the fault, the power generated at the wind turbine is delivered to the load, and excess is supplied to the grid. At 5.00 s, the fault gets activated, and the voltage dip is observed at the common coupling point. During the fault, STATCOM and SVC help to improve voltage dip, thus by making LVRT operation of wind turbine possible. The settling time is the time taken for the voltage to regain stability after the fault. Settling time is observed in cases of system with STATCOM, with SVC, and without connection of FACTS devices. The voltage vs. time graphs are plotted for two sets of different loads which are shown in the next section. The tabular column with settling time in cases of with STATCOM, with SVC, and without connection of any FACTS device is shown in next section.

4 Discussion

Figures 1 and 2 present the distribution system under consideration with STATCOM and SVC being connected, respectively. The results are obtained using two different loads one being dynamic load, and the other is static load. The voltage at the common coupling point is taken and is plotted with respect to time. The comparison is being made with respect to STATCOM and SVC of same rating. Figures 3 and 4 give the comparison of voltages at common coupling point using dynamic and static load, respectively. The graphs in Figs. 3 and 4 show the initial transients, voltage dip due to fault, and recovery of voltage. The part of graph is magnified for clear visualization of voltage comparison. The voltage settling time for cases of system without connection of FACTS devices, with STATCOM, with SVC is observed using dynamic loads and

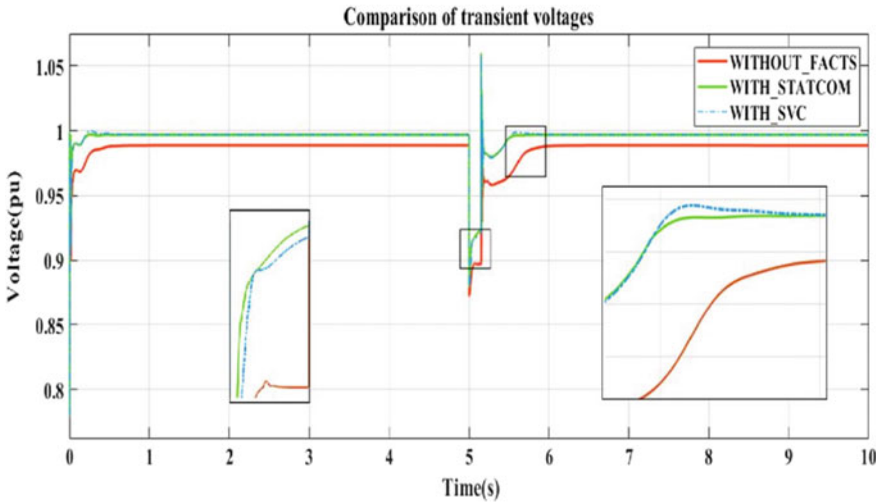

Fig. 3 The comparison of transient voltages using dynamic loads

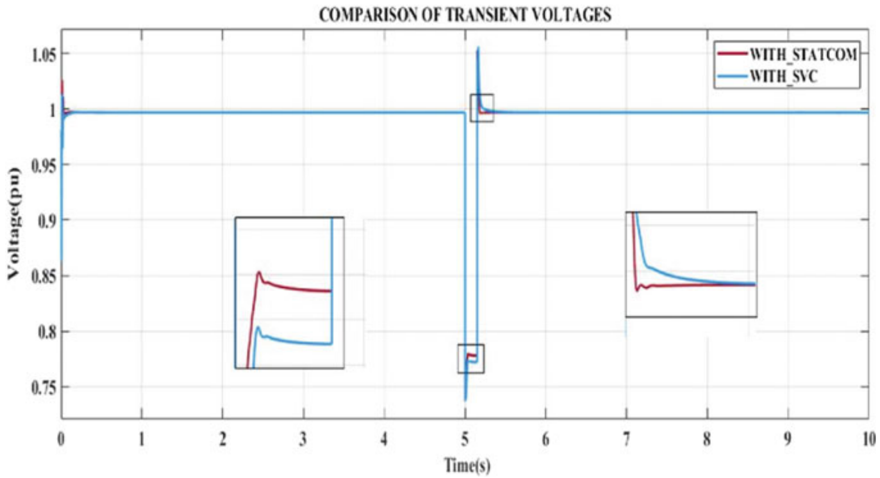

Fig. 4 The comparison of transient voltages using static loads

tabulated as Table 1. The system connected with STATCOM shows faster voltage recovery after the fault when compared to SVC. The settling time can be said to be time taken for the voltage to regain stability after an occurrence of fault or any disturbance. The transient stability is improved in case of a system with STATCOM when compared to SVC. The study presented in this paper becomes vital when more renewable energy resources, FACTS devices, and smart inverters are integrated into the system when stability and power quality aspects are dealt [20–35].

Table 1 Settling times for different cases

S. no.	Description	Settling time (s)
1	Without any FACTS device	1.17
2	With SVC	1.03
3	With STATCOM	0.71

5 Conclusions

Thus, the transient voltage stability of a system containing wind turbine and FACTS is improved compared to the system without any connection of FACTS devices. The performance of STATCOM is better when it is compared with SVC of the same rating for the developed system model. Studies presented in this paper will serve as a benchmark for researchers and planning engineers working in the domain of smart grid as more DG's along with FACTS devices which are integrated into a power system network.

Acknowledgements Authors are highly thankful to SASTRA Deemed to be University for providing the support to carry out the research.

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